

DELFT UNIVERSITY OF TECHNOLOGY
&
INSTITUTO SUPERIOR POLITÉCNICO JOSÉ ANTONIO ECHEVERRÍA – CUJAE

Tourist Port Havana

Studies and design of a ferry terminal and
marina in the Bay of Havana

T.F. van der Biezen
W. Kuhlman
J.J. Schoen
G.N. Stam
D. Witteman

PREFACE

Delft University of Technology provides students with the opportunity to fulfil part of the master's curriculum as a multidisciplinary project in a foreign country. We have embraced this option and are grateful to have had the possibility to execute this project in the fascinating country of Cuba.

We have learned much from working in an environment completely different from what we are used to. It has brought us some expected and unexpected challenges, the experiences of which we shall not quickly forget.

Foremost, we would like to thank prof.dr.ir. Luis Fermín Córdova López (CUJAE) and ir. Henk Jan Verhagen (TU Delft) for making our stay in the beautiful city of Havana possible and providing us with their knowledge, experience and humour. We would also like to thank ir. Gerbrant van Vledder (BMT Argoss), ir. Arjen Luijendijk (TU Delft & Deltares), prof. Maria Liliana Alba Menéndez (CUJAE), Kristy Groeneveld, ir. Erik Hertel (Damen), ir. Michiel de Jong (TU Delft & Royal HaskoningDHV) and Genevieve van der Vlugt (BOAZ).

Furthermore, we would like to thank our sponsors and of course all other people not mentioned, for their contributions in making this project possible.

La Habana, April 2013

Tim van der Biezen
Wouter Kuhlman
Jesper Schoen
Gerwin Stam
Dennis Witteman



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SUMMARY

To achieve economic growth, the intentions of Cuba are to focus on tourism. The current facilities of the Port of Havana are however in a state of heavy decay and the city is not able to receive tourists travelling by yacht or ferry. For this reason the master plan Tourist Port Havana has been created.

The objective is to find a feasible solution in the Havana Bay to receive large numbers of tourists that will visit the city by yacht or ferry. There are four components to achieve this objective: designing a marina, designing an international ferry terminal, designing improvements to the transport network around the port and performing a study to gain detailed hydrodynamic knowledge of the Bay of Havana.

This has resulted in the design of Marina La Coubre, which holds enough berths for 276 yachts of varying sizes, and the design of Havana International Ferry Terminal. With its four berths, the ferry terminal can process ferry lines connecting Havana and for instance Key West, Miami, Tampa, the Bahamas or Cancún.

The Ensenada de Atarés in the west of the Bay of Havana is a prime location for both components. The location is close to the historic city centre of Havana, and sufficient area is available on land as well as on water. From a hydrodynamic point of view, the Atarés bay is suitable due to the absence of currents that can be of hindrance to yachts. Locally generated wind waves are however of concern and to ensure the quality of Marina La Coubre a floating breakwater is required.

The roads around the port are adapted so the extra generated traffic can be distributed without blocking the through flow. Marina La Coubre is connected to a new roundabout, with a layout that increases the traffic safety. Traffic towards the Havana International Ferry Terminal is rerouted to increase the capacity of the network.

Marina La Coubre and Havana International Ferry Terminal are two great assets to the city of Havana and fit neatly in the master plan Tourist Port Havana. The designed components ensure that the port will be able to receive large numbers of tourists visiting the city by yacht or ferry. When evaluating the project, there are however some challenges that arise.

The nautical analysis has shown that due to an increase in nautical traffic in the bay, the entrance channel becomes a bottleneck. If the Port of Havana decides to focus on tourism, the attractiveness of the port as a destination for cargo vessels decreases significantly. A decision should be made whether the future of the Port of Havana is as a tourist port or a cargo port. This report makes clear that a combination of both will lead to conflict.

A main factor when evaluating viability is the embargo by the United States. The expected inflow of tourists greatly depends on the status of the embargo. A thorough market research is recommended to quantify tourist activity in case of a change in the embargo. To anticipate a volatile demand for the services provided by Tourist Port Havana, construction phasing is of high importance when designing the international ferry terminal and marina.

The financial and economic evaluations of the project show that without incorporating indirect effects to the local economy, the project has limited viability. Financial support by the government is however justified, as the project generates extra value to the society.

1 INTRODUCTION – TOURIST PORT HAVANA

1.1 BACKGROUND

The Cuban government assumes that the most important sector in which the country can achieve economic growth is tourism. For this reason the master plan ‘Tourist Port Havana’ has been developed (see figure 1.1 and Appendix A: General perspective of Tourist Port Havana). The overall facilities of the Port of Havana are however in a state of heavy decay. In order to fulfil the master plan, these facilities must be improved drastically.

Within the master plan ‘Tourist Port Havana’, a part of the harbour is reserved for both a marina and an international ferry terminal. However, no detailed or preliminary studies for the design of a marina and a ferry terminal have yet been carried out. These designs are required if the city of Havana wants to anticipate the expected increase of tourists that will visit the city by yacht or ferry.

The expected increase in tourist numbers also generates challenges concerning the infrastructure of the city. The traffic network should be adapted to accommodate the expected increase in traffic.

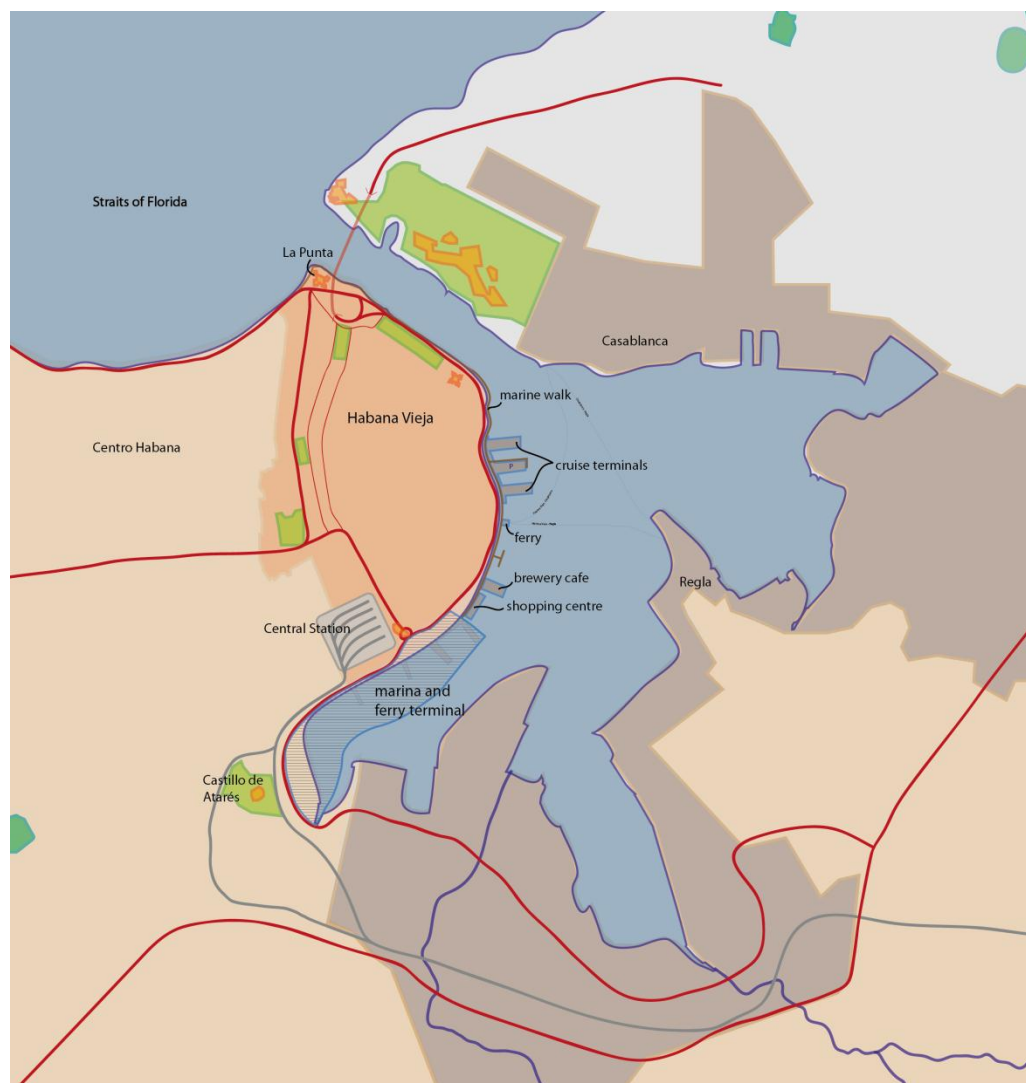


figure 1.1 – Tourist Port Havana

1.2 PROBLEM DEFINITION AND OBJECTIVES

The problem definition for this project is defined as:

“The Port of Havana is currently not able to receive large numbers of tourists that will visit the city by yacht or ferry. This contradicts the overall vision of the Cuban government, which is to play an important role in the Caribbean tourist market.”

The objective is to find a feasible solution in the Havana Bay to receive these large numbers of tourists that will visit the city by yacht or ferry.

The objective has been divided into four parts:

- Designing a marina that is able to accommodate yachts and mega yachts.
- Designing a ferry terminal to accommodate international ferry lines.
- Designing an improved transport network around the port to prepare it for the increase in traffic due to the addition of an international ferry terminal and a marina.
- Performing a hydrodynamic study to gain detailed knowledge of current patterns and wave conditions in the Bay of Havana. This study must provide detailed design conditions in the area reserved for the ferry terminal and marina. It must also be done to acquire general knowledge about the hydrodynamic conditions in the bay as a whole, as these are currently not sufficiently quantified.

Internally and externally imposed boundary conditions as well as the requirements that apply to the design of the international ferry terminal, marina and their connections to the transport network are summed in Appendix L: Boundary conditions and design requirements.

1.3 REPORT STRUCTURE

To create a general understanding of the design area and to lay the foundations for the designs, a thorough, fourfold analysis has been done. The general analysis starts with a tourism analysis in chapter 2, followed by the analysis of the infrastructure in chapter 3 and a nautical analysis in chapter 4. Chapter 5 contains the most important conclusions of an elaborate hydrodynamic analysis of the Bay of Havana. The designs of the marina and the international ferry terminal are described in chapters 6 and 7, respectively. These chapters are followed by chapter 8, which discusses the connections of both components to the land infrastructure, and chapter 9, which discusses the updated design of nautical infrastructure.

In the subsequent three chapters the project is evaluated, by means of a financial and an economic evaluation (chapters 11 and 12), which are supported by a project planning (chapter 10).

The report closes with general conclusions in chapter 13 and the most important recommendations in chapter 14.

For convenience a glossary of terms is added to the report, which can be found on page 51.

All details concerning the analyses, designs and evaluations, can be found in the appendices following this main report.

2 TOURISM ANALYSIS

As stated in the introduction, economic growth through tourism is an essential motive for the design of the marina and the international ferry terminal. The number of tourists determines the required capacity of the port facilities and therefore knowledge on the tourist market is an important input for the design process.

In order to find an estimated number of annual tourists, an analysis has been done on the role of Cuba in the Caribbean market as well as its development. The results from this analysis are presented in this chapter. The complete analysis can be found in Appendix D: Tourism analysis. Paragraph 2.1 covers the current situation of tourism in Cuba, followed by the development of tourism in paragraph 2.2. Finally, the effects of the tourist development on Cuba's economy are discussed in paragraph 2.3

2.1 CURRENT SITUATION OF TOURISM IN CUBA

Tourism in Cuba has been, and is, heavily dependent on the political circumstances in the country. Currently, the tourism business is seen as an important economical asset that has to be developed. In the past, however, tourism was almost completely banned by the revolutionary government of Fidel Castro as it was seen as a capitalistic 'sin' (Padilla, 2003). The socialistic course of the government resulted in a still active embargo from the United States and an enormous decrease of tourist facilities.

After the collapse of the Soviet Union, and with it the financial support for Cuba, tourism was embraced once again in the nineties as a replacement industry. Even though the consequences of the tourism ban are still felt today, the number of annual tourists has increased substantially in the last decade. In table 2.1, the number of travellers per year and their origin is shown, as well as the annual growth. Of these travellers, the market share for holiday purpose is 95%, with an average length of stay of eleven days (CTO, 2012).

table 2.1 – traveller arrivals in Cuba (CTO, 2012)

Year	United States	Canada	Europe	Other	Total	Change (%)
2007	40 521	660 384	924 025	527 291	2 152 221	-----
2008	41 904	818 246	909 086	579 104	2 348 340	+9.1
2009	52 455	914 884	838 340	624 130	2 429 809	+3.5
2010	63 046	945 248	809 514	713 936	2 531 745	+4.2
2011	n/a ¹	1 002 318	852 065	861 934	2 716 317	+7.3

These figures also make clear that the number of tourists from the U.S. is just a minor fraction of the total number. This indicates that the embargo has a major influence on tourism as the U.S. hold the biggest market share of tourists in the Caribbean, while the share of tourists from the U.S. in Cuba was only 2.5% in 2010.

¹ The number of tourists from the U.S. in 2011 is included in 'other'.

Currently, foreign companies can invest in Cuba only via a joint-venture with the state. This is done by several hotel chains, but foreign investments are limited due to this structure.

Cuba's market share in tourism is growing; the country currently has a share of 14% in the Caribbean market. Only the Dominican Republic receives a higher number of tourists with a market share of 22%. This means that Cuba does not fulfil its full potential as its market share was almost 27% back in 1957. The U.S. embargo can be indicated as the main cause of this limitation as tourists from the U.S. form the larger part of tourists in this region.

2.2 TOURISM DEVELOPMENT

General development in Cuba

The future of tourism in Cuba is hard to predict and depends on several factors. The first and probably most important factor is the trade and travel embargo of the U.S. If the U.S. would raise this embargo, one can expect that the number of travellers from the States would increase; the exact number is however hard to predict.

Furthermore, other political factors will influence tourism. A governmental change from the current centralized, socialistic system to a more decentralized and democratic system would have major consequences. When the economy opens up to foreign investors and the obligatory joint-venture structure is banned, the number of tourist facilities will increase, attracting more tourists. On the other hand, the unique culture that attracts a different type of tourist will also change. Besides the political environment, it has to be seen if Cuba can restore its market share of 1957 as other countries have invested in their infrastructure and image in the past decades.

The consequences of Tourist Port Havana

The development of Tourist Port Havana, as described in Appendix A: General perspective of Tourist Port Havana, can play an important role in the development of tourism in Cuba. When finished, the cruise facilities are able to handle flows of 10 000 tourists a day. The addition of an international ferry terminal extends the possibilities for tourists, creating the option to bring passenger cars. With studies of Sanders (2002) and Robyn (2002) the demand for an international ferry terminal is estimated to be 1 200 to 1 400 passengers per day.

Ferry connections can be established with the U.S. and other countries in the Caribbean. More details on these possible connections are discussed in chapter 4.

A marina in the Bay of Havana could make the city an important player in the Caribbean yachting market. This market has played, despite its small numbers, an important role in the Caribbean tourism industry. A marina is considered an addition to a tourist destination that will attract 'land vacationers' as well. Especially in the northern Caribbean, yachting is popular due to the several ports of call within sailing distance. The current peak of yachting events in the region attracts up to 500 yachts at the same time (Zappino, 2005). If Havana would be able to organize a sailing event of importance, it could have similar proportions.

Development scenarios

In order to quantify the expected number of tourists, a distinction between three scenarios has been made. The first scenario is based on the continuation of the current growth, under the same political conditions. The second scenario covers the raise of the U.S. embargo, with an increase of tourists from the U.S. as a result. The third, and last, scenario combines the embargo raise with a change in political structure with positive consequences for tourism. The expected tourist flows of these scenarios are shown in table 2.2. These numbers cover tourism in the entire country, not just the city of Havana.

table 2.2 – tourism development scenarios

Scenario	Tourists in 2015 (millions)	Tourists in 2020 (millions)
1	3.0 – 3.5	3.5 – 4.0
2	3.5 – 4.0	4.0 – 4.5
3	3.5 – 4.0	7.0 – 9.0 ²

2.3 EFFECTS ON THE ECONOMY

The inflow of foreign tourists to Cuba will have its consequences on the economy. The development of tourism injects foreign money in the local economy. Furthermore, the labour market will benefit from the development as new jobs are created in the tourist sector. The development also has negative consequences for the environment as the construction of facilities causes hindrance and produces exhaust gases. The increase of tourism also leads to an increase in traffic. This can lead to congestion in the area, which has great negative consequences on the economy.

The positive and negative effects on the economy can influence decision making about possible investments in a marina and ferry terminal. The implementation of a marina and an international ferry terminal do not only have direct effects on the tourism market, but also indirect effects on the labour market and the land market. Furthermore, external effects like congestion and pollution of the environment are generated. These effects on the economy are evaluated in Appendix V: Economic evaluation.

² In case of political changes at least 5 years ahead.

3 INFRASTRUCTURAL ANALYSIS

For both the marina and the international ferry terminal, a good accessibility is essential. The visiting tourists must be able to come and go from the marina without creating congestion in the transport network around the bay. On the other hand, the international ferry terminal generates high peaks of passenger flows when ferries arrive or depart. A smooth flow of passengers is a requirement for a properly operating ferry terminal.

This chapter covers the results of the infrastructural analysis (Appendix E), performed to anticipate problems with the connections of the marina and the international ferry terminal. The scope of this analysis is focussed on the arterial roads around the bay and their connections. The road layout is discussed in paragraph 3.1, followed by the analysis of the traffic in paragraph 3.2. Subsequently, the safety and the development of the traffic system are discussed in paragraphs 3.3 and 3.4, respectively. This data leads to the essential bottlenecks in the network (paragraph 3.5), for which a solution has to be found.

3.1 ROAD LAYOUT

The most important road for the connections of the marina and ferry terminal is the main road around the bay: the Avenida del Puerto. This road leads from la Punta, at the mouth of the entrance channel, all the way along the bay towards Regla. The most relevant connections of the Avenida del Puerto are the intersections with Avenida de Bélgica, Arroyo and Jesus Lopez since these connections distribute the traffic from Habana Vieja in north, west and south direction, respectively. An overview of these roads is given in figure 3.1. A detailed description of all arterial roads in the area is included in Appendix E: Infrastructural analysis.

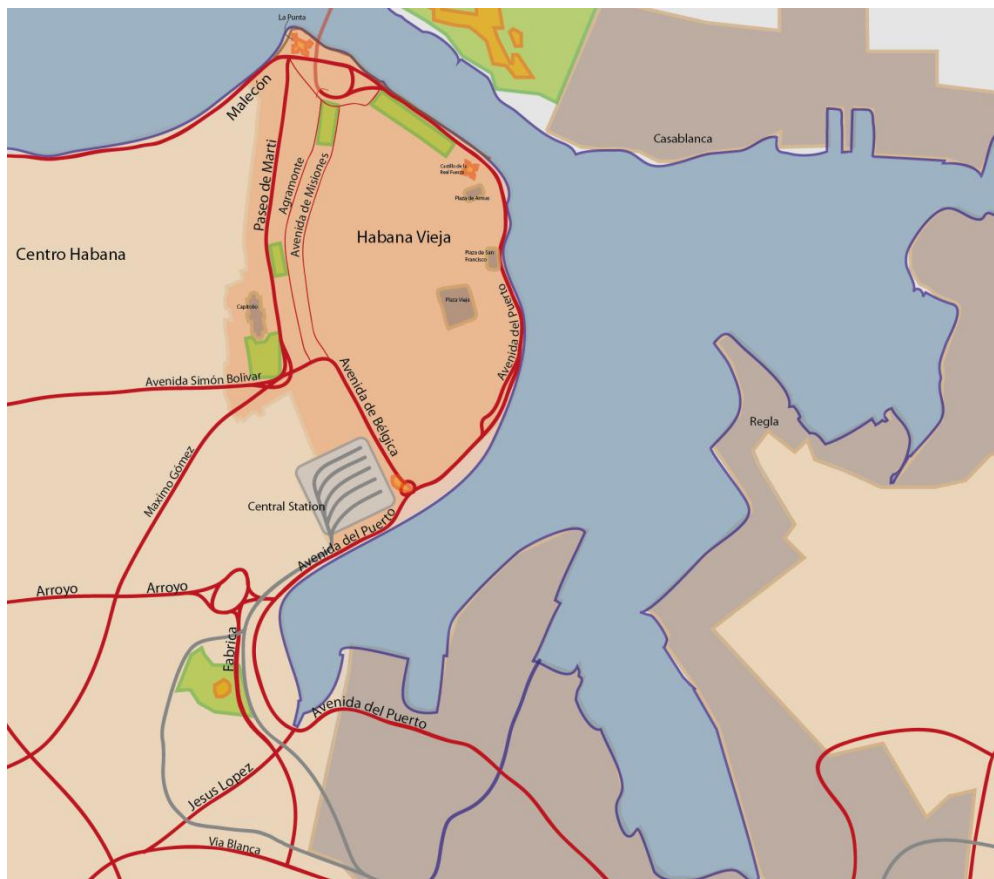


figure 3.1 – road network overview around the bay

3.2 TRAFFIC COUNTS

Traffic characteristics

The project area has a very diverse mix in traffic. Old and new cars, old buses and trucks, many pedestrians and tourist activities make this area very diverse in its functions. This is an important factor in designing the road infrastructure.

Since the traffic from the Havana Vieja quarter is only distributed by the Avenida del Puerto on one side and by Paseo de Marti on the other side, the Avenida del Puerto is an important distributor road. But with the increase of tourism around the bay, this conflicts with the access functions at the harbour and Havana Vieja. This location is the main touristic area of Havana, with many tourists walking on both sides of the Avenida del Puerto (see Appendix C: Analysis of the surrounding area). The addition of a marina and a ferry terminal in the south-western part of the bay will enlarge this problem.

Traffic counts

In order to find the normative flows in the project area, data of counts on three intersections has been analysed. The complete analysis of this data can be found in Appendix E: Infrastructural analysis. The data shows a peak hour flow of 3 158 Vehicle Equivalent³ (VE) at the intersection between Avenida del Puerto and Arroyo between 9 and 10 am. Most of this traffic originates from the Habana Vieja quarter (see figure 3.2). This means that intensities on the road are currently very low. The intersection between the Avenida del Puerto and Jesus Lopez is even more remote with a peak hour flow of 2 475 VE. The intersection between the Avenida del Puerto and the Avenida del Bélgica is not analysed for counts, as data is lacking.

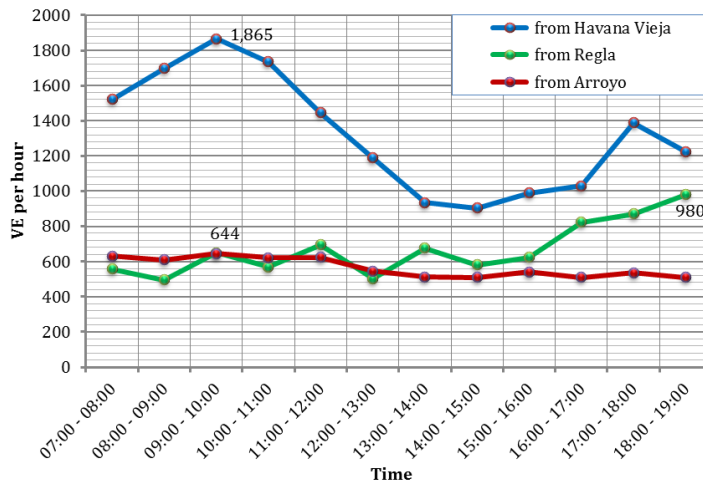


figure 3.2 – flows per origin at intersection Avenida del Puerto and Arroyo

A clear morning peak is visible in the flow-time diagram, the evening peak is less apparent. This does not apply for all roads. On Fabrica, a road parallel to the Avenida del Puerto, a clear evening peak is visible in opposite direction.

Furthermore, the data shows that trucks play an important role in traffic at the southern end of the bay. The commercial harbour activities generate a high share of cargo transportation here. In the northern part, towards Havana Vieja, the share of trucks decreases notably.

³ This equivalent converts all traffic modes to passenger cars, creating a single number for the traffic load.

3.3 SAFETY

This paragraph discusses the traffic safety concerns in the project area. The crash statistics of the period 2003-2008 are analysed to locate the locations with a high crash risk. Second, the principles of Sustainable Safety⁴ are applied to the current road layout to indicate possible safety improvements.

3.3.1 CRASHES

The crash data consists off all recorded crashes in the larger area of Havana between 2003 and 2008. From this source, the data of the relevant roads for the project has been filtered. Because the data on the consequences of these crashes is inconsistent, only the number of crashes is analysed to identify high risk locations. The top 10 locations with most crashes are indicated in figure 3.3. The area of research is indicated in grey.

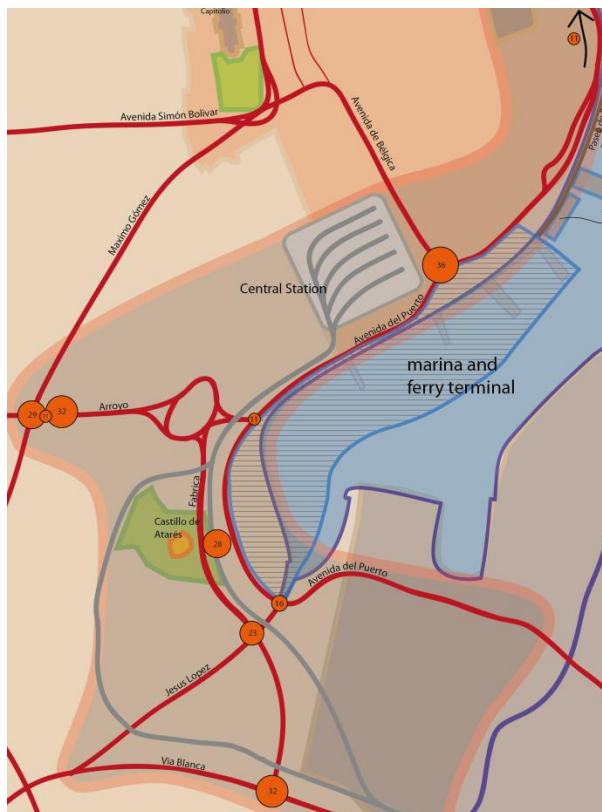


figure 3.3 – high crash risk locations (number of crashes in five years)

The intersection between Avenida del Puerto and Avenida de Bélgica tops the list with 36 crashes. This roundabout is therefore indicated as a high risk location. The nearby intersections of Jesús López with Avenida del Puerto and Fabrica are on places 6 and 7, respectively. When taken together, they would have been in the first place. This is even without the crashes involving a train, as these are mentioned separately in place 5. This is done because of the sometimes unclear reference to the location.

It is clear that the safety of these locations is an issue when designing the marina and the international ferry terminal, as the entries are close to some high risk locations. Safe transportation from and to the port facilities has to be guaranteed.

⁴ This vision on traffic safety is developed by the Dutch SWOV Institute for Road Safety Research. (www.sustainableafety.nl)

3.3.2 IMPROVEMENTS FROM SUSTAINABLE SAFETY

The principles from sustainable safety (functionality, homogeneity, predictability, forgivingness and state awareness) are elaborated upon in Appendix E: Infrastructure analysis. With these principles as guideline, the following improvements of the traffic system could be identified:

- Clear speed signage;
- Decreased speed at intersections (with roundabouts or plateaus);
- Consistent lining indicating directions and transition of lanes;
- The shielding of obstacles along the road;
- Removal of parking in the centre of the road;
- The addition of pedestrian crossings;
- The enlargement of sidewalks.

These possible safety improvements are taken into account in the design of the connections of the marina and international ferry terminal.

3.4 TRAFFIC DEVELOPMENT

The traffic growth in Cuba, specifically in Havana, is obviously a very important factor for a design of a new road layout around the marina and ferry terminal. Currently, the car use is increasing rapidly. The Department of Roads of CUJAE University (2013) estimates the current traffic growth at 8% per year. If this growth continues for a planning horizon of 50 years, this would mean an increase of traffic with a factor 47. This is very implausible as the traffic growth will almost certainly not continue at the current rate. For long term planning in Cuba, commonly a growth rate of 1.5% is used, but this does not match the current growth. Therefore a top-lognormal function has been applied on the growth rate, to fit both the current growth as well as the expected eventual growth in 2060. The results of this function are given in table 3.1. The flows are expected to approach the estimated peak of 2060 in the next 15 years, after which the growth will flatten out (see figure 3.4; top-lognormal growth).

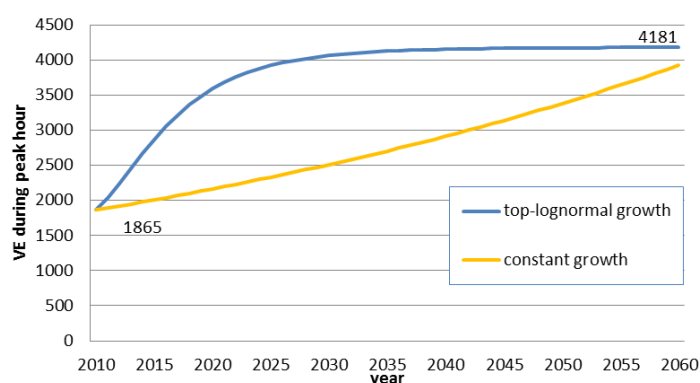


figure 3.4 – growth of normative peak hour flow

table 3.1 – traffic flow development

location	direction with largest flow	Largest current flow (VE/h)	Largest estimated flow in 2060 (VE/h)	Estimated peak at entire intersection in 2060 (VE/h)
Arroyo	From Habana Vieja	1 865	4 181	7 024
Jesus Lopez	From Havana Vieja	1 350	3 003	5 505
Fabrica	Fabrica towards Arroyo	1 610	3 581	9 101

3.4.1 TRAFFIC GENERATED BY THE MARINA

The traffic flow generated by the marina is very small. Even if all 270 yachts would have a car available and leave in the same hour, which is practically unthinkable, this would still be only a minor part of the total flow. However, the marina does create merging and crossing traffic in an area where space is very limited due to surrounding buildings. It also has to be well accessible for supply trucks and tankers for provision of the marina.

3.4.2 TRAFFIC GENERATED BY THE INTERNATIONAL FERRY TERMINAL

The international ferry terminal, in contradiction to the marina, does create peak flows of passengers. A departing ferry is estimated to attract 420 cars, but this flow is spread over approximately two hours as passengers have to go through the customs procedure. This generated extra traffic could still cause capacity problems on the Avenida del Puerto in peak hours.

Short term parking facilities have to be present, as well as taxi stands, bus stands and so called kiss and wave stands. Long term parking should be provided within walking distance of the terminal building.

3.5 BOTTLENECKS

A total of twelve bottlenecks in the network around the project area has been identified. The entire list can be found in Appendix E: Infrastructural analysis. Only the most relevant bottlenecks are discussed here: the intersections of the Avenida del Puerto with Avenida de Bélgica and Arroyo.

3.5.1 INTERSECTION BETWEEN AVENIDA DEL PUERTO AND AVENIDA DE BÉLGICA

The intersection between Avenida del Puerto and Avenida de Bélgica is near the entrance of the marina. This roundabout has the most crashes in the project area, therefore it can be concluded there is a road safety problem at this location. With the expected growth of traffic and the extra connection of the marina, this problem will further increase. Therefore, measures have to be taken to increase safety at this point. The remains of the old city wall in the centre and next to the roundabout are a limiting design factor in this location, together with the proximity of the terminal.



figure 3.5 – overview of intersections of Avenida del Puerto with Avenida de Bélgica (left) and Arroyo (right)

3.5.2 INTERSECTION BETWEEN AVENIDA DEL PUERTO AND ARROYO

The intersection between Avenida del Puerto and Arroyo is near the international ferry terminal. Here the connection is hindered by two railway tracks, one on ground level and one elevated. This connection is essential to the main network of the city of Havana. Currently, it is a very confusing intersection, which will become a problem with increasing flows and more tourists driving in the area.

4 NAUTICAL ANALYSIS

In this chapter an overview is given of the design vessels (chapter 4.1), the existing nautical infrastructure (chapter 4.2), future growth (chapter 4.3) and finally vessel interactions (chapter 4.4). More details on these topics can be found in Appendix G: Nautical analysis.

4.1 DESIGN VESSELS

Entrance channel

The depth of the channel, restricted by the tunnel beneath, limits the maximum draught of particularly cargo vessels like bulk carriers. The design vessel regarding the entrance channel is therefore a cruise ship, which combines a relatively small draught with a wider beam.

The maximum dimensions of a cruise ship are limited by the length of the pier of the cruise terminal. The maximum length of a ship the terminal can accommodate is 245 m, so an example of a normative vessel is the “MS Zaandam” with dimensions of 237x32.3x8.1 m³.

Ferry service

The possible ferry connections and the corresponding sailing times are given in table 4.1.

table 4.1 – possible ferry connections with Havana

Destination	Distance in a straight line [km]	Sailing distance [km]	Sailing time, 15 kn [h]	Sailing time, 30 kn [h]
Key West, Florida (U.S.A.)	170	170	6.2	3.1
Miami, Florida (U.S.A.)	365	400	14.5	7.3
Tampa, Florida (U.S.A.)	535	550	20	10
Cancún, Yucatán (Mexico)	510	575	21	10.5
Nassau, New Providence (Bahamas)	555	600	22	11

The Damen Fast Ropax 6016 (see figure 4.1) is, given its sailing speed, recommended for the connection with Key West and Miami. The Damen Fast Ropax 5114, with a lower capacity, can be used in the early operational stages of the ferry.



figure 4.1 – the Damen Fast Ropax 6016, dimensions: 60x16.2x2.0 m³, maximum speed: 35.0 kn capacity: 660 passengers and 49 cars

Mega yachts

Mega yachts will be normative for the dimensions of the marina. Examples of mega yachts are the 'Amels 180' with dimensions of 55x9.4x3.4 m³ or the 'Limitless' with dimensions of 97x12x3.7 m³.

The national market for yachts in Cuba is currently non-existing as the only inhabitants with a private boat are fishermen (Valle Benero, 2013). It is therefore expected that the marina in the Bay of Havana will hardly be used as a homeport.

4.2 CAPACITY OF THE EXISTING INFRASTRUCTURE

Depth

The minimum cross section of the channel determines what sizes of vessels are able to enter the port basin. Particularly the depth of the channel is a restriction as it determines the maximum draught of a vessel that can enter the basin. The maximum draught of a vessel that the port can accommodate is 11.58 m (see Appendix F: Analysis of existing port infrastructure and facilities).

Width capacity of the entrance channel

From table 4.2 it can be concluded that cargo vessels and cruises cannot be accommodated in a two-way configuration in the entrance channel. Ferries and yachts can use the channel in a two-way configuration. Note that ferries and cruises will usually not arrive and/or depart at the same time since these lines make use of a strict time schedule. Besides, it is not expected that more than a single mega yacht will arrive at the same time. It is therefore assumed that in the current situation:

- Cargo vessels always sail in one-way traffic configuration.
- Cruises, ferries and mega yachts will sail in a one-way traffic configuration.
- Yachts of average dimensions can sail in two- or even more way configuration.

table 4.2 – required channel widths for the entrance channel (B = Beam)

Type of vessel	One-way		Two-way	
	Beam (B)	Length (L)	Beam (B)	Length (L)
Container	4.1B	102.5 m	8.4B	210 m
LNG	5.1B	112.2 m	10.4B	228.8 m
Cruise	4.1B	132.0 m	8.4B	270.5 m
Ferry	3.6B	58.3 m	7.4B	119.9 m
Mega yachts	3.6B	43.2 m	7.4B	88.8 m
Yachts (2m width)	3.6B	7.2 m	7.4B	14.8 m

Berthing facilities

The Port of Havana currently has only one terminal that is able to receive tourist related vessels: the cruise terminal which has just one pier in use. The master plan of 'Tourist Port Havana' however requires different berths for several types of tourist vessels (see Appendix A: General perspective of Tourist Port Havana).

Anchorage

Three dedicated anchorages are present in the Bay of Havana. The locations of these anchorages are depicted in figure 4.2.

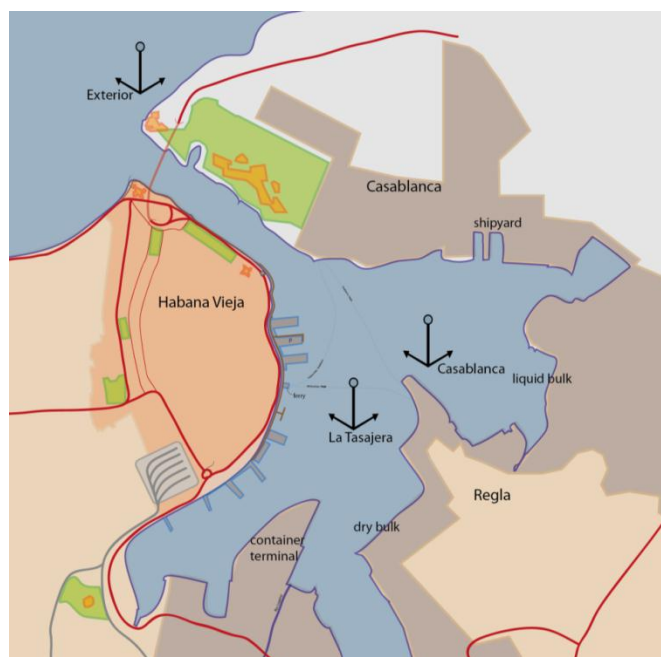


figure 4.2 – anchorages in the Bay of Havana, current situation

4.3 INTENSITY AND FUTURE GROWTH

Little is known about the current shipping intensities in the Bay of Havana. Only the container terminal has regular calls with three times a week. By account of the traffic control service, on average one liquid and one dry bulk vessel arrive per week. In general, two or three vessels arrive at the port on an average day.

The expected economic growth in Cuba, especially after the possible lifting of the embargo, will lead to an increase in commercial activities in the country and the Bay of Havana. Moreover, as a result of Tourist Port Havana, an increase in traffic of tourist related vessels is to be expected. The overall harbour activities will as a result intensify, and thus more calls and traffic are expected.

In order to become successful, it is vital that the port can accommodate future tourist supply in a safe and comfortable way. Conflicts must therefore be prevented by providing sufficient capacity and/or a traffic control system. Hindrance of tourism and commercially related vessels must be minimized as much as possible.

The intensity of traffic in the bay that can be expected partly depends on the development of other ports on the island. Cargo ships can be attracted by other ports in Cuba by for example better equipment, shorter sailing distances, shorter service times or to avoid waiting times. As a result, the number of calls in the Port of Havana could be negatively affected. Cuba has a total of seven major ports: Havana, Mariel, Santiago de Cuba, Cienfuegos, Matanzas, Antilla and Nuevitas (Achermann, 2007). Especially the developments in Mariel will influence the future of the Port of Havana.

Marinas in other parts of the country can conversely cause an increase of the number of calls of yachts in Havana. With multiple marinas in the country, Cuba would be a more attractive destination for yachts as it would make a trip around the island possible. Marinas in the close proximity of Havana will of course have a negative effect on the number of calls in the future marina.

4.4 VESSEL INTERACTIONS

A sailing vessel generates waves and currents that may influence the berthing conditions in the marina. The results of computations done in Appendix G: Nautical analysis are presented here, for the computational method is referred to the appendix.

Return currents and sinkage

The water displacement of the ship causes a return current to the stern of the vessel in order to ‘refill’ the space behind the ship. This current also causes a ‘sinkage’ of the vessel, or more specifically a decrease of the water level next to the ship (see table 4.3).

table 4.3 – return current and sinkage

	Damen Fast Ropax 6016
Sinkage, z [cm]	1.3
Stern wave, z_{max} [cm]	2.4
Return current, U_r [cm/s]	4.2
Eccentric return current, $U_{r,ecc}$ [cm/s]	4.7

Vessel generated waves

The bow and stern of a sailing ship generate diverging waves, which move out from the vessel’s sailing line, and transverse waves that propagate behind the vessel. The wave characteristics can be seen in table 4.4.

table 4.4 – vessel generated waves

Vessel velocity, V_s [kn]	4.0	6.0	8.0
Vessel velocity, V_s [m/s]	2.1	3.1	4.1
Wave period, T [s]	1.1	1.6	2.1
Wave length, L [m]	1.9	4.0	7.1
Wave height, H [cm]	1.1	5.1	15.7

Propeller wash

The flow behind a ship generated by the propellers of a vessel is of importance when a ship is near a berthing structure and has the characteristics of a jet (Schierck, 2006). This is influenced by the diameter of the propeller, the distance from the jet in the centre of the flow line x , the radial distance from this centre r and the initial flow of the jet U_0 (see table 4.5).

table 4.5 – propeller wash of vessels

	Damen Fast Ropax 6016		
Power, P [kW]	2 880		
Diameter, d [m]	0.75		
Initial flow, U_0 [m/s]	19.66		
Radial distance, r [m]	0	100	7
Distance from centre, x [m]	1	560	39.2
Flow, U [m/s]	41.3	0.045	0.64

5 HYDRODYNAMIC ANALYSIS OF THE BAY OF HAVANA

A hydrodynamic analysis is required to gain detailed knowledge of flow patterns, flow velocities and wave conditions in the Bay of Havana. There is little to no research available about the hydrodynamic conditions of this bay, which is connected with the Gulf of Mexico and the Straits of Florida.

The hydrodynamic analysis is founded on two pillars, ‘flows’ and ‘waves’. The flow conditions are analysed in paragraph 5.1, the wave conditions in paragraph 5.2. In Appendix H – K, the complete hydrodynamic analysis can be found, in this chapter only the conclusions are given.

5.1 FLOWS

The bay has been analysed in two ways, using an analytical approach (section 5.1.1) and in a more exact way using the mathematical model Delft3D-FLOW (section 5.1.2). The use of a mathematical model has been deemed necessary to visualize flow patterns in an exact manner, and to compute flow velocities in the whole bay. The model has also been used to simulate the flow conditions during Hurricane Wilma. Simulating an extreme situation is relevant for both the client and for academic reasons.

5.1.1 ANALYTICAL APPROACH

A first characterization of the bay can be done by investigation of the response to tidal forcing. The basin is said to be small (order of kilometres) for the water surface to rise and fall uniformly (co-oscillate) in response to its forcing, the tide. This is true if the tidal period is long compared to the time required for a shallow-water wave to propagate from the inlet to the farthest point in the bay (Coastal Engineering Manual, 2006). This means that the following should apply:

$$T \gg \frac{L_b}{\sqrt{gd_b}}$$

in which:

- L_b = the greatest distance from inlet to the end of the bay (about 5 km)
- d_b = average depth of the bay (entrance channel - end of bay; about 12 m)
- T = tidal wave period (semidiurnal tide; wave period approximately 44 400 s)

In this case, the tidal wave propagates in circa 460 s through the system; a value much smaller than the tidal wave period. This means that there is almost no phase lag between the tidal forcing and the water level at the farthest point in the bay (a co-oscillating system). Furthermore, the inlet has a substantial water depth (well over 10 m), so it is possible that the tidal wave is not hindered when entering the bay.

For a first estimation of flow velocities a basin storage approach is used. This can be done when the basin is much smaller than the wavelength of the tidal signal. The method above has also shown that only storage of water is determining flow velocities, in this case the following can be applied:

$$Q = A_b \frac{dh_b}{dt}$$

in which:

Q = discharge of water through the channel (m^3/s)

A_b = storage area of the Havana Bay (5.2 km^2)

dh_b/dt = rate of change of water level (m/s), a tide with an amplitude of 35 cm

This method shows that during in- and outflow through the channel, a peak discharge of $129 \text{ m}^3/\text{s}$ occurs, resulting in a maximum depth averaged flow velocity of 4.3 cm/s . Measurements done in the channel show that a velocity occurs of 7.33 cm/s near the surface under normal circumstances (Lázaro, 2006). The values are in the same order of magnitude, corroborating the statement that the bay can be characterised as a co-oscillating system.

5.1.2 DELFT3D-FLOW – MODELLING RESULTS

Normal day situation – tidal forcing

The output of the Delft3D-FLOW simulation shows a depth averaged current in the entrance channel of 4 cm/s , both during low tide as during high tide (see figure 5.1). This is close to the value obtained from the basin storage approach. The simulation also shows that only negligible flowing occurs in the Ensenada de Atarés in the southwest of the bay.

In reality the situation is more complex, as measurements show that a distinction can be made between two density layers (Lázaro, 2006). Lázaro states that an upper layer of undetermined depth contains a constant outflow of relatively fresh water. The simulations are not of sufficient detail to provide other than depth averaged currents. Further research should clarify the exact flow patterns considering the vertical water column in the entrance channel. It is however not of practical use since the currents are of such a magnitude that they are not of concern to shipping, it can however be useful for an investigation into water quality.

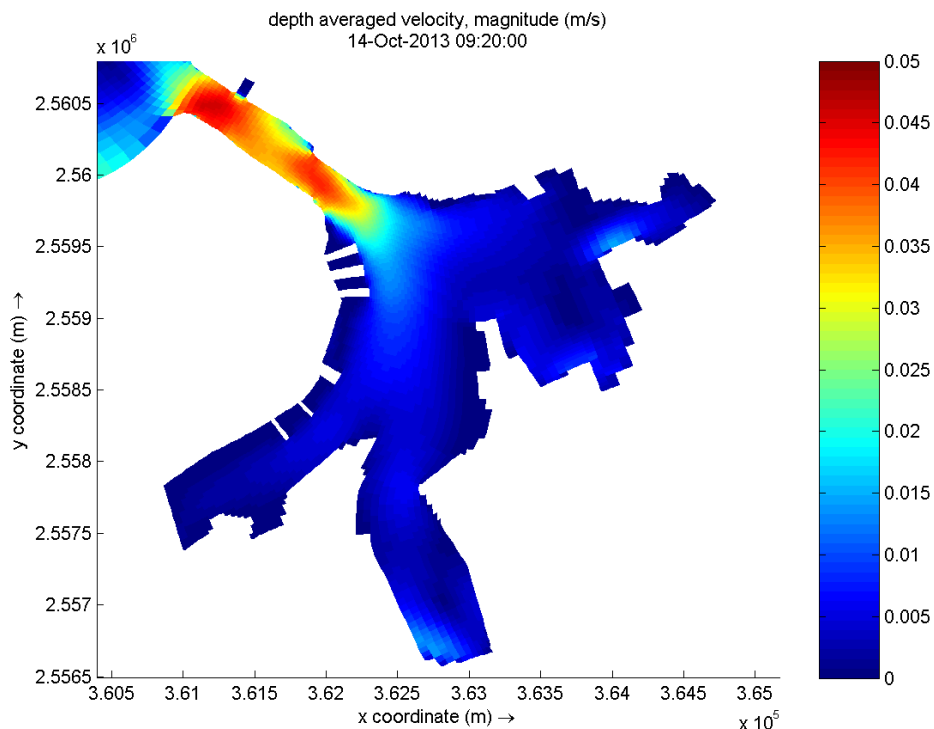


figure 5.1 – depth averaged flow velocities for a normal day situation (magnitude)

Extreme case situation – Hurricane Wilma

Hurricane Wilma can be considered to be similar to a normal tidal situation. The main difference between the two is that for Wilma there is a much higher water elevation, although it is only for a relatively short time. This scenario has been used to investigate whether the bay-inlet system is still able to swiftly adapt to the higher water elevation. As input for the scenario a normal tide is used, upon which a storm surge is superimposed, resulting in a maximum water elevation of 2.25 m. The highest flow velocities (about 40 cm/s) during this extreme scenario occur in the channel (see figure 5.2).

The most important conclusion is that the flow velocities are more dependent on the inlet-bay dimensions than on the external forcing, which is proven by the simulations. This is due to the relatively great depth and width of the entrance channel. Moreover, during such a hurricane there are other processes taking place which, considering the results, can be rated as ‘more important’. These are for example damage due to winds and flooding due to extreme rainfall and overtopping.

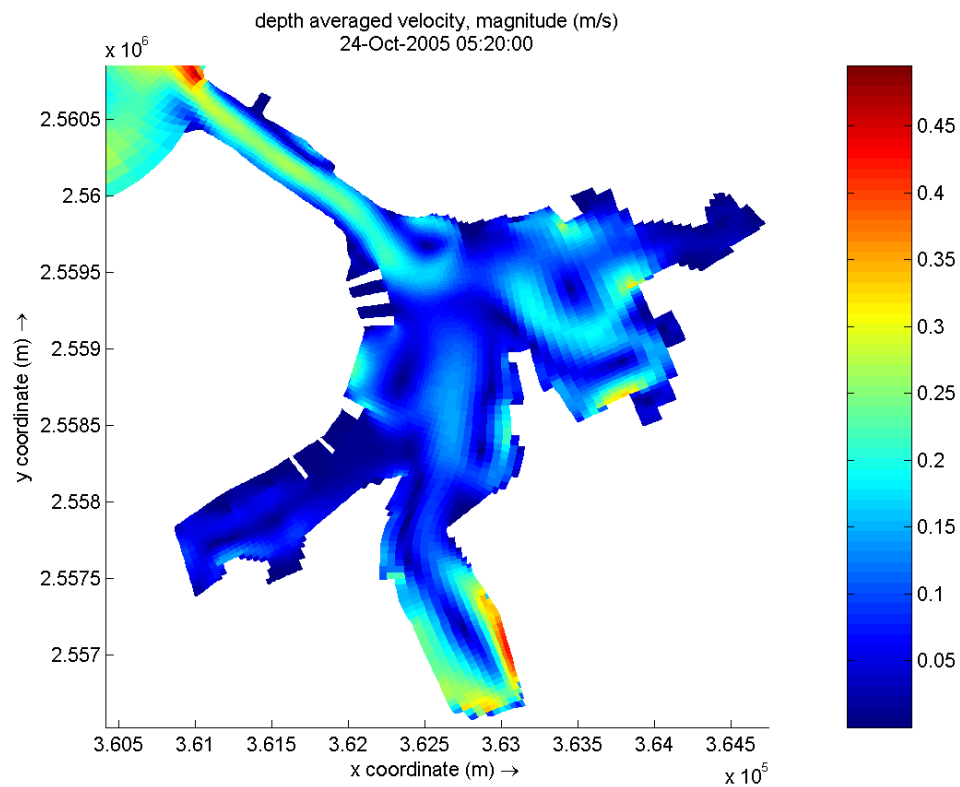


figure 5.2 – depth averaged flow velocities during Hurricane Wilma (magnitude)

5.2 WAVES

The wave conditions inside the Bay of Havana have been investigated for two reasons. The first reason is to quantify wave conditions in the Ensenada de Atarés, which is designated for the ferry terminal and marina. The second reason is to gain a general understanding of the waves in the bay, which is useful for shipping and other purposes.

A distinction is made between internal and external waves (see figure 5.3):

- The first section focusses on *internal waves*, i.e. waves generated *in* the bay by local wind conditions (section 5.2.1).
- The second section is on *external waves*. These waves will originate offshore at deep water and will propagate to the location of the bay. It is likely that these waves will penetrate the bay through the entrance channel. In section 5.2.2 these external waves are quantified.
- The third section focusses on a coupling of internal and external waves, in an extreme case scenario (section 5.2.3).

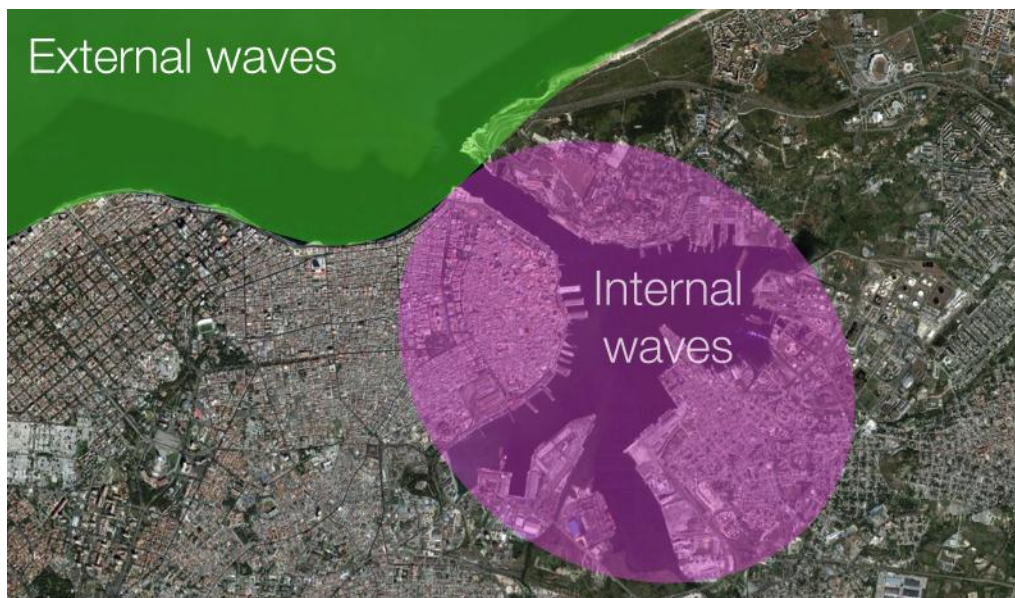


figure 5.3 – area of interest for internal and external waves

5.2.1 INTERNAL WAVES

Two means have been used to determine internal waves, for which wind speed and direction are the main input. An approximation has been made using empirical methods, followed by a more exact approach using the mathematical model SWAN. Fetch length is one of the determining factors for the wave conditions; figure 5.3 shows that the largest fetch lengths are achieved with winds from a general northeast direction, which is the prevailing wind direction. To determine the wave characteristics in the Ensenada de Atarés, only these wind directions have been taken into account.

Five wind speeds have been considered, representing: an average day (5.5 m/s), the maximum wind speed that allows vessel manoeuvring in the bay (10.7 m/s) (see chapter 9), a once per year returning wind speed (21.7 m/s), the average yearly maximum wind speed (27.0 m/s) and a wind speed during an extreme event (40 m/s).

The results of the mathematical model runs are shown in table 5.1. These results are comparable with the empirical calculations, but are considered to be more reliable. Especially considering that the SWAN model contains detailed bathymetry and incorporates effects such as diffraction and refraction.

table 5.1 – significant wave height and peak period for the location of marina

Wind speed [m/s]	East		ENE		N-East		NNE		North	
	H _s [m]	T _p [s]	H _s [m]	T _p [s]	H _s [m]	T _p [s]	H _s [m]	T _p [s]	H _s [m]	T _p [s]
5.5	0.13	1.52	0.15	1.58	0.15	1.59	0.13	1.53	0.09	1.34
10.7	0.28	2.05	0.31	2.12	0.32	2.96	0.28	2.07	0.21	1.91
21.7	0.64	2.82	0.71	2.96	0.71	2.96	0.65	2.85	0.51	2.61
27.0	0.82	3.11	0.90	3.29	0.89	3.31	0.80	3.22	0.66	2.99
40.0	1.23	3.57	1.34	3.84	1.33	3.93	1.18	3.96	0.96	3.31

5.2.2 EXTERNAL WAVES

The effect of penetration of external waves into the bay has been investigated with the mathematical model SWAN. To quantify solely wave penetration, no wind is added to the model, which would cause wave generation in the basin. Several offshore wave conditions have been imposed, propagating from different directions.

The investigation into what wave conditions produce the most wave penetration has led to the conclusion that wave penetration solely due to waves (without wind) is limited to the entrance channel (see figure 5.4).

The marina area and the rest of the basin are without notable waves due to external forcing. The penetration, for any combination of wave direction and imposed wave condition, is limited to the entrance channel.

As expected, the northwest is the wave direction that produces the most penetration. But the difference with waves from the north and west is not significant, as from all directions the waves have damped out at the end of the channel.

The minor variations in observed wave heights show that as the initial imposed wave height is increased significantly, the penetrated wave height is also larger, but it appears it is limited to maximum heights in the order of only centimetres.

For the design of the marina it can be concluded that the contribution of external waves to the internal wave field is negligible compared to the internal waves caused by wind forces. At most, the contribution can be quantified to be in the order of centimetres, which is of no consequence to berthed ships.

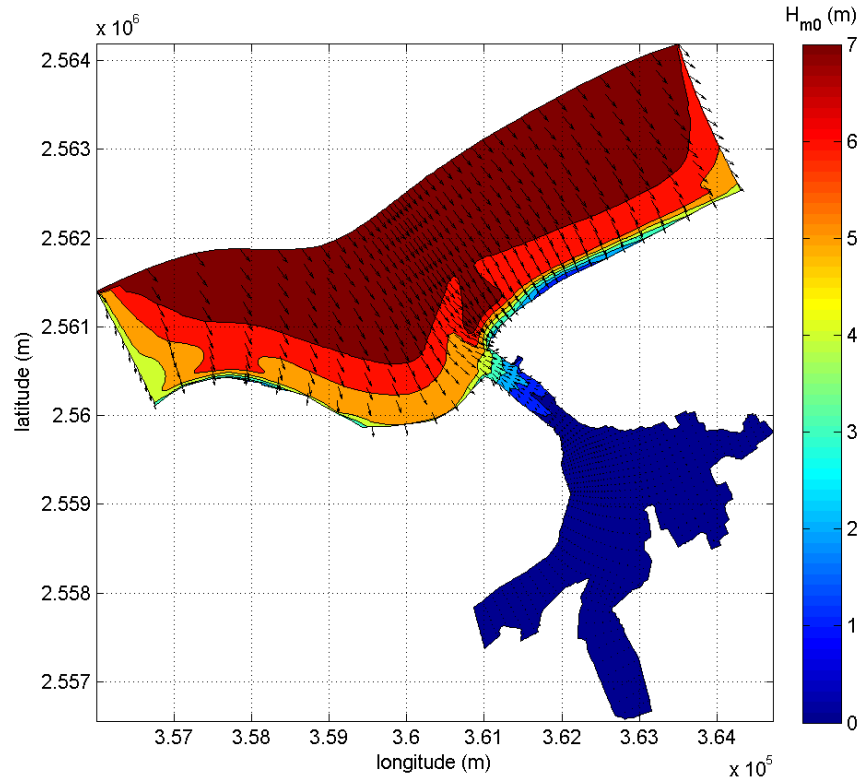


figure 5.4 – wave penetration from an incoming wave with $H_s = 8$ m and $T_p = 12$ s, from the northwest

5.2.3 COMBINING WIND AND WAVES – EXTREME SCENARIO

A north-eastern wind in combination with north-western waves, both using a probability of exceedance of 1/225 per year has been simulated (among other scenarios). The most severe waves occur in the western part of the bay, due to wind only (as can be seen from the wave direction). This again shows that the wave conditions *inside* of the bay are determined by *local wind conditions*.

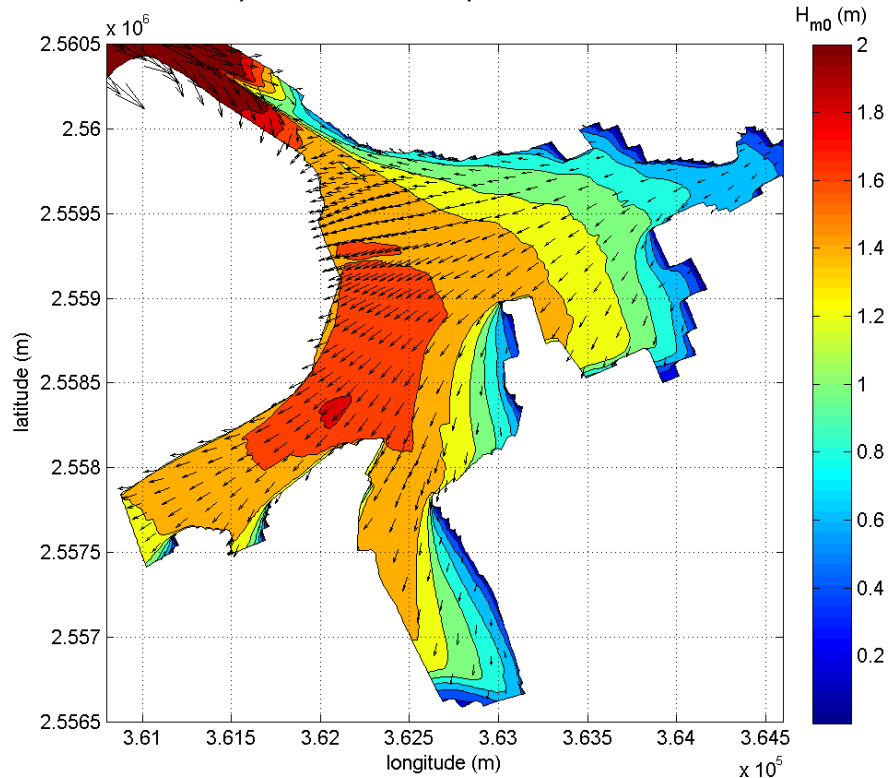


figure 5.5 – significant wave heights in the bay in an extreme scenario

6 DESIGN OF MARINA LA COUBRE

Marina La Coubre is designed around the Espigón de la Coubre. This is the location of the disaster of the French freighter 'La Coubre', which exploded during the unloading of 75 tons of ammunition in March 1960 with an estimated 100 casualties. It has been decided to name the marina after this freighter, in honour of the victims of this tragedy. Some impressions of Marina La Coubre are given in figure 6.1 and figure 6.2.

This chapter gives an overview of the design of Marina La Coubre. A distinction has been made between the berthing area in paragraph 6.1 and the on land facilities in paragraph 6.2. The entire design process has been covered in Appendix N: Preliminary design of the marina and Appendix O: Design of the marina.

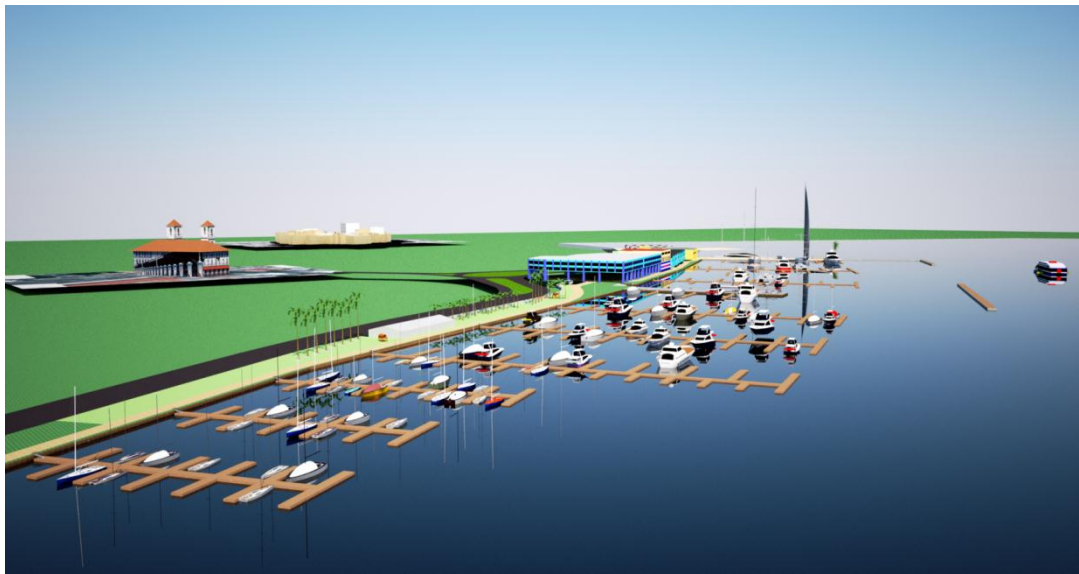


figure 6.1 – artist impression of Marina La Coubre (1)



figure 6.2 – artist impression of Marina La Coubre (2)

6.1 BERTHING AREA

This chapter focusses on the details of the berthing area. The berthing area has been divided in three main components: the berthing layout (section 6.1.1), the breakwater (section 6.1.2) and the walkways between the berths (section 6.1.3).

6.1.1 BERTHING LAYOUT

The proposed berthing layout of the marina is depicted in figure 6.3. Berths of the same length class are grouped at a single walkway. The berthing layout consists of a total of 276 berths:

- 2 berths for mega yachts with a length of 50 – 120 m
- 60 berths for super yachts with a length of 24 – 50 m
- 178 berths for medium size yachts with a length of 10 – 24 m
- 36 berths for smaller yachts with a length of 4.5 – 10 m

The Espigón de la Coubre forms the boundary between the eastern part of the marina with berthing places for super yachts and the western part for medium and smaller yachts. Service vessel will use the most western part of the marina. The eastern side of the Espigón Iglesias will be used to moor the biggest (mega) yachts. An advantage of this arrangement is that vessels can be assigned a berth place close to shore when the capacity of the marina is not fully used. When the ultimate capacity is not yet required the walkways can be shortened because of the flexible construction method of pontoons. The berths have the same orientation as the direction of the prevailing winds, so berthed yachts have a minimum area that is affected by wind.

The Espigón de la Coubre will also contain the main fuel service station and the boat ramp. The Espigón Díaz will be removed to minimize the berthing area of the marina.

A technical drawing containing exact dimensions of berthing slips, walkways, finger piers and fairways is found in Appendix W: Technical Drawings.

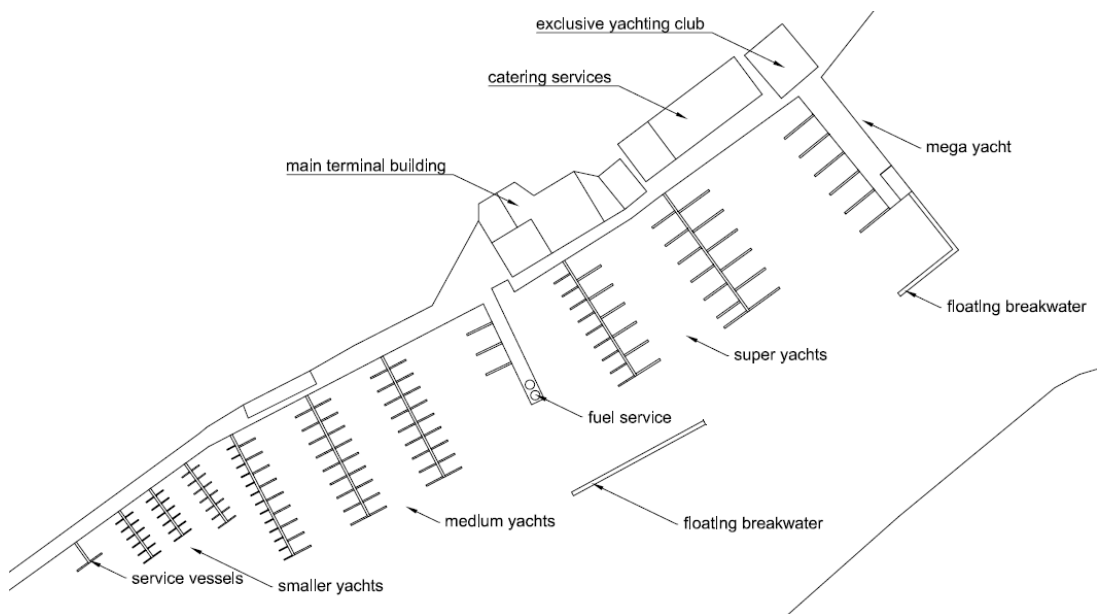


figure 6.3 – berthing layout and on land facilities of the marina

6.1.2 FLOATING BREAKWATER

Although Marina La Coubre is sheltered from sea waves by the natural Bay of Havana, strong winds can generate short-crested waves in the bay itself (see paragraph 5.2). No specific criteria exist about the maximum tolerated wave conditions in a marina, but recommendations have been made (see table 6.1). Without protection from waves, the marina does not qualify for a ‘moderate wave climate’. It is therefore necessary to create a breakwater to defend the berthing area from waves. Based on quality, cost and technical efficiency a floating breakwater has been designed to ensure a ‘good wave climate’ for the marina. A reflective type floating breakwater with a draught of 1.5 m and a width of 4.5 m satisfies the once in a week and once in a year conditions. For a once in 50 years event, a transmitted wave height of 0.94 m occurs, this is however allowed since during these conditions the marina is not operational and wind forces will probably cause more damage.

The breakwater is placed in such a way that it minimizes obstruction of vessel manoeuvrings. Two breakwaters are therefore placed with a fairway, wide enough for super yachts, in between (see figure 6.3). This placement has the advantage that the floating breakwaters can be used as waiting pontoons as well.

table 6.1 – criteria for a good wave climate; criteria for a moderate wave climate are achieved by multiplying H_s by 1.25 (Department of Fisheries and Oceans, 1981)

T_p [s]	H_s per return period [m]		
	1 in 1 week	1 in 1 year	1 in 50 years
< 2	0.30	0.31	-
> 2	0.15	0.30	0.61

6.1.3 WALKWAYS

The walkways between the yachts are polyethylene floaters with a wooden top layer. All main walkways have a width of 2.5 m, whereas the finger piers have a width of 1.0 m for smaller yachts, 1.5 m for medium size yachts and 2.0 m for super yachts. It is recommended to use multiple connected small pontoons to allow flexibility in construction. The lifetime of a floating pontoon is about 25 years, which means they require at least one replacement in the considered lifetime of the marina and regular maintenance is advised.

The pontoons require anchoring to keep them fixed in position. Piles are not recommended due to the great depth, instead gravity based anchors placed on the seabed are used. Due to the small tidal range the allowable vertical motion is not compromised. The small tidal range also allows for the use of common gangways to connect the walkways to shore.

The walkways are also used to house utility services. These services consist of cleats and bollards to moor the vessels, fenders to protect the walkways from mooring impacts and service bollards to provide electricity, water and secondary services.

Two types of cleats should be acquired, one for the smaller yachts with a pulling capacity of 3 tons and one for the super yachts with a pulling capacity of 6 tons.

For safety reasons the walkways should be illuminated at night and have fire extinguishers and ladders at regular intervals.

6.2 ON LAND FACILITIES

Entrance and exit

The official entrance of the marina will be located at the old La Coubre terminal entrance gate. The retained relation with the disaster of La Coubre gives historical value to the marina and is in honour of the victims of the tragedy. Besides, the train station and remains of the historic city wall are located close to the entrance.

The current terminal building will be demolished to make room for supply trucks. The exit of Marina La Coubre will be located near the parking area on the eastern side of the terminal building at the Muelle Díaz no. 1 to connect to the Avenida del Puerto.

Main terminal building

The terminal building at the Muelle Díaz no. 1 will be renovated for the use of main building in the marina. The two lowest storeys will be combined as a single spacious base floor with a transparent style to connect the marina and the city.

The information service desk, surveillance guard and harbourmaster's office will be placed on this base floor close to the entrance at La Coubre. The boat launch installation will be located at the east side of the Espigón de la Coubre. The southwest corner of the terminal building will therefore have the destination of a small boat yard, where minor repair activities can take place. Some sanitary facilities will be placed in this building as well.

The eastern part of the building, close to the warehouse on Díaz no. 2, will be a covered parking area for costumers of the hotel, restaurant and marina. When needed, a number of parking spots can be used as covered dry berthing place.

On the second floor (the current third floor), a supermarket will be located that will sell boat gear as well. A fitness gym and small spa will be placed next to the supermarket.

A hotel will be placed on the top floor of the building. This hotel can be used by costumers of the marina that do not want to stay on the vessel during the night. Visitors of the country arriving by ferry can also use the hotel.

Sideline activities

The old warehouse at the Muelle Díaz no. 2 will be used to house a restaurant, bar and yachting club. Sufficient area is available to give these facilities a spacious layout. It is therefore recommended that the restaurant and bar will not only provide for the costumers of Marina La Coubre, but that regular inhabitants are also welcome. The authentic atmosphere of the old warehouse will be preserved, although some adjustments will have to be made to make the building functional for its new purposes. Some sanitary facilities will be placed in the building as well. Other service related facilities, like a money exchange and customs service, can be located in the western part of the warehouse.

On the strip along the Muelle de la Coubre small kiosks containing cafeteria, bar and shop activities will be located in the western warehouse. Only this western building will be reused, the eastern warehouse will be demolished. In this way also this section is integrated in the marina. Also some sanitary facilities will be placed in this building for owners of the yachts berthed in the western part of the marina. Some parking places dedicated for costumers of the marina will be placed on this strip as well.

Yachting club

The old Hines building will be reused as an exclusive club for super and mega yacht owners. Several shops for luxurious products will be located in this building as well. The Espigón Iglesias will only be accessible to the owners of the berthed super yachts, his guests and for employees of the marina.

Marina reception and customs

At the head of the Espigón Iglesias the marina reception will be located, where newly arrived yachts will have to check-in to be assigned a berthing place. The initial customs and immigration services can take place here as well. Because these services are often time-consuming, the floating breakwater can also be used as a temporary mooring place for waiting vessels. When a more extensive immigration and/or customs service is needed, this can take place in the main building on the Muelle Díaz no. 1.

Dry berthing

It has been assumed that the marina of Havana will mainly be a port-of-call; negligibly few customers of the marina will use it as a homeport. It is therefore plausible to state that only a small minority of the yachtsmen will want to put their vessel on dry land. The parking area in the terminal building can be used as a small, temporary dry berthing area for these yachtsmen. If in the future more people choose Havana as their home port, the dry berth facility must be expanded, possibly outside the general marina area. It is however recommended to make the marina in the Bay of Havana a tourist marina for short-stay purposes. Yachts that will be berthed for a longer period are recommended to move to Marina Hemingway.

Promenade

The entire marina will be linked by a walking promenade that will be connected to the marine walk at the Almacén San José. This will decrease the instinctive distance between the marina and the city centre and will increase the attractiveness of the marina for other visitors as well.

Car rental services

A car rental service is already situated at the cruise terminal and car renting is in general demanded more by ferry passengers than by yachtsmen, it has therefore been decided to locate a car rental service at the ferry terminal. Two car rental services in the close proximity of the marina have been assumed to be adequate.

Waste treatment

The sewage water, chemical waste and garbage treating facilities will be situated at one place, to cluster these wastes. To minimize hindrance caused by smell and noise, this building is located at the very south-western end of the marina.

7 DESIGN OF THE INTERNATIONAL FERRY TERMINAL

The proposed design of the international ferry terminal is presented in this chapter. The ferry terminal is located in the south-west corner of the bay, in the Ensenada de Atarés, according to the allocation analysis (see Appendix M: Allocation analysis). The design vessel used is the Damen Ropax 6016. More information on this vessel, and other design conditions, can be found in chapter 4. In order to anticipate the versatile future developments, flexibility is implemented as an important design variable.

As the international ferry terminal connects the city of Havana to the open water, the chapter is divided into two parts; a 'water' part, covering the nautical design (paragraph 7.1), and a 'land' part, covering the on land facilities (paragraph 7.2).

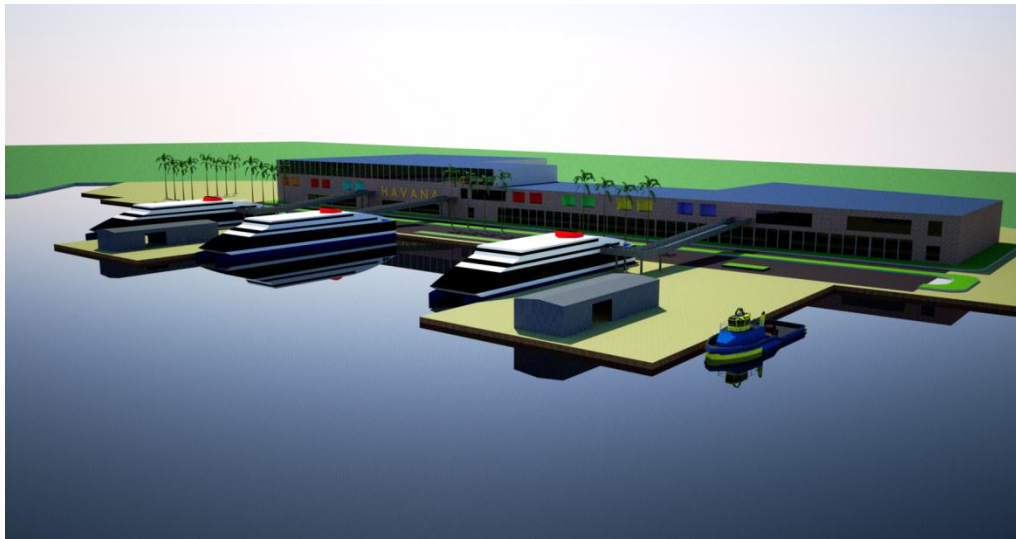


figure 7.1 – artist impression of Havana International Ferry Terminal

7.1 WATER SIDE

First, the water side is discussed. This covers the design for berthing and mooring of ferry vessels as well as the dimensions of the piers.

7.1.1 SAILING

Easy approaching and mooring at the terminal is desired in order to minimize mooring time, hindrance to other traffic and collision probabilities. Therefore, the sailing distance inside the bay is minimized, as well as the number of turns the ferry vessels must perform in order to moor. This means the most direct route to the berth is used. The subject of sailing is elaborated upon in more detail in chapter 9: Design of nautical infrastructure.

7.1.2 BERTHING

The design contains three berths, as discussed in Appendix P: Design of the ferry terminal. These berths are provided by two pier structures that will provide ship to shore connections at both the stern and side of the vessel. A pier system is more space efficient compared to a quay system as each pier is able to receive two ferry vessels; one at each side. To meet the desired high level of flexibility, initially one pier will be completed. The second pier will be constructed later, depending on the developments and demands. Initially only one side of this second pier will be used as a berth for ferry vessels, the other side of this pier adds flexibility to the terminal design. If demanded in the future, this side of the pier can also be used as dedicated berth for a fourth ferry line.

Berthing method

Because practically no currents or waves are present in the Ensenada de Atarés, the ferry can be berthed in a so-called 'corner berth lay-out' (Ligteringen, 2009), of which a top view is shown in figure 7.2. This method is characterized by fenders placed at one side of the vessel; and either at the bow or the stern. The ship is held in position by mooring lines.

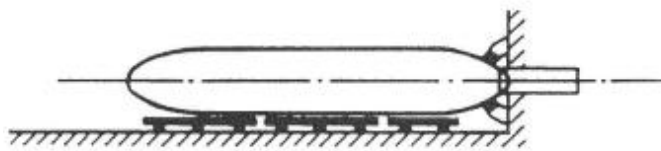


figure 7.2 – corner berth layout (PIANC, 1995)

7.1.3 MOORING

From a logistic point of view, it is preferred to (un)load motorized traffic at the head of the pier. In this way the traffic flow from the vessel to the terminal and public road system can be handled in a proper and effective way. This arrangement can only be achieved by a side connection. This side connection is located near the bow of the vessel. Therefore rearward directed mooring is required. The quay structures thus require stern fenders.

Fender

The selected fender must be able to handle mooring forces of 743 kN and absorb an impact energy of 256 kNm, as computed in Appendix P: Design of the ferry terminal. The highest reaction forces will be created at the fenders that support the stern of the vessel. A D-type fender is considered the most appropriate fender, because it is able to handle high loading forces, it has high durability for frequent mooring and it is cost efficient. For the applicable forces, mentioned above, a 12" D-type fender is recommended.

Ship to shore method

Considering the low tidal range in the Bay of Havana and the wish to have as few as possible maintenance, the fixed land ramp has been chosen as the preferred system to use in the Havana International Ferry Terminal. Moreover, the system has the advantage of being flexible and robust. Although initial costs are higher compared to the floating pontoon system, the fixed ramp is expected to be less costly due to the limited maintenance.

7.1.4 PIER LOCATION

The quay is located on the west side of the Ensenada de Atarés, here the required wet area, as well as on land area, is spaciouly available. Sufficient depth is available in the whole basin (see Appendix F: Analysis of existing port infrastructure and facilities), both initially as in a long term perspective. As a result dredging works are not required. The present quay is reused as it is on the ideal location and in reasonable shape. Consequently, little rehabilitation has to be done, which reduces the construction costs. For the same reason, the piers are constructed in the shallow areas of the basin, minimizing the required construction materials.

The piers are orientated perpendicular to the quay, in the direction of the approach channel. This is done to provide an advantageous orientation to the prevailing wind direction, creating the optimal angle to the prevailing winds of 30 degrees

(Ligteringen, 2009). Moreover this pier orientation minimizes the quantity of manoeuvres the ferries must carry out in order to enter the terminal.

7.1.5 PIER DIMENSIONS

The space between the piers is designed to be four times the beam of the vessel according to Ligteringen (2009). Furthermore, the two berths both require a width of the beam of the berthed vessel. Adding up, the basin width in between the two piers is six times the beam of the vessel: 97.2 m. Dimensions of the piers and basin in between are depicted in figure 7.3.

Width of the piers

The piers must provide sufficient space to house the facilities required at the piers. These are: a marshalling area, a supply storage building and an apron to moor and provide logistic operations (PIANC, 1995). Since the pier is used for mooring at both sides, the supply storage building is located in the middle of the pier, close to both berths. The width required for these functions defines the total width of the pier at 46 m. The precise dimensions of the different components can be found in Appendix P: Design of the ferry terminal. Bollards should be placed in a lowered position in the quay to decrease the hindrance to the traffic on the aprons. These bollards should have a pull capacity of at least 19 tons.

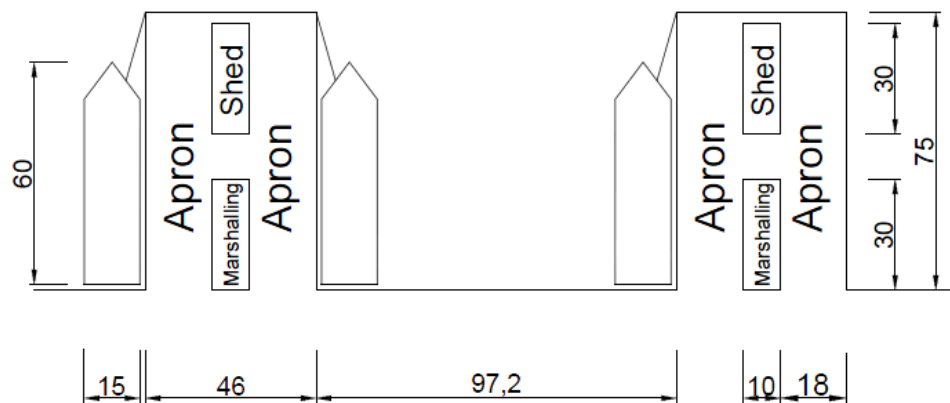


figure 7.3 – pier layout

Length of the piers

The length of the pier is 75 m, consisting of 60 m to support mooring along the whole side of the vessel and an additional 15 m for flexibility and spaciousness of the pier. Furthermore, the mooring lines of the vessel are tied up at the corner of the quay. In this way the angle of the line is diminished, which increases the capacity for longitudinal berthing forces. Dolphins may be desired in case bigger vessels will be applied to the ferry line in the future. Concluding, the pier dimensions have been designed at 75x46 m².

Height of the piers

The pier construction is situated on a flattened surface on the solid rock bottom, at a depth of 5 m below MSL. The construction height is 7.5 m at the centre of the pier. Along the facing line at the quay wall the construction is lowered to 6.4 m due to the required slopes for the use of the ramp. The usability is normative here, as the water conditions are calm at this location according to the hydrodynamic analysis. This comes down to 1.4 m above MSL, meeting the conditions for both overtopping during high water conditions, as well as usability during low water conditions.

7.2 LAND SIDE

This paragraph covers the terminal buildings and the traffic flows inside the international ferry terminal. The connection of the terminal to the transport network of Havana is discussed separately in chapter 8.

7.2.1 TERMINAL BUILDINGS

The terminal site contains four main buildings. The main terminal building contains check-in service, customs services, waiting lounges, money exchange and ticket sales. Furthermore, catering services and small shops are located in the same building so these facilities are directly available for both waiting and arriving passengers. A complete overview of the functions inside the terminal building is provided in Appendix P: Design of the ferry terminal.

Besides the main terminal building, the site holds two customs buildings; one for outbound traffic and one for inbound traffic, both accompanied by entrance gates. Furthermore, a garbage collecting service is located behind the long term parking area, besides the quay, and storage is provided at the end of both piers.

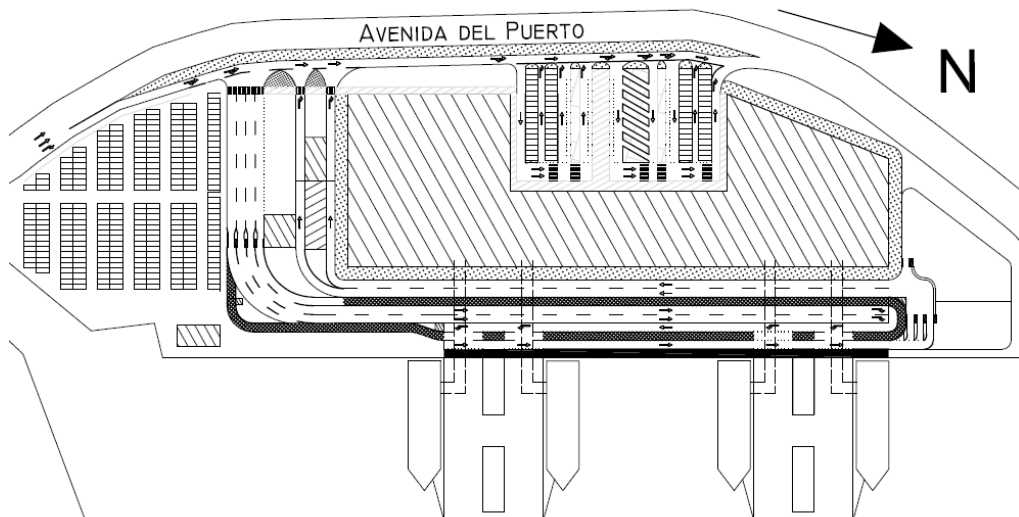


figure 7.4 – overview international ferry terminal

7.2.2 TRAFFIC FLOWS IN THE FERRY TERMINAL

The terminal court area is characterized by the vehicle traffic system. The layout for this system is determined with the use of the report *Ferry developments and their consequences for ports* (PIANC, 1995).

The traffic inside the terminal contains two different flows that have to be separated: the inbound traffic (arrivals) and the outbound traffic (departures).

The quay is the only location where this is impossible, therefore the area in front of the pier must be clearly marked and controlled in order to guarantee safety. To keep the ferry terminal flexible in case of coinciding arrivals and departures, it is recommended to create the possibility of crossing traffic at the quay. This also makes the terminal more attractive as more ferries can arrive and depart at their preferred time. Around the terminal building and along the quay, strips for possible expansions in the future are implemented. This increases the flexibility of the terminal as the different lanes are easily shifted according to new developments.

Next to the outbound and inbound traffic, discussed below, two other infrastructure facilities are of importance: the pedestrian flows and the service lane. The pedestrian flows are completely separated from the vehicles as pedestrians use the direct connection of an elevated walkway between the apron and the terminal building.

The service lane is required for breakdown vehicles and vehicles with document clearance. In addition, emergency vehicles can use the service lane to have quick access to the entire terminal.

Outbound traffic

The outbound traffic follows the scheme presented in figure 7.5. The ticket sales and control is combined at the same location in order to minimize processing times. In front of this building a buffer area makes sure waiting vehicles do not block the drive through leading to the ferry terminal. Furthermore, it provides the possibility for customs to search vehicles.

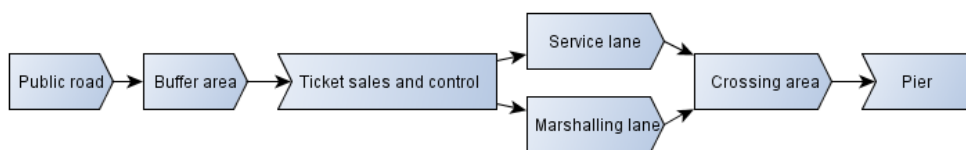


figure 7.5 – flow scheme outbound traffic

Inbound traffic

The flow scheme of inbound traffic is given in figure 7.6. From the pier the vehicles enter the crossing area, where clear indication leads to the passport control. When leaving the ferry terminal, the vehicles have to pass customs inspection. Here a special hall is located for vehicle searches. Past the customs control the vehicles enter the drive through, leading to the Avenida del Puerto.

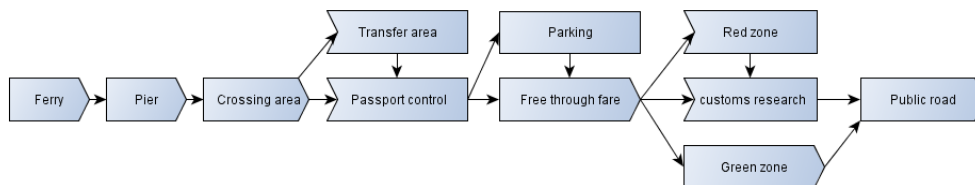


figure 7.6 – flow scheme inbound traffic

Forecourt of the terminal building

The forecourt is situated in an indentation of the terminal building. In this way the relation with the ferry terminal is emphasized and traffic is urged to reduce its speed. The forecourt is divided into the departures terminal and the arrivals terminal. At the departures terminal short-term parking, setting down lanes for taxis, busses and passenger cars are available. The arrivals terminal has the same facilities, plus a short stay parking area for busses. Here, also public transport busses are able to stop and pick up tourists.

8 DESIGN OF LAND INFRASTRUCTURE

This chapter discusses the design of the connections of the marina and the international ferry terminal to the transport network of Havana. Both facilities are connected to the Avenida del Puerto, the main road along the Havana Bay. In the infrastructural analysis in appendix E, the intersections of the Avenida del Puerto with Avenida de Bélgica and with Arroyo are identified as the most important bottlenecks for these connections. As these locations coincide with the entries of the marina and the ferry terminal respectively, the connections and these intersections are designed integrally. In order to find the best solution, for both the connection of the ferry terminal as the connection of the marina, a Multi Criteria Analysis (MCA) has been carried out, of which the results can be found in Appendix Q: Design of the connections to the transport network.

First the Avenida del Puerto is discussed in general (paragraph 8.1) followed by the connection of the international ferry terminal (paragraph 8.2) and the connection of the marina (paragraph 8.3).

8.1 AVENIDA DEL PUERTO

This paragraph covers the adaptations to the Avenida del Puerto. The road layout is changed in several locations in order to meet the requirements raised by the development of Tourist Port Havana (see Appendix L: Boundary conditions and design requirements). These adaptations consist of changes to the general road layout, as well as the modification of the road section in front of the Sierra Maestra cruise terminal and the intersection with Jesus Lopez.

8.1.1 GENERAL ROAD LAYOUT

The overall layout of the Avenida del Puerto remains roughly the same. The road will consist of two lanes per direction, except for some road segments with additional public transport lanes or pick-up areas. The maximum speed is 50 km/h to ensure a uniform speed on the road, smoothening the flow of old and new cars. Parking spaces are moved from the centre of the road to the side of the road to minimize crossing pedestrians and merging cars. Pedestrian crossings are implemented at intersections, in order to converge the flows of crossing pedestrians to safe locations. The lining is redone extensively, creating a uniform system of recognizable guidance on the road, together with the signs on the side of the road.

8.1.2 SIERRA MAESTRA TERMINAL

The road section at Sierra Maestra changes completely with the relocation of the parking square onto the pier. The road is expanded from one to two lanes per direction, removing the capacity drop of the Avenida del Puerto at this location. With this adaption, the entire road along the bay consists of two lanes per direction, creating a consistent capacity. In addition, a public transport lane is implemented on both sides to pick up and drop of tourists. This provides the possibility to transport tourists, arriving with a cruise, visiting Plaza San Fransisco de Asis, or visiting Habana Vieja in general, without blocking the through traffic.

A large pedestrian crossing is implemented at the Plaza San Fransisco de Asis, with LED lights implemented in the road and sidewalks to increase the visibility. Tourist facilities, like food stands, tourist information and money exchange services, are located alongside the Plaza, next to the church.

8.1.3 INTERSECTION WITH JESUS LOPEZ

The intersection with Jesus Lopez is currently a very unclear junction (see Appendix E: Infrastructural analysis). This problem is solved with a traffic management system, containing an integrated connection with the railway gates and traffic lights that are coupled to those on the intersection between Jesus Lopez and Fabrica. Because the waiting capacity on Jesus Lopez is only about 30 cars, the green times of these two intersections have to be synchronized in order to avoid blocking back onto Fabrica. With this traffic management system the safety is improved substantially but this is at the expense of capacity for this link. This decrease in capacity is compensated with an extra lane for traffic waiting to turn left from Jesus Lopez onto the Avenida del Puerto.

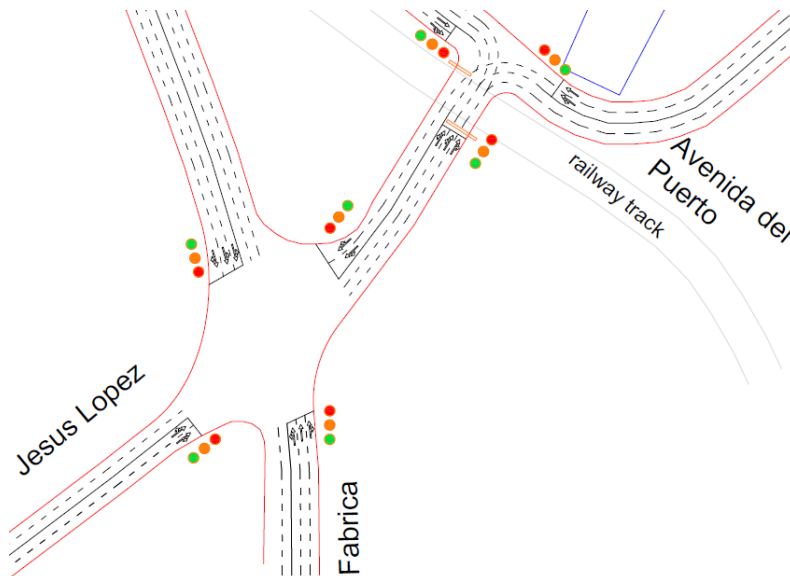


figure 8.1 – Jesus Lopez

In addition to the traffic management, the layout changes as well (see figure 8.1). The possibility to move from Fabrica, left onto Jesus Lopez is currently not available. This movement is added to create the possibility to reach the ferry terminal from the northern section of Fabrica, improving the accessibility of the ferry terminal. By adding this movement, a complete junction with all possible movements is created. This has effect on the traffic management as well, as combined green times have to be rearranged.

8.2 CONNECTION OF THE FERRY TERMINAL TO THE TRANSPORT NETWORK

The ferry terminal is connected to the Avenida del Puerto between the intersections with Arroyo and Jesus Lopez. In order to optimize the accessibility and the capacity of the network, several modifications of the road layout in this area are applied. The design space of the ferry terminal connection to the network of Havana is limited by the railway track on the city side and by the ferry terminal building on the bay side. More information on the surroundings can be found in Appendix C: Analysis of the surrounding area and Appendix E: Infrastructural analysis.

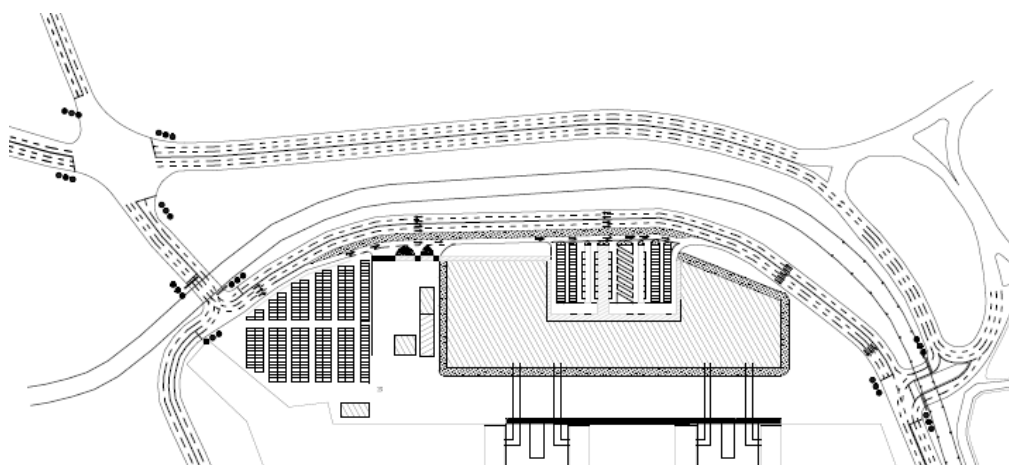


figure 8.2 – connection of the ferry terminal

8.2.1 ENTRY OF THE FERRY TERMINAL

The ferry terminal is connected to the public road with a drive through lane to minimize the hindrance of merging traffic and to create a safe traffic flow at low speeds towards the terminal. From the intersection with Jesus Lopez, an extra lane is added to the Avenida del Puerto in the direction of the ferry terminal (north). At 100 m from the intersection, this lane diverges from the main road. From here, the drive through leads along both the departures and the arrivals terminal, where parking facilities and drop off locations are located (see paragraph 7.2). Beyond the arrivals terminal, departing vehicles are led back to the main road, where the drive through is connected to the Avenida del Puerto again, at a distance of 200 m from the intersection with Arroyo.

The implementation of this drive through causes the ferry terminal to be only accessible from the south, at the intersection with Jesus Lopez. Traffic originating from Habana Vieja has to make a minor detour via Fabrica and Jesus Lopez. This limits the hindrance on the Avenida del Puerto by the traffic from and to the ferry terminal. This traffic flow is only a small fraction compared to the flow from Habana Vieja towards Regla (see Appendix E: Infrastructural analysis.). Crossing traffic is prevented, but merging traffic still occurs at both ends of the drive through. The hindrance of merging is minimized by clear signage at sufficient distance from the intersections.

8.2.2 INTERSECTION WITH ARROYO

The intersection with Arroyo is managed with traffic lights and railway gates to increase safety without a major capacity drop. An extra lane from the south is added to the road layout (see figure 8.2) to increase the capacity of this bottleneck. Now three lanes enter the intersection from the south, of which two continue straight on the Avenida del Puerto and one turns left onto Arroyo.

At the northern section of the Avenida del Puerto, the direction of the middle lane of five is changed towards Regla. The larger flow, from Habana Vieja towards Regla, now has three lanes, which are needed to handle the future traffic flows (see Appendix E: Infrastructural analysis.). On the other side of the railway track, the capacity of the roundabout is expanded to four lanes. Two of these lanes can accommodate traffic waiting to turn onto the Avenida del Puerto.

8.3 CONNECTION OF THE MARINA TO THE TRANSPORT NETWORK

The marina is connected to the Avenida del Puerto at the intersection with Avenida de Bélgica. At this point, the current roundabout is adapted to increase the capacity and implement the entrance and exit of the marina. The available space for these connections is limited due to the old city wall and surrounding buildings (see Appendix C: Analysis of the surrounding area and Appendix Q: Design of the connections to the transport network).



figure 8.3 – connection of the marina

8.3.1 TURBO ROUNDABOUT

The current, chaotic roundabout is replaced by a new, three-lane roundabout, inspired by the so called 'knuckle roundabout' by Fortuijn (2012). This type of turbo roundabout creates a large capacity, combined with a high level of safety. The number of conflict points in this roundabout is minimized by using a changing radius of the lanes. More details of this roundabout can be found in Appendix Q: Design of the connections to the transport network.

8.3.2 ENTRANCE AND EXIT OF THE MARINA

The entrance and exit of the marina are connected directly to the roundabout, but at the opposite ends (see figure 8.3). One lane on the roundabout leads to the entrance of the marina at La Coubre, which is sufficient for the relative small traffic flow towards the marina. This optimizes the through flow of the roundabout. Inside the marina, one lane leads to the parking area, on the east side of the main building, where the required 50 parking spaces are situated. The exit leads from the parking building onto the roundabout.

The marina is also accessible from the Avenida del Puerto for supply trucks and tankers. They can approach the marina from the west and enter directly from the Avenida del Puerto. The fuel supply pier is located close to the entrance. After the provision, the trucks exit the marina onto the Avenida del Puerto at the same point they entered.

The marina is accessible for pedestrians via the walkway along Tourist Port Havana. In front of the marina this walking route continues via a tunnel under the roundabout, leading to the La Coubre bus station. Here, tourists can take the bus to touristic hotspots or continue walking towards the central train station and the Capitolio. The tunnel has an exit in the centre of the roundabout, where the remnants of the La Coubre disaster are relocated on the opposite side of the old city wall.

9 DESIGN OF NAUTICAL INFRASTRUCTURE

A port requires a well-designed nautical infrastructure in order to receive visiting vessels in a safe and comfortable way. The nautical infrastructure consists of an approach channel (paragraph 9.1) and proper navigational utilities (paragraph 9.2). Because an increase in the number and variety of vessels is expected in the future, traffic intensity will increase to a point where mitigating measures are required. The problem of increasing traffic intensity and a plausible solution are evaluated in paragraph 9.3. More details about the subjects in this chapter can be found in Appendix R: Design of nautical infrastructure.

9.1 APPROACH CHANNEL

It is recommended to design an approach channel to let vessels sail into the bay in an orderly way. The designed general approach channel is depicted in figure 9.1. The approach channel is preferably aligned with the prevailing wind and wave direction to minimize the cross currents. At a distance of 2 km northwest of the entrance to the bay, a bend will be located to change the direction of the approach channel to the fixed direction of the natural entrance of the bay.

The length of the entrance channel is determined by the distance covered in the time tugs need to make fast, slow down the vessel and the eventual stopping length. This leads to a total required distance of the entrance channel of 1.6 km.

The entrance channel ends in a swinging area where the vessel can stop, turn and subsequently sail or be towed to its berth. The minimum diameter of this turning circle is twice the design vessel's length, which results in a diameter of about 450 m. To have enough clearance between the turning basin and the embankment, the total length of the entrance channel has been designed at 1.7 km.

After the turn in the swinging area, the ferry or yacht will make its way to the Ensenada de Atarés, where its berth is located. The Ensenada de Atarés cannot be reached by sailing in a straight line, so a bend has to be made. The interior channel ends again in a turning basin in front of the berthing area. This turning circle is needed as the ferries have to be moored astern (see chapter 7).

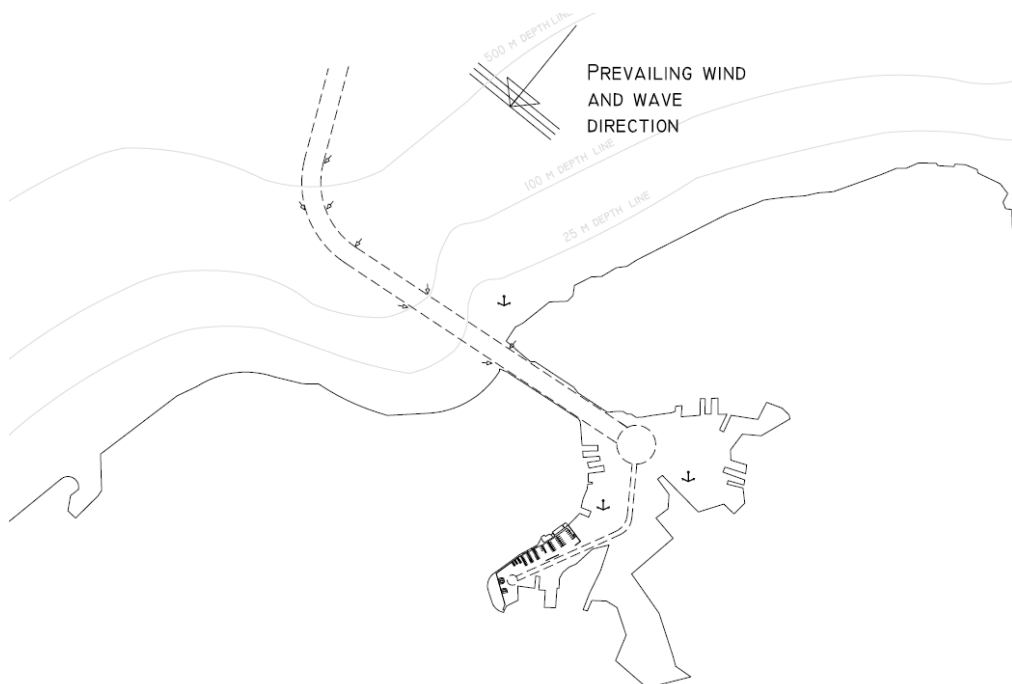


figure 9.1 – approach channel, turning basins and anchorages for the Port of Havana

9.2 NAVIGATIONAL UTILITIES

Anchorage areas

An anchorage area is necessary to give vessels a safe location where they can await permission by the port authorities to enter the bay. The location of an anchorage area at the outer side of the bay is limited by the rapidly increasing water depth. The currently used anchorage area, about 250 m north of the Castillo del Morro will therefore be retained. The Fondeadero de Casablanca can be used as anchorage in the bay. The current main anchorage site, Fondeadero la Tasajera will be relocated slightly to the west and will be used for waiting yachts. These anchorage areas can also be seen in figure 9.1.

Buoys

The alignment of the approach channel should be clearly marked by buoys at either side of the channel. In a one-way channel, the required minimal marks are three buoys at the inside of the bend: one at the apex and one at the entry and exit of the bend. The width of the entrance channel can be marked by the two buoys currently located at the entrance of the channel (see figure 9.1).

Towage service

Although ferries and cruises have a high manoeuvrability by themselves, especially cruise ships may be vulnerable to high wind speeds and may require tug assistance to pass the entrance channel. Given the water displacement of a cruise ship, a total bollard pull of 70 ton is required. A regular tug has a bollard pull capacity of approximately 60 ton. This means that two tugs are sufficient: one operating fore and one aft.

Pilot service

The Port of Havana works with a compulsory pilot service for vessels that are calling the port. This will be limited to cargo, cruise vessels and mega yachts in the future. Yachts are able to enter the port without pilot assistance as they will experience little problems with their relatively small dimensions. The ferry service will be captained by a sailor with a lot of experience in the bay.

Traffic control tower

The traffic control centre should be located at a place close to the entrance channel with a good visibility on the approaching vessels, as well as the bay itself. The current location of the traffic control tower close to the Castillo El Morro is suitable and is recommended to be retained.

9.3 NAUTICAL TRAFFIC

9.3.1 LIMITATIONS

According to the current legislation, no manoeuvring is allowed in the entrance channel with wind speeds of 6 Bft and higher. However, even with these wind speeds, the entrance channel should have sufficient width for vessels entering or leaving the port in accordance with the guidelines. Nevertheless, the current legislation has been evolved by practical experience over years, and should therefore be respected (PIANC, 1995).

Although wind speeds of 6 Bft and higher only occur about 5% per year (see Appendix H, paragraph H.4.4), it is preferred to decrease downtime as much as possible. A possible method to investigate this is by means of a manoeuvring simulation program.

9.3.2 TRAFFIC SCHEDULING

Vessels calling the Port of Havana are divided in four categories: cruises, ferries, yachts and cargo ships. These four classes are each given a window during which they can enter or leave the port. The recommended order of priority is given below:

1. Ferries

Ferries sail according a tight schedule that will be similar every day. Therefore the ferries are given the highest priority when encountering another vessel.

2. Cruise ships

The cruise industry will be of major importance for the Cuban economy. As Havana will probably be a significant cruise destination, high wages can be asked of the cruise operators. The Port of Havana will have to give some reliability in return, as cruise companies will skip Havana just as easily if waiting times are excessively high. After all, cruise lines are thriving today without Havana as destination. Furthermore, if the Port of Havana wants to be a 'tourist port', the cruise activities should become the central activity. The only reason why ferries should be assigned a higher priority is that the schedules of ferries are more reliable and more or less in control of the port authorities.

3. Cargo vessels

Cargo transporting ships will not welcome waiting times, but they can notify the port authorities about their arrival days in advance. The authorities can anticipate on this call by adjusting the time schedule or, more plausibly, by notifying the captain of the cargo vessel about the exact time window at which entrance is allowed. The captain can then adjust the sailing velocity in such a way that the estimated time of arrival fits in the window. Cargo vessels are used to this strategy, as many ports are operating with a tidal window. Moreover, this method reduces fuel costs. It is however still a hidden form of waiting time (Ligteringen, 2009).

4. Yachts

The number of yachts is numerous. Moreover, yachts have unreliable arrival times and have above all a non-commercial nature. They are therefore given the least priority. It is recommended to assign a fixed window to the entrance of yachts which is commonly known among yachtsmen. When necessary, the duration of the window can be adjusted to the yachting season. Multiple yachts can then enter the bay during this window at which commercial shipping is temporarily prohibited. Yachtsmen can adjust the estimated time of arrival to this window, or otherwise have to wait until the next window. When a yacht cannot make the window on time, it is also possible to sail to Marina Hemingway.

Using the above priorities an example traffic schedule has been drafted (see table 9.1). During the touristic high season, four cruise ships have to enter in the morning and leave in the evening. This leads to long windows for cruise ships after which the windows for cargo vessels cannot be maintained. Although cargo ships have a higher priority than yachts, it has been decided to sustain the yachting window around 14:00 h. Consistency is important for the window for yachts, as yachtsmen are not easy to be informed about daily changing window times. It is therefore apparent that cargo shipping is only possible at night during touristic high season. Hence, if the Port of Havana decides to focus on tourism, the attractiveness of the port as a destination for cargo vessels decreases significantly. As a result, cargo activities of especially bulk carriers and container ships should probably be relocated to other ports in the country.

table 9.1 – example of a daily traffic schedule during cruise season

Opening [h]	Closing [h]	Vessel	Remark
06:00	07:30	Ferry	Arrival from overnight trips, departure to Key West
07:30	12:00	Cruise ship	Arrival of cruise ships
12:00	15:00	Yachts	
15:00	16:30	Ferry	Arrival and departure to Key West
16:30	17:30	Cargo	Particularly the departure of cargo vessels, as window is too short for arrival
17:30	22:30	Cruise ship	Departure of cruise ships
22:30	23:00	Yachts	For yachts that missed the first window
23:00	01:00	Ferry	Departure of overnight trips, arrival from Key West
01:00	06:00	Cargo	

10 PROJECT PLANNING

Project planning is required since it gives insight into the timescales of the progress of the project, secondly because there is interaction with both the construction methods and the financial analysis. The vision on the construction methods is given in paragraph 10.1, the time frames for the project are discussed in paragraph 10.2 and paragraph 10.3 discusses phasing. Appendix P: Project planning provides more details on the project planning and what can be done to increase its accuracy.

10.1 VISION ON CONSTRUCTION METHODS

The use of Cuban resources to construct Marina La Coubre and the international ferry terminal is the main drive behind the vision on construction methods. The use of the Cuban labour force and locally available resources can greatly reduce costs. The import of foreign materials or equipment should be limited to items that Cuba is unable to provide. These can for instance consist of luxurious hotel equipment, electronics or possibly the floating pontoons for the marina.

Another pillar behind the construction vision is the reuse of existing facilities where possible. This reduces costs and maintains some of the spirit of the area as it exists today. A detailed description of construction methods of all project components can be found in Appendix S: Construction methods.

10.2 POSSIBLE SCENARIOS FOR PLANNING AND RESULTING TIME FRAMES

The planning of the project is greatly dependent on the expected demand for the marina and international ferry terminal. The embargo imposed by the U.S. government is the main factor when considering project planning. To allow for this factor of high uncertainty, several scenarios have been drafted and investigated:

Fast

In this scenario it is assumed both political and building progress is achieved relatively fast. The embargo by the U.S. is raised promptly and without time consuming difficulties. As a result, the demand for the marina and ferry lines will increase swiftly and available financial resources increase.

The construction processes are performed in a steady way without severe delays. The delays and required construction time per component are assumed to be short. This scenario gives insight in the lower limit of the total time required to finish the entire project (see table 10.1).

table 10.1 – planning characteristics for scenario 'fast'

Characteristic	Point in time / Duration
Start date	01-01-2014
End date	2029
Total duration	15 years
Total duration of construction delays	4 years, 6 months

Moderate

In this scenario a moderate progress of both political and building progress is assumed. The raise of the embargo by the US is executed step by step, taking into account that some time consuming difficulties will arise. Also, the building processes have fluctuating progress. This scenario gives insight in the expected time required for the execution of the entire project (see table 10.2).

table 10.2 – planning characteristics for scenario 'moderate'

Characteristic	Point in time / Duration
Start date	01-01-2014
End date	2042
Total duration	28 years
Total duration of construction delays	13 years

Slow

In this scenario it is assumed both political and building progress is achieved relatively slow. The embargo by the US is sustained for a relatively long time. The demand for the marina and especially ferry lines to cities in the United States is as a result low. Also, it is assumed building processes are delayed for relatively long times. This scenario gives insight in the upper limit of the total time required to execute the entire project (see table 10.3).

table 10.3 – planning characteristics for scenario 'slow'

Characteristic	Point in time / Duration
Start date	01-01-2014
End date	2056
Total duration	42 years
Total duration of construction delays	28 years, 6 months

10.3 PHASING AND ADDITIONAL DELAYS

Phasing can be used to adapt to a varying demand in capacity. To incorporate phasing into the project planning, both ferry terminal and marina are divided in two phases. The first phase of the marina consists of constructing and equipping the structures that are vital for a proper existence of the marina. The second phase of the marina has been characterized by the expansion of the berthing area and the construction of less essential buildings.

The phasing of the ferry terminal is less apparent as all main components are required to be operational from the start. The second phase of the ferry is therefore based on the second pier being operational.

The additional phasing of the two main components can be seen in table 10.4 and table 10.5. It is possible to apply finer gradations in phasing, e.g. with varying pier lengths, this has however not been considered in the current project planning.

table 10.4 – additional marina delays, initial delay is delay before the actual design process commences

Marina Scenario	Initial delay (year)	Marina 2 nd phase delay (year)	Operational (year)	End date (year)
Fast	1	8	2026	2036
Moderate	5	15	2044	2062
Slow	20	30	2068	2104

table 10.5 – additional ferry terminal delays

Ferry Scenario	Initial delay (year)	Ferry 2 nd pier delay (year)	Operational (year)	End date (year)
Fast	1	10	2028	2040
Moderate	5	30	2042	2076
Slow	20	50	2067	2126

11 FINANCIAL EVALUATION

This chapter covers the financial evaluation of the project. This evaluation has been used to measure the cost recovery and liquidity of the project. The evaluation constitutes an inventory of the financial in- and outflows, combined with the project planning (see chapter 10) in order to see if this project can be qualified as a good investment from a financial point of view.

For a public project like this, a financial evaluation has to be combined with an economical evaluation, as profitability is not the sole purpose of this project. The conclusions from the economical evaluation are discussed in chapter 12.

A sensitivity analysis has indicated that the spreading of the loan is essential for the profitability of the project. The results from this analysis, as well as other details on the financial evaluation, can be found in Appendix U: Financial evaluation.

11.1 CASH FLOW

The cash flows cover all cash inflows as well as the cash outflows. The cash flow analysis indicates the height of the required loan as well as the liquidity during the entire project. The financing costs, consisting of the loan and the interest charges, are included. For the interest charges, a rate of 5% has been used. The loan is adapted to the required amount of money per year, plus an extra 10% to avoid liquidity problems in case of unforeseen expenditures.

Cash outflows

The main cash outflows can be related to the phases in the lifetime of the project, including the financing costs at the start of the project. Where possible, outflows have been divided in material costs (including equipment) and labour costs. A full overview of all the accounted expenditures can be found in Appendix U: Financial Evaluation.

Cash inflows

Regular cash inflows start when part of the construction is finished and the operation of either the marina or the ferry commences. Other sources of inflow are at the start of the project, when financing is sought in the form of loans or subsidies. Similar to the outflows, a full overview of all the accounted revenues can be found in Appendix U: Financial Evaluation.

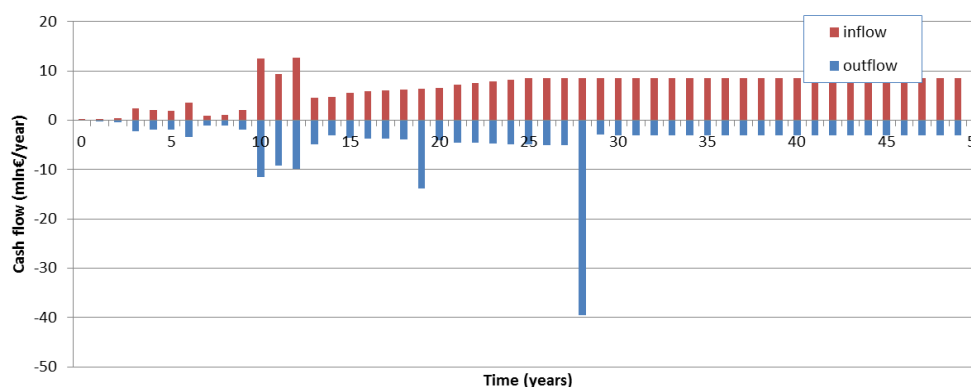


figure 11.1 – cash flows per year

The sum of all revenues and expenditures is given in figure 11.1. The construction costs are clearly visible at the start of the project. They are compensated by the loans. From year 12 on, the project start to gain revenues, increasing slowly until a steady flow of revenues is generated in year 25. The construction of the second phase is visible in year 19 and the initial loans are paid back in year 28. The total sum of money to be borrowed is € 36.7 million. The inflow peak in the last year is due to the rest value of the project, assuming a lifetime of 50 years after construction.

The cumulative cash flow is shown in figure 11.2, indicating a net flow of almost zero in the first years, due to the loans. When enough revenues have been generated, phase two is implemented with this money. The loan is repaid at once in year 28, from where on the project will yearly generate a steady profit.

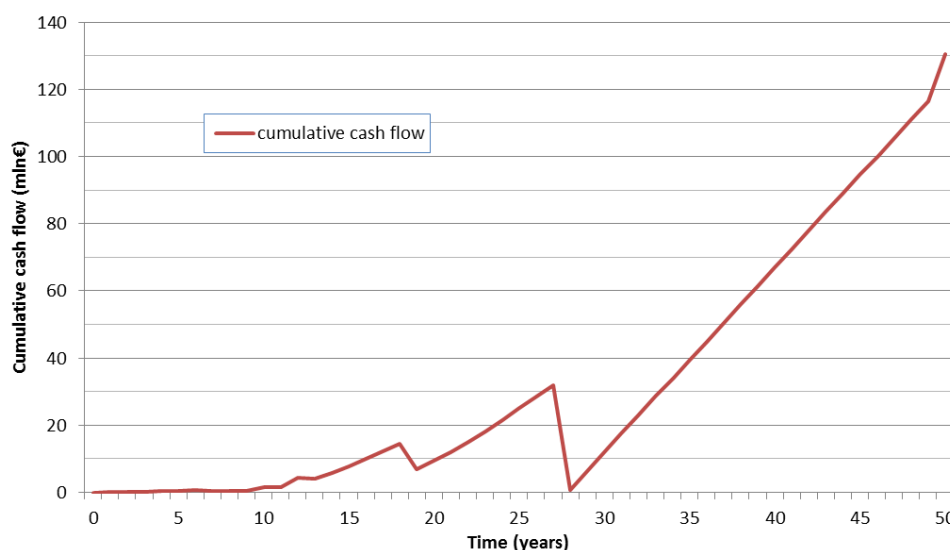


figure 11.2 – cumulative cash flow

11.2 NET PRESENT VALUE

The Net Present Value (NPV) of the project is shown in figure 11.3. The discount rate is assumed to be 5%. This is a lower boundary for this value, meaning that the outcomes can be less positive as displayed.

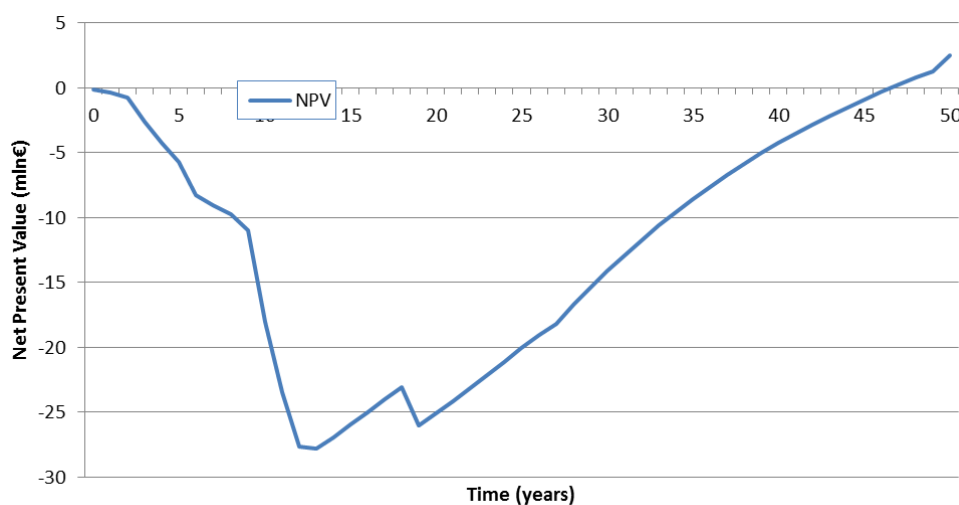


figure 11.3 – Net Present Value

Due to the high initial investments and interest charges, the NPV of the project remains fairly negative. It does not reach zero until year 46 of the project. This period is very long, even for a public project. Taking into account the uncertainties in this financial analysis and the project itself, it becomes clear that more research is required before investing in this project.

11.3 COST RECOVERY

In order to check if the project has enough revenue generation, two methods of cost-recovery analysis have been applied. First the pay-back period has been determined, second the unit cost method has been applied.

Pay-back period

The pay-back period indicates the cost recovery potential of a project. As can be seen in figure 11.2 the initial loan can be paid back in year 28 of the project. This period is very long, even for a public project. This indicates that the recovery potential of the project in its current configuration can be questioned.

Unit Cost method

The unit cost method determines the price that should be charged for the product or service created by the project in order to make the NPV zero. This comes down to the minimal costs per unit to reach break-even for feasibility of the project.

For the marina the average unit cost of a berth has been computed to be € 130 per day. This is significantly higher than the values determined in Appendix U: Financial evaluation, i.e. € 75 per day. This indicates that, in the current configuration, the revenues of the side line companies have to compensate for the costs of the marina itself.

The unit cost for the ferry has been computed to be € 6 250 per berthing in the Havana International Ferry Terminal, in case of three ferries berthing per day. If a fourth line would be implemented in year 23, the unit cost drops to € 5 325 per berthing. The number of ferries calling in to the terminal clearly has a great impact on the unit cost.

The qualification of a 'good' investment in this case is not applicable for the reasons stated above. It is probable that other projects are imaginable that create higher returns on investment. These projects do not have to be very different than the evaluated project. It is possible that a marina or ferry terminal in some other form, for instance another location or capacity, can be qualified as a 'good' investment.

In the case of a public project, it might be that the considered project is more attractive. This is because other effects, which are not directly linked to the project, can enhance its value. These effects are investigated in Appendix V: Economic evaluation.

12 ECONOMIC EVALUATION

This chapter discusses the results of the economic evaluation. This evaluation has been done to incorporate the indirect and external effects of the project on the local economy. Including these effects on social welfare and the environment fits the governmental perspective in a better way than a financial evaluation on its own does. All details on this evaluation can be found in Appendix V: Economic evaluation.

12.1 ACCOUNTED EFFECTS

The accounted effects of the project are categorized into three categories; direct effects, indirect effects and external effects.

Direct effects

Direct effects are those effects that are physically linked to the project. The direct effects are confined to the in- and outflows of the project, and have been evaluated in Appendix U: Financial evaluation.

Indirect effects

Indirect effects are the effects of a project on other industries. Two indirect effects have been taken into account: the labour market and the local economy.

The effect on the labour market is included with a discount factor, assumed to be 20%, as local labour is expected to create jobs in the local economy.

The tourists arriving with a yacht or ferry spend money outside of the project area. A part of this money, assumed to be 5% of their total expenditures in Havana, will flow into the local economy.

External effects

External effects are defined as effects from the project which constitute a benefit or cost to society but which are not reflected in the project expenditures or revenues. In this project there are two external effects taken into account: congestion and environmental costs.

The improvements of the transport network around the bay have a positive influence on the mitigation of congestion in the area, which is valued by using a value of time. On the other hand, the project also generates more traffic, with negative consequences for congestion.

The environmental costs consist of two categories; the exhaust and hindrance during construction of the port facilities and the increase of pollution due to the increased traffic, both nautical and on land.

12.2 NET PRESENT VALUE

The NPV for the project, including the effects mentioned above, is given in figure 12.1. By taking the indirect and external effects into account, a 'NPV for society' is created.

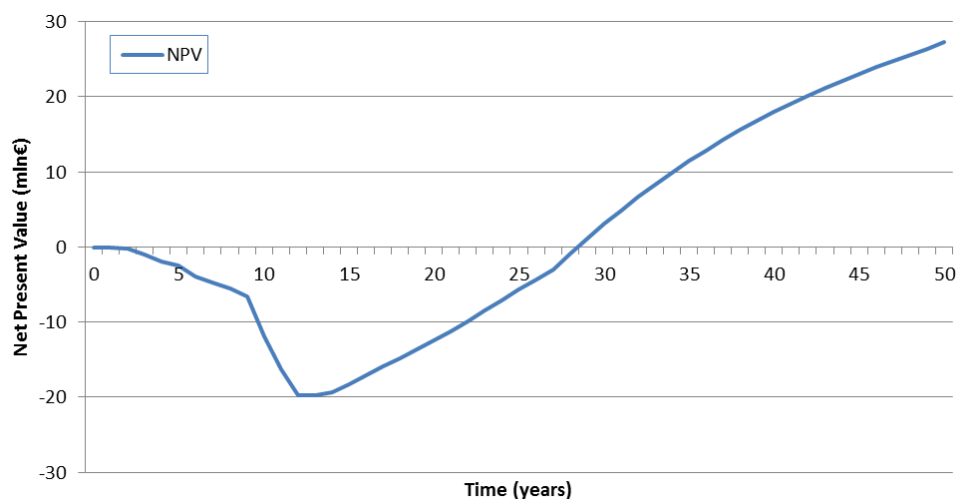


figure 12.1 – Net Present Value

The NPV reaches a value of zero after 28 years, increasing to € 28 million after 50 years. The fact that there is a positive NPV for society, justifies an application for a subsidy. It is however necessary to mention that the time to get to a NPV of zero is quite long, as is generally the case for projects undertaken by governments. Furthermore, the eventual NPV is not very high compared to the investments. Another important note to mention is that the NPV has been calculated with a relatively cheap interest rate, which might not be the case at all. Especially when foreign funds have to be loaned by the Cuban government, a much higher interest rate is to be expected.

13 CONCLUSIONS

Main objectives

Marina La Coubre and the Havana International Ferry Terminal are two great assets to the Port of Havana and fit neatly in the master plan Tourist Port Havana. The in this report designed components ensure that the port will be able to receive high numbers of tourists visiting the city by yacht or ferry.

Embargo

Taking the embargo by the United States into account is of the utmost importance when proceeding with Tourist Port Havana. All factors in the design depend on the available demand in the tourist market. Commencing construction of an international ferry terminal is to be delayed until it is possible to operate frequent connections with the U.S. The same conclusion holds for Marina La Coubre, as American yachtsmen are expected to form the bulk of future visitors.

Hydrodynamic conditions

The Bay of Havana is a very sheltered environment. Concerning the daily conditions the Ensenada de Atarés is a prime location for the designed components. To ensure the quality of Marina La Coubre, a breakwater is however needed to protect the berthing area from locally generated wind waves. Where extreme events like hurricanes are concerned, the hydrodynamic conditions are of relatively low importance. The meteorological conditions like extreme winds and rainfall during such extreme events are of more concern to the marina and ferry terminal.

Transport network

An updated transport network is required to handle the increased flow of tourists. With the current growth rate, the transport network will reach its capacity in about 10 years. In order to keep the network from overloading, the capacity is increased by the designs presented in this report. A traffic management system will guide the demand and create a better through flow of the network. Furthermore, the current infrastructure has to be renovated to increase the safety in transportation.

Port priorities

Due to an increase of nautical traffic in the bay, the entrance channel becomes a bottleneck. If the Port of Havana decides to focus on tourism, the attractiveness of the port as a destination for cargo vessels decreases significantly.

Phasing

To anticipate a volatile demand for the services provided by Tourist Port Havana, construction phasing is of high importance when designing the ferry terminal and marina. Flexibility is a great asset to the current design of Marina La Coubre, whereas the Havana International Ferry Terminal has fewer options for phasing.

Viability

The financial evaluation has shown that the project is currently not sufficiently viable to be qualified as a good investment. The economic evaluation has however shown that when the added benefits to society are taken into account, the project becomes more interesting from a governmental point of view.

14 RECOMMENDATIONS

Embargo – Market research

A thorough market research should be done to quantify tourist activity in the Caribbean in case of a change in the embargo. This market research is required to dimension the components of Tourist Port Havana as well as for the financial evaluations.

Hydrodynamic conditions – Additional research

Additional research into the hydrodynamic conditions for shipping purposes is not recommended. To create an understanding of the exact flow patterns in the entrance channel, in the horizontal and in the vertical water column, a more detailed research should be done. The use of a fully three dimensional mathematical model in combination with reliable measurements is recommended.

Transport network – Development research

In order to adapt the transport network according to the increasing demand, it is recommended to perform an extensive study on the development of traffic in Havana. It is recommended to evaluate the performance of the transport network with a microscopic transport model, to test the effect of the solutions.

Port priorities – Decision making

A decision should be made whether the future of the Port of Havana is as a tourist port or a cargo port. This report has made clear that a combination of both will lead to conflict.

Phasing – Constructing when necessary

In the design of the international ferry terminal, phasing is difficult to incorporate. It is recommended to adjust the design where possible to prevent unused facilities when exploitation commences.

Viability – Cost recovery

It is recommended to couple market research with cost recovery to estimate the required unit costs of each component. This can improve the financial evaluation and reduce uncertainty about the viability of the project.

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GLOSSARY OF TERMS

A Access road

The function of this road type is focussed on the exchange of traffic

Anchorage

Area for vessels to wait until performing mooring manoeuvres is allowed

Apex

The geometric centre of a turn

Apron

Platform on an embankment to accommodate ship-to-shore processes

B Beam

The largest width of a vessel

Berth

Spot to accommodate a vessel - 'parking place on the water'

Bow

The front side of a vessel

D Diffraction

Diffraction is the turning of waves towards areas with lower amplitudes due to amplitude changes along the wave crest (Holthuijsen, 2007).

Distributor road

This road type has a flow function on the road sections and an exchange function on the intersections

Diverging wave

Sailing induced, sideward propagating waves

Draught

The distance between the still water level and the keel of the vessel

E Empirical

Based on experience and experiments

Ensenada

Spanish for 'Bay'

Espigón

Spanish for 'Pier structure'

F Fairway

Area of water to sail on - 'road of water'

Fondeadero

Spanish for 'Anchorage'

- H Hydrodynamic conditions**
Referring to conditions of waves and currents
- K Keel**
The underside of a vessel's hull
- M Master plan 'Tourist Port Havana'**
The general plan framed to revitalize tourist port activities inside the Bay of Havana
- Microscopic model**
A mathematical transport model simulating vehicle interactions
- Muelle**
Spanish for 'quay'
- N Nautical**
Relating to sailing
- R Refraction**
Refraction is the turning of waves towards shallower water due to depth- or current-induced changes of the phase speed in the lateral direction (i.e., along the wave crest) (Holthuijsen, 2007).
- Ropax**
The 'Damen Shipyards'-assortment of ferry vessels
- S Slip**
see: Berth
- Stern**
The rear side of a vessel
- T Transversing wave**
Sailing induced, in rearward direction propagating waves
- V Vehicle equivalent**
The unit that characterizes the traffic load by single number. This unit is composed by the converting of all traffic modes to passenger cars.

APPENDICES

Appendix A: GENERAL PERSPECTIVE OF TOURIST PORT HAVANA

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A.1 INTRODUCTION

This appendix is focussed on the existing integral plans to develop new tourist facilities inside the Bay of Havana. To understand this plan, first the important historical background is elaborated. Second, the current situation in both Cuba and the Havana Bay is considered. This chapter concludes with the explanation of the master plan Tourist Port Havana.

A.2 HISTORICAL BACKGROUND

The Bay of Havana has always been a bay with opportunities. The unique shape of this natural bay provides a very protected and quiet area of water that is well suited for harbour activities. Furthermore, the location in the Caribbean, close to the Straits of Florida, was of strategic importance in the trade route from Europe to the Americas. During the colonial era, the port of Havana was therefore a key component for the Spanish conquistadores: by royal decree in 1561, the port of Havana became the official 'stop-over' for (trade) ships on the route of Spain to its colonies. Havana also became the capitol of the Spanish American colonies: *the key to the New World* (Bayer, 2009). The ancient city centre, 'Habana Vieja', was built in this period.

At the end of the 19th century, Cuba became independent of the colonial rulers from Spain, although this was not the start of a stable political situation. The United States were not pleased about the unrest in what they became to see as their 'backyard' and started to exert an influence on the island. This influence reached so far that the USA militarily intervened twice to ensure their role in the Cuban politics. Also, the American influence became visible in everyday life. Havana became the prime resort for wealthy Americans and among others the mafia. This unstable period culminated in the dictatorship of general Batista.

The Cuban people revolted to his regime and, under the command of the jurist Fidel Castro and ideologist Ché Guevara, they managed to remove the corrupt regime of Batista in 1959. Castro soon proved to reject the influence from the USA on the island by nationalizing American companies on Cuba. During subsequent incidents, the relationship between the USA and Cuba got worse and eventually Castro sought a rapprochement with the Soviet Union and officially established a socialistic system. He also approved the settlement of Russian weapons on the island to prevent another coupe d'état from the United States, after the failed invasion at the Bay of Pigs. This situation culminated in a political low point with the Cuba Crisis, when the Soviet Union and the United States stood on the brink of a nuclear war. The American reaction to the socialistic direction of Cuba was a blockade in trades with the country. This embargo is currently still effective and prevents any American company to trade with Cuban companies. Furthermore, any ship that has moored in a Cuban port is not allowed to enter a US port for six months.

Cuba now became very dependent on the Soviet Union and the COMECON. When the Soviet Union collapsed in 1989, Cuba lost its supplies and support. Without the lucrative contracts with the COMECON countries, the country fell in an economic crisis. With no economical cornerstones of international importance, Cuba struggled to find its way with all the consequences for the inhabitants.

Because of the unique culture, Caribbean climate and its ideal location in the Caribbean, tourism seemed to be a logical economical pillar to focus on. Fidel Castro has always disapproved tourism in his country as it was seen as a western ideal that was non-consistent with the socialistic goals, but was forced to tourism as a replacement industry (Padilla, 2003). Castro's Cuba and tourism was however a

marriage of convenience, as tourists are more or less separated from the inhabitants. Tourists are 'placed' in the resorts of Varadero and this separation is clearly visible in a coupled monetary system. There are two currencies in use, the regular Peso (used for the basic needs and meant for inhabitants) and the Cuban convertible Peso, CUC (meant for tourists and foreigners).

A.3 CURRENT SITUATION

The consequences of the economic crisis are currently still visible in for example the decay of buildings. After the resignation of Fidel Castro, his younger brother Raul now acts as president of the Cuban republic. Under his government, the focus on tourism is increased. The old city centre around Plaza Vieja is already rehabilitated and other parts of Habana Vieja will follow in the near future. Also the people have received more rights; among others, entrepreneurship is now allowed, be it at a low level. Presumably also as a result of this, the USA are slightly changing their view on Cuban politics and an improving relationship seems a matter of time. However, the US embargo is still in effect, although preparations are made in Cuba to anticipate on the raise of this embargo in the future.

A.3.1 THE PORT OF HAVANA

Currently, the nautical activity is very limited in the bay. Because of the embargo many shipping companies, both cruise lines as well as commercial lines, avoid Cuban ports. This lack of activity has resulted in the decay of many terminals. As a result, for example only one of the three piers of the cruise terminal is currently in use.

Besides the Sierra Maestra cruise terminal, the main focus of the Port of Havana was on commercial activities. This means that there is currently no safe and attractive boulevard for pedestrians and that there is no or limited recreational and catering industry along the waterfront. Yachts cannot be berthed in the bay; the closest marina is the Marina Hemingway in the western part of Havana.

In order to anticipate on the raise of the embargo, Cuba has already developed an integral plan to be prepared for a post-embargo tourism industry. In this integral plan, called 'Tourist Port Havana', the western part of the Bay of Havana, from La Punta in the north to Castilla de Atarés in the southwest, will be focused on tourism and recreation. Several construction works have already started, while other parts of the plan are still in development, although activities are limited due to the current financial situation of the Cuban government.

A.4 MASTER PLAN TOURIST PORT HAVANA

The project 'Tourist Port Havana' consists of different components. An elaboration on all components from north to south is given in the coming sections.



figure A.1 – overview of the Bay of Havana

A.4.1 LA PUNTA

The Castillo de San Salvador de la Punta, or simply La Punta, is a fortress at the corner of the Malecón at the entrance channel of the Bay of Havana. It was constructed in 1600 together with the adjacent fortress El Morro. These fortresses have been the most important protection for the harbour for years. During the colonial era, the two fortresses closed the bay at night with a chain to prevent any ship entering or leaving the bay.

The Malecón is a seawall with a length of 7km, constructed from the early 1900's, and is one of the most important components of the city's road system. Over the years the Malecón, with a height of about four meter above MSL, turned out to have shortcomings as a sea defence system during hurricanes (Bart, et al., 2006). Recent heavy storms inundated the road and the area directly behind the Malecón. In order to prevent these inundations, studies have been carried out to improve the Malecón sea defence and to keep the road open for traffic during storms.

Currently, a walking promenade in southern direction to another fortress Castilla de la Real Fuerza along the entrance channel starts at La Punta. From this boulevard one also has a view on the Fortaleza de San Carlos de la Cabaña, the fourth fortification of the bay on the other side of the channel.

A.4.2 MARINE WALK

In front of the Castillo de la Real Fuerza, the boulevard will continue as a marine walk that continues in southward direction to the Almacén San José. It will mainly consist of floating elements. The aim for this marine walk is to be the 'life line' of the Tourist Port Havana. It will connect the different components of the port in a safe and attractive way.

A.4.3 CABALLERIA PIER – GRIT CHAMBER

For many years, the sewerage of the city was directly discharged into the sea or bay. Because of the high rate of contamination, a new sewer system will be implemented in Habana Vieja. An important component of this new system is the so-called Cámara de rejas, a grit chamber that houses a mechanically-cleaned bar screen to dispose the sewerage of relatively big items, such as cans, tree branches and bottles.

A.4.4 TERMINAL SIERRA MAESTRA – CRUISE TERMINALS

In front of the Plaza de San Francisco de Asis the Terminal Sierra Maestra is located. It consists of three piers: San Francisco, Machina and Santa Clara (from north to south). The terminal was opened in 1914 and has been used as a passenger terminal since. These three piers and the terminal itself will be completely renovated. The two outer piers will be used as cruise terminals in order to be able to moor a total of no less than four cruise ships. The Machina pier will mainly be a car park and a public space (while the other two piers are placed past the customs).

Because only the San Francisco pier is currently in use as a cruise terminal, the renovation will start with the currently unused Santa Clara pier. When finished, the cruise activities will be transferred to this pier so the San Francisco pier can subsequently be renovated.

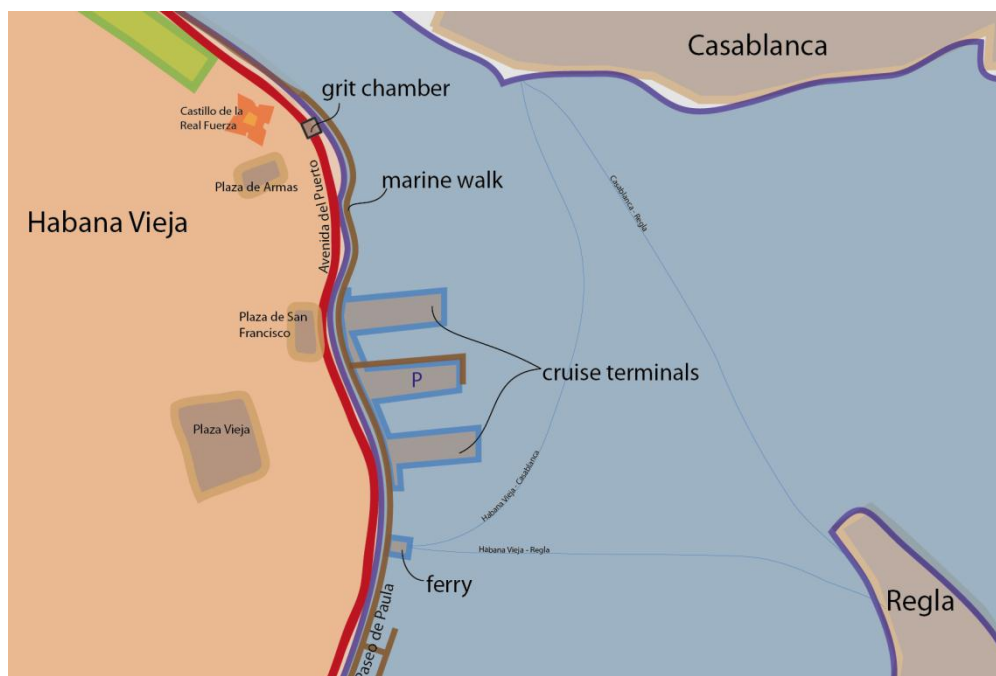


figure A.2 – northern part of Tourist Port Havana

A.4.5 EMBOQUE DE LUZ – LOCAL FERRY

Just south of the Terminal Sierra Maestra, the Emboque de Luz is located. In this terminal the regional ferry terminal to other areas around the bay, Casablanca and Regla is settled. Over time, and because of decay of the original ferry station, these ferry services have been replaced to other locations around. In the future, all the Bay of Havana ferry lines will be set off from this location again. Tourists can use this ferry for example to visit the two fortifications on the other side of the channel. Because of the name ('mouth of light'), the architectural design will be very transparent due to much use of glass.

A.4.6 PASEO DE PAULA – MARINE WALK

Three of the four piers of the Terminal Margarito Iglesias will be demolished to make place for an extension of the marine walk in bay direction. This T-shaped wooden pier will grant the pedestrians a view on the old city as well as the Bay of Havana. Just as the marine walk itself, the wooden pier will be a floating structure.

A.4.7 ESPIGÓN DE MADERA Y DE TABACCO – BREWERY CAFÉ AND COMMERCIAL CENTRE

On the fourth pier of the Terminal Margarito Iglesias, the former pier of Wood and Tobacco, a cross-link of a café and a brewery will be erected. In this café, visitors can see how the beer will be brewed and of course drink the end product.



figure A.3 – southern part of Tourist Port Havana

A.4.8 ALMACÉN SAN JOSÉ – SHOPPING CENTRE

Next to brewery café is the Almacén San José, a former warehouse. The base floor has been turned into a big market hall full of shops and stalls with souvenirs. On the second floor the San José Cultural Centre will be placed.

A.4.9 LA COUBRE AND OSVALDO SANCHEZ – MARINA AND FERRY TERMINAL

Just south of the Almacén San José is the Terminal Díaz located. This terminal has two piers: Espigón Iglesias and Espigón Díaz. More to the southwest, after the intersection with the Avenida de Bélgica and Avenida del Puerto, is the Terminal La Coubre located with the small Espigón La Coubre. The quay of the terminal continues to the southwest with half way the Espigón del Vacadero. In the south-western corner is the terminal Osvaldo Sanchez located. These locations are discussed in more detail in ‘Appendix F: Analysis of existing port infrastructure and facilities’.

Currently there are some companies active on these locations; they will be transferred to another location in the future, see also ‘Appendix B: Stakeholder analysis’.

No design plans for this area are currently present, but these three locations are dedicated to accommodate a marina and an international ferry line terminal.

The current marina of Havana is the Marina Hemingway, located 15 km to the west of Habana Vieja, with a capacity of 170 moorings. This marina is however not considered to be suitable as the main marina of Havana. Therefore, a new marina has to be designed in the Bay of Havana, located close to the city centre. The required capacity of this new marina is indicated by the client as:

- 60 moorings for super yachts with a length of 24-50 m
- 160 moorings for yachts with a length of 10-24 m
- 50 moorings for yachts 4.5-10 m

Moreover, the marina should be able to accommodate at least two mega yachts with a length of 50-120 m.

Possible connections of the ferry service with the most plausible destinations with Havana are given in table A.1. Although the American destinations are not a possible option with the current political situation, several cities in Florida are already anticipating on possible political changes by researching the opportunities of a ferry connection with Havana (Valle Banero, 2012). The port of Miami for instance has entered the possibilities of a ferry connection with Cuba in its 2035 master plan.

table A.1 – possible ferry connections with Havana

Destination	Distance in a straight line [km]	Sailing distance [km]	Sailing time, 15 kn [hr]	Sailing time, 30 kn [hr]
Key West, Florida (U.S.A.)	170	170	6.2	3.1
Miami, Florida (U.S.A.)	365	400	14.5	7.3
Tampa, Florida (U.S.A.)	535	550	20	10
Cancun, Yucatán (Mexico)	510	575	21	10.5
Nassau, New Providence (Bahamas)	555	600	22	11

Considering the sailing distances and potential supply of passengers (see 'Appendix D: Tourism analysis'), a regular connection with Key West and Miami seems the most feasible solution. A daily service with particularly Key West is, considering the sailing time, recommended, see table A.1. A daily service with Tampa seems, considering the sailing time and relative proximity of Miami and Key West, not feasible. The potential supply of passengers in Cancun and Nassau seems too low for a daily service, as these locations are largely touristic destinations itself. The sailing time is furthermore too long for Havana to be an attractive destination for a day trip.

It is recommended to carry out a feasibility study in order to determine the capacity and intensity needed for a connection with the given destinations. For now a daily service with Key West and Miami and a weekly service with Tampa, Cancún and Nassau is assumed, which shall be further discussed in 'Appendix G: Nautical analysis'.

Appendix B: STAKEHOLDER ANALYSIS

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B.1 INTRODUCTION

In this section, an analysis will be given of the stakeholders in this project. The name 'stakeholder' is a collective term for individuals and involved parties, which are affected by the design of the marina and ferry terminal. This works in both ways, stakeholders can also have influence on the design itself. Therefore it is very important to identify the different stakeholders in an early stage of the project. Stakeholders can have very different opinions with respect to the project; they either support the project or cause conflicts. The latter can result in delay of the project.

B.2 METHOD

First, all possible stakeholders involved in this project will be identified. Next, the interests of these stakeholders should be defined. Sometimes these interests are not known beforehand. Contacting the stakeholder or assuming an expected interest can solve this problem. For each interest one can determine if there is a conflict with the project or a general agreement. From this, the attitude towards the project can be given; this is either positive or negative.

Sometimes, stakeholders have power (political power or legal power) to influence the project in a specific way; as a result the project should be altered and/or can be delayed if there is no conformity with this stakeholder. This can also be done by groups of individuals. If such a group is large enough, they can significantly influence the project.

The interest combined with the influence of each stakeholder determines the relative priority. A high priority means that the involved party/person must be involved as soon as possible in the project. The priorities will be rated on a scale of 1-5, in which 5 represents a high priority. This method is obtained from the course 'Integral design in Civil Engineering', (de Ridder, et al., 2009).

B.3 STAKEHOLDERS

All known stakeholders in the project can be seen in table B.1. Their interests, attitude towards the project, influence and relative priority are also shown in the table.

table B.1 – interests, influences, priorities and attitude towards the project for each stakeholder

Stakeholder	Interest	Conflict / agreement to the project	Attitude	Influence	Priority (1 – 5)
'Oficina del Historiador de la Ciudad'	Preserve historic parts of the city / attract tourism	Main client of the project. General agreement	Positive	High	5
Ministry of economics and planning	Get more revenue from tourist branch. Wants renovation of the Havana Bay	Supporting tourism, so general agreement	Positive	High	4
'Instituto Planificación Física'	Determines area and releases permits for building	General agreement: this plan fits the vision of the government	Positive	High	4
Shipping companies	Building / maintaining ships	Agreement, overall business opportunities	Positive	Low	2
Ferry companies	To have a profitable business	Agreement due to new ferry possibilities	Positive	Medium	3
Users of the marina	Using the marina and marina facilities	Agreement	Positive	Medium	3
Users of the ferry terminal	Using the ferry terminal and facilities	Agreement	Positive	Low	2
Local inhabitants in the region	Improvements to the neighbourhood and a high quality environment	Hindrance during construction. Positive effect is improvement to the area	Positive / Negative	Medium / High	4
Tourists visiting the area	Using facilities nearby and preservation of historical city	General agreement if historical buildings are preserved	Positive	Low	2
Companies in the to be demolished buildings	Staying in the building and continuing their business	Conflicting: these companies have to move due to tourist port Havana.	Negative	Low	2
Commercial harbour companies	Growing business for import/export	Conflict: bay area more focused on tourism, instead of cargo activities	Negative	Medium	3
Fisherman	Fishing and making money	Conflicting due to the increased shipping in the harbour	Negative	Low	1
Environmental organisations	Preserving nature and environment	Conflicting due to expanding of the port	Negative	Medium / High	4
Construction companies	Construct the project and make money	Overall agreement	Positive	Low	1
Port authorities	Assure safety in the port at all times	Conflicting due to the increased shipping activities	Negative	Medium / High	4
Infrastructure companies (water, cables etcetera)	Deliver services without any downtime	Conflict during constructing	Negative	Medium	3

With the information gained above, a stakeholder classification matrix can be given. In this matrix the influence is located on the vertical axes and the attitude towards the project on the horizontal axes. The matrix is given in table B.2.

table B.2 – stakeholder classification matrix

	Positive attitude	Negative attitude
High influence	<ul style="list-style-type: none"> • 'Oficina del Historiador de la Ciudad' • Local inhabitants in the region • Ministry of economics and planning • 'Instituto Planificación Física' 	<ul style="list-style-type: none"> • Local inhabitants in the region • Environmental organisations • Port authorities
Medium influence	<ul style="list-style-type: none"> • Ferry companies • Users of the marina • Local inhabitants in the region 	<ul style="list-style-type: none"> • Commercial harbour companies • Environmental organisations • Port authorities • Infrastructure companies (water, cables etcetera)
Low influence	<ul style="list-style-type: none"> • Shipping companies • Users of the ferry terminal • Tourists visiting the area • Construction companies 	<ul style="list-style-type: none"> • Fisherman • Companies in the to be demolished buildings

B.4 CONCLUSION

In the matrix, the column with 'negative attitude' is of most importance. Particularly, the combination of negative attitude with the categories 'medium influence' and 'high influence' are causing harm to the project.

- According to the matrix, the 'local inhabitants in the region' is the group for which the attitude and influence is mostly indistinct as it appears four times in the matrix. Therefore it is recommended to inform and involve this group in an early stage of the project to obtain their attitude towards the project.
- 'Environmental organisations' can have a high influence and it is most likely that they have a negative attitude. If the project doesn't take environmental issues into account, this group can cause unwanted delay.
- The group 'port authorities' appears two times in the matrix, it is assumed that this group has a high or medium influence. Also for this group it holds that they need to be informed about the project in an early stage of the as the interaction with the design of the port is strong. The main conflict with this group is the scheduling of different shipping activities. Safety must be assured at all times, so rules have to be formulated when different types of ships are entering the bay at the same time. Involving this stakeholder in the project and solving this problem together can avoid this conflict at all.
- It is likely that commercial harbour companies cannot expand their business when the focus of the harbour is more orientated towards tourism. This is an inevitable effect of the project. Together with governmental agencies a solution can be found, e.g. shifting the cargo facilities to other ports.
- Infrastructure companies need to adapt the current infrastructure to fit the new situation. This holds for telephone cable-wiring, water supply, electricity supply and sewage systems. Informing this group in an early stage is sufficient.
- The stakeholder 'companies in the to be demolished buildings' needs some special attention. This stakeholder has major conflicting interests with the project, but is considered to have a low influence. This is because the companies are only users of the buildings, not the owners. As the government in Cuba owns these buildings, they can simply decide if a building has to be removed, e.g. when the government has a new vision for the area. The companies that are located in these buildings are supposed to find other accommodations.

Appendix C: ANALYSIS OF THE SURROUNDING AREA

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C.1 INTRODUCTION

In this appendix, an analysis will be given about the area surrounding the Havana Bay. This chapter will focus on the buildings and facilities near the project location, i.e. what places are interesting for tourists and where are these places located. But also other locations are mentioned, for instance commercial activities in the harbour. These facilities all have an impact on developing this project by either generating tourism, generating traffic or as obstacles for new plans.

Complementary to this appendix, 'Appendix A: General perspective of Tourist Port Havana', a detailed analysis about the project 'Tourist Port Havana' and its corresponding facilities is given. Furthermore, in 'Appendix H: Hydrodynamic analysis – Preliminary investigation - FLOW' a brief overview will be given on the bay itself, i.e. dimensions, locations, bay characteristics, etcetera. In 'Appendix E: Infrastructural analysis', one can find which roads are currently located near the area of interest and where bottlenecks in the infrastructure can be found. But first the highlights of the city should be stated in order to see where bottlenecks will be in the future when an increase of tourism is expected.

In figure C.1 the main tourist attractions can be seen with respect to the project area. Many more tourist attractions can be found, but these are closest to the project area and are likely have the highest impact on the project.



figure C.1 – main tourist attractions with respect to the marina and ferry terminal

C.2 TOURIST ATTRACTIONS IN THE NEARBY AREA

C.2.1 'HABANA VIEJA'

'Habana Vieja' means 'old Havana' and with buildings from the 16th and 17th century, this name is rightfully acquired. Approximately 700 buildings can still be found dating from the 18th and 19th century. In 1982, this part of Havana has been added to the list of UNESCO world heritage monuments. This part of the city houses many tourist attractions, which some of them are discussed below. It attracts many tourists that stroll through the narrow streets. Currently, a largely set up renovation plan is carried out, creating a striking contrast between the renovated areas and the decayed buildings waiting for their turn. The Habana Vieja quarter is on walking distance from the project area.



figure C.2 – Habana Vieja

C.2.2 PLAZA VIEJA

This plaza, shown in figure C.3, dates back to 1587 and at the end of the 17th century the most important market was located here. The plaza is very near of the cruise terminals and can be seen, together with Plaza de San Francisco, as a starting point for tourists.



figure C.3 – Plaza Vieja

C.2.3 PLAZA DE SAN FRANCISCO DE ASÍS

Plaza de San Francisco de Asís is closest to the project location and dates back from the 16th century. The plaza underwent a full restoration in the late 1990s and is most notable for its uneven cobblestones and the white marble 'Fuente de los Leones', which means 'Fountain of Lions'. At the southern side of the plaza, a concert hall and the 'Museo de Arte Religioso' can be found. The plaza is currently being renovated, as can be seen in figure C.4.



figure C.4 – Plaza San Francisco de Asís

C.2.4 PLAZA DE ARMAS

Close to the entrance channel of the Havana Bay, 'Plaza de Armas' is located, see figure C.5. It is the oldest plaza of Havana and it is said that Havana has been founded on this location. The plaza is located in 'Habana Vieja'. Currently it holds book markets, attracting many wandering tourists.



figure C.5 – Plaza de Armas

C.2.5 MALECÓN

The Malecón (official street name: 'Avenue Antonio Maceo') is the biggest boulevard in Havana and covers a total length of five kilometres. On the seaside of the boulevard a seawall has been built, which protects the city from flooding. In the evening, many people gather to sit on this seawall and the surname of the seawall is 'love wall'. Because the wall is bursting with life, it has become a big attraction for tourists, see figure C.6. The Malecón is located in the north of Havana and begins (or ends) at 'la Punta'.



figure C.6 – the Malecón boulevard

C.2.6 CAPITOLIO NACIONAL

One of the most impressive buildings in Havana is the 'Capitolio Nacional' (figure C.7). It's an exact replica of the Capitol in Washington, but the one in Cuba is 6 metres higher. The main client of this building was Gerardo Machado, who was one of Cubans former dictators and was known for his cold-blooded regime. This is one of the main reasons why the Capitol is not being used as a governmental building. Instead, the Cuban academy for science is located in the building, as is the technical library. The building was finished in 1929 and can be visited by means of guided tours. The Capitol is located at the west of 'Habana Vieja', at a distance of approximately one kilometre from the project area as well as from the cruise terminal.



figure C.7 – Capitolio Nacional

C.2.7 MUSEO DE LA REVOLUCIÓN

A little further north, the 'Museo de la Revolución' can be found, see figure C.8. This is one of Cuba's most visited museums. Here, the story is being told of the revolution and the rise of Cuba in present day. Outside of the museum the 'Granma' is located, the ship which was used by Fidel Castro and Che Guevara to sail to the south coast of Cuba in 1956. The museum is located at the edge of Habana Vieja, at walking distance from the Havana Bay.



figure C.8 – Museo de la Revolución

C.3 CULTURAL BUILDINGS

C.3.1 CHURCHES AND CATHEDRALS

Iglesia del Santo Angel Custodio

At the opposite direction of the 'Museo de la Revolución', the church 'Iglesia del Santo Angel Custodio' is located, which means 'church of the guarding angel'. In this church Jose Marti was baptised. The present church was rebuilt in the mid-19th century, after it was destroyed by a hurricane in 1846. The original church dates back to 1672.



figure C.9 – the northern and oldest part of Habana Vieja

Catedral de San Cristóbal de la Habana

This cathedral is located on 'Plaza de la Catedral' and building was initiated in 1704. It was expanded in 1767 by the Spaniards. The remains of Christopher Columbus were buried here from 1795 to 1898, when they were moved to Seville. Nowadays, many tourists visit this place, see figure C.10.



figure C.10 – Catedral de san Cristóbal de la Habana

C.3.2 FORTRESS AND CASTLES

Castillo de la Real Fuerza

This is Havana's oldest fortress, which was built between 1538 and 1544. At some places, the walls are 6 metres thick and 10 metres high. The fort was built to protect the city from pirates, which was not really successful; the British captured Havana in 1555 and decided to expand the fortress. This was ready in 1577. This fort is very near of the marina and ferry terminal and definitely worth the visit.



figure C.11 – locations of the forts and castles

Castillo de los Tres Santos Reyes Magos del Morro

This stronghold was built between 1588 and 1630 and the common name is 'el Morro', see figure C.12. Nowadays, this fortress can be visited and the complete history of the British attack on Cuba can be seen here. There is also a lighthouse located and dates back from 1845. The fortress is located at the north-eastern side of the entrance channel. It can be reached by the local Ferry, currently departing just south of the cruise terminals and arriving in Casablanca, or with the car, going through the tunnel under the entrance channel of the Havana Bay.



figure C.12 – Castillo 'el Morro'

Castillo de San Salvador de la Punta

Near 'el Morro', but at the other side of the entrance channel, 'Castillo de San Salvador de la Punta' is located, briefly 'la Punta' (figure C.13). It is also a stronghold that was built to defend the old city against pirate attacks and nowadays, this place is characteristic for the beautiful view over Havana.



figure C.13 – Castillo de San Salvador de la Punta

Fortaleza de San Carlos de la Cabaña

The common name for this fort is 'la Cabaña'. It is a big, elongated fort and it was built between 1764 and 1774, see figure C.14. This fortress can also be visited and is located at the south of 'el Morro', at the eastside of the entrance channel. It also holds a museum dedicated to Che Guevara.



figure C.14 – Fortaleza de San Carlos de la Cabaña

Castillo de Atarés

This castle is located near the marina and ferry terminal and together with the two enclosed train tracks it forms an obstacle for expanding infrastructure (figure C.15). It is not a common tourist attraction as many other castles as it can only be reached by a guarded entrance road from the Avenida del Puerto.

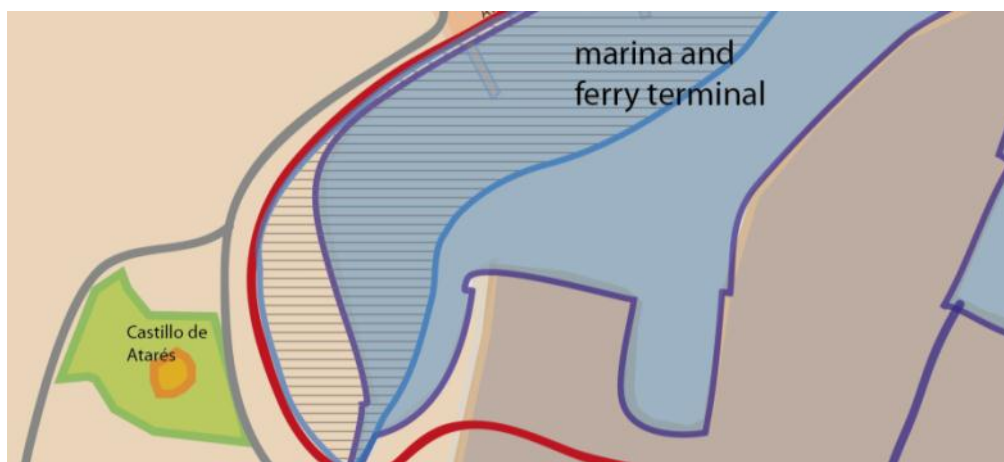


figure C.15 – location of 'Castillo de Atarés' with respect to the project location

C.3.3 OLD CITY WALL

In 1633, the start of the city wall was initiated and this wall covered old Havana. It was finished in 1674, but because of the rapidly expanding city it was almost completely demolished in 1863. Some parts of the wall can still be seen, for instance near the train station located at the south of the current 'Habana Vieja', figure C.17. One of the three remaining parts is located in the centre of the roundabout connecting the Avenida de Belgica to the Avenida del Puerto. A longer part is located along the Avenida de Belgica. The last part is in front of the train station and holds an Arsenal, giving the connecting road its name. In figure C.16, a part of the old city wall in the centre of the roundabout can be seen, with the central train station on the background.



figure C.16 – old city wall

C.3.4 CENTRAL TRAIN STATION

The central train station is located near the location of the marina and ferry terminal (figure C.17) and can be a relevant obstacle for expanding infrastructure. It consists of a passenger terminal as well as a cargo terminal. The cargo terminal is fallen into decay, as is the rail infrastructure. It is obvious that the passenger terminal must continue to be operating, but the future of the cargo terminal remains unclear.



figure C.17 – location of the central train station and the old city wall nearby

C.4 OTHER FACILITIES

C.4.1 COMMERCIAL PORT ACTIVITIES

Commercial port activities are mainly located at the east side of the Havana Bay, see also figure C.18. This causes interaction between commercial shipping and recreational shipping. For dry infrastructure, no major conflicts are expected because of the great distance between the separate locations. The only thing worth mentioning is a possible increase in cargo orientated transport by roads, which also increases the traffic intensity.

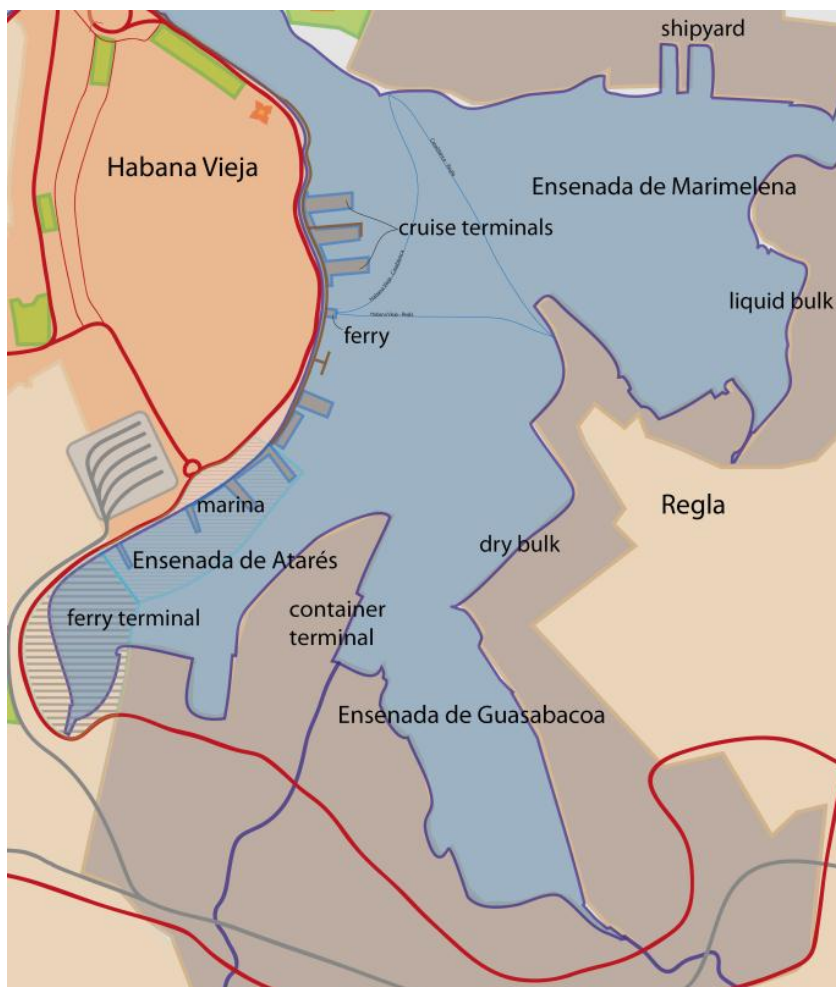


figure C.18 – commercial port activities with respect to the marina and ferry terminal

C.4.2 ELECTRICITY SUPPLY

There are plans to replace the existing electricity net, which is electrical wiring through the air, by an electrical net that is buried underground. Also, the capacity of the net will be increased in order to meet future demands. New wiring near the marina and ferry terminal can then simply use this renovated network. The design of this electrical infrastructure is outside the scope of this project.

C.4.3 WATER SUPPLY

It is of great importance to fit the new water supply of the marina and ferry terminal to the existing water infrastructure. Currently, the water infrastructural net is being renovated in the old Havana, so coupling the new and renovated net should not give many problems. Also here applies that a detailed design of such water infrastructure is outside the scope of this project.

Appendix D: TOURISM ANALYSIS

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D.1 INTRODUCTION

In order to obtain the capacity that is needed for the design process, it is important to know the number of people that will visit the area and will use the marina or ferry. This appendix is therefore an analysis about the tourism industry in Havana.

First, a historical background is given to understand the position of Cuba in the Caribbean tourism industry. Next, the possible future of tourism on the island will be elaborated upon, in order to give an estimate about the number of visitors in the future. Finally the demands and needs of a tourist or visitor for a marina or ferry terminal will be discussed.

D.2 HISTORY OF TOURISM INDUSTRY IN CUBA

Cuba has experienced three tourism cycles: one in the 1920s, one in the late 1950s and the third after the collapse of the Soviet Union, from 1989 up to the present. During these three periods, Cuba was and is among the leaders of the Caribbean tourism industry, mainly because it is the largest island in the region (Padilla, 2003).

In the first prime period, during the 'roaring twenties', Cuba became popular as a holiday destination in the United States. Some intelligent planned activities, like a visit from President Coolidge and a flight of Charles Lindbergh to promote the Florida-Cuba airline, caused a positive image of Cuba in the US and consequently a sharp increase of tourists. In 1928, visitors spent \$26 million in Cuba, about \$300 million worth nowadays (Schwartz, 1997). However, five years later, this expenditure fell under \$5 million caused by the Great Depression and political instability after President Machado was overthrown.

After the Second World War, tourism was increasing again; Cuba had however a shortage of hotel rooms and lost market share in the Caribbean. President Batista thought to find a solution of this problem to decide that a casino would be allowed in any hotel with an investment of at least one million dollar. Although the revolutionary turmoil was evident in the country, this law marked the start of the height of tourism in Cuba. Big hotels like Hotel Nacional, Havana Hilton (now Habana Libre) and the Riviera were erected and Havana became highly popular, especially amongst US citizens, which formed 90% of the total number of tourists. Over 380,000 people visited the country in 1957, a market share of 27% of the Caribbean tourist market, see table D.1. The casino law also caused Havana to have the image of a gambling resort under influence of the US mafia; Meyer Lansky owned several hotels and the Riviera later became famous due to a scene in The Godfather movie. The major part of the tourism industry was situated in Havana; Varadero had for example only 300 hotel rooms to offer. Moreover, tourism was a relatively small industry compared to the sugar and tobacco industry. This period only lasted for four years and ended with the revolution of Castro in 1959.

table D.1 – number of tourist arrivals in 1956/1957 (source: Caribbean Tourism Organization)

Country	Total visitors (x1000)	Market share (%)
Cuba	382	26.80
Neth. Antilles	28	1.96
Bahamas	192	13.44
Barbados	18	1.26
Bermuda	121	8.47
Dominican Republic	48	3.36
Haiti	68	4.76

Jamaica	161	11.27
Puerto Rico	208	14.56
Trinidad and Tobago	103	7.21
Virgin Islands	100	7.00
Total	1 429	100

Shortly after Fidel Castro announced that the revolutionary government would set a socialistic course, tourism became undesirable as it was seen as a capitalistic 'sin'. In the 1960s and 1970s, only 3000 foreigners visited Cuba yearly, mostly journalists and Soviet communist party members. During this period, that marked the start of the tourism explosion in other Caribbean countries (Padilla, 2003), Cuba lost its leading role in the tourism market in the region: during the late 1980s, the country had a market share of only 4% of the Caribbean tourism market.

After the collapse of the Soviet Union, and with its withdrawal of economic support, Cuba turned again towards tourism and began to see it as an industry of economic importance. Foreign companies were allowed to invest in the country via joint-ventures with the government; direct investments were not allowed. In 1990, the first of these joint-venture hotels opened in Varadero, others soon followed. Tourism was increasing rapidly in the country, in 1999, the number of hotel rooms had been increased with 167% compared to 1990 and the number of tourist arrivals increased on average 14% a year between 1994 and 2002.

In the last few years, the number of tourists increased, although not as strong as in the late nineties, as can be seen in table D.2. In spite of the travel embargo, there are several tourists from the United States that travel from other locations than the USA to Cuba, although the market share of this group is only 2.5% in 2010. The number of US travellers in 2011 is included in *Other*. There is no data available about cruise ship travellers, so these numbers are not included in the table, although these numbers are not expected to be relevant due to the embargo.

The average length of stay is about eleven days and the market share for holiday purpose is about 95%.

table D.2 – arrivals of visitors in Cuba (source: CTO)

Year	United States	Canada	Europe	Other	Total	Change (%)
2007	40 521	660 384	924 025	527 291	2 152 221	
2008	41 904	818 246	909 086	579 104	2 348 340	+9.1
2009	52 455	914 884	838 340	624 130	2 429 809	+3.5
2010	63 046	945 248	809 514	713 936	2 531 745	+4.2
2011	n/a	1 002 318	852 065	861 934	2 716 317	+7.3

Cuba has an increasing market share in the Caribbean tourist market; in absolute numbers only the Dominican Republic has received more tourists than Cuba, as can be seen in table D.3. Compared to the numbers of table D.1, there are some remarkable differences. Mexico has entered the Caribbean market with the tourist resorts in Cancun and Cozumel to gain a notable share and the increase of the market share of the Dominican Republic is enormous. The market share of Cuba is lower than in 1957, but this is no surprise considering the few tourists from the United States (2.5 %), compared to market leader Dominican Republic (30%) and nearby countries Bahamas and Cayman Islands (both 79%). There is no data available of tourism in Haiti and Trinidad and Tobago in 2011. Also, the given number of visitors are only 'stop-overs', people that stay at least overnight. With

other words, cruise travellers are not included in the countries which have only a port-of-call.

table D.3 – number of tourist arrivals in 2011 (source: CTO)

Country	Total visitors (x1000)	Market share (%)
Cuba	2 716	14.10
Neth. Antilles (former)	1 686	8.75
Bahamas	1 344	6.98
Barbados	568	2.95
Bermuda	236	1.22
Cayman Islands	309	1.60
Dominican Republic	4 306	22.35
Jamaica	1 952	10.13
Mexico (Cancun)	1 672	8.67
Puerto Rico	1 446	7.51
Virgin Islands	1 016	5.28
Other	2 016	10.46
Total	19 267	100

It has already been noted that cruise tourism is negligible, compared to other forms of tourism, in Cuba. This is however not the case in other countries in the Caribbean, as can be seen in table D.4. In the Bahamas and Cayman Islands, cruise tourism is very important and is about three times and five times as large as regular tourist arrivals respectively. These high numbers are however to be expected due to the nature of cruise tourism, where several ports are called in consecutive days. Many cruise travels start in Florida, and the close proximity of the Bahamas and Cayman Islands makes these islands popular first stops before the routes 'fan out' over the Caribbean. It is also remarkable that cruise tourism only plays a small part with market leader Dominican Republic. The former Dutch Antilles are not included in the table because of possible inconsistency due to the double counting of passengers on the now politically separate islands.

table D.4 – number of cruise passengers in 2011 (source: CTO)

Country	Cruise passengers (x1000)	Tourist arrivals (x1000)
Cuba	n/a	2 716
Bahamas	4 161	1 344
Barbados	619	568
Bermuda	416	236
Cayman Islands	1 401	309
Dominican Republic	348	4 306
Jamaica	1 125	1 952
Mexico (Cozumel)	2 871	1 672
Puerto Rico	1 124	1 446
Virgin Islands	2 485	1 016

D.3 FUTURE OF TOURISM INDUSTRY IN CUBA

The future of tourism in Cuba is hard to predict and depends on several factors. The first and probably most important factor is the trade and travel embargo of the United States. If the USA would raise this embargo, one can expect that the number of travellers from the States would increase; it is however hard to predict the exact number.

Furthermore, other political factors will influence tourism. Since the current Cuban political leaders are of age, a governmental change can be expected in the near future. It is not easy to predict, though, if the current centralized, socialistic system will be sustained by the new political leaders, or if they will shift to a more decentralized and democratic system. Both options will influence the number of tourists in an encouraging as well as in a discouraging way: a democratic system will attract a type of tourist that currently avoids Cuba, but a socialistic system on the other hand will preserve the unique culture that attracts another type of tourist. Moreover, if the political system would sustain the closed economy, foreign companies would be more hesitant to invest in the country because of the obligatory joint-venture to be made with the Cuban government, with all its bureaucratic consequences.

If the political situation would change, it is also to be expected that many of the Cuban emigrants will take this opportunity to be reunited with their family.

Lastly, it is to be seen if the market share that Cuba had in the late 1950s can be equalled or even be improved. Other countries have invested in its infrastructure, services and image compared to 1957. Also, the Caribbean tourist market in that time consisted mainly of US tourists; a destination as near as Cuba is therefore logically a popular one. Nowadays, tourists from Europe, South-America and other parts of the world are not to be neglected. The Caribbean countries in the south are for the same reasons more popular for South-American tourists, while European visitors mainly choose (former) colonies as holiday destinations.

It is however clear that Cuba has many advantages above other Caribbean destinations. Next to the beneficial geographic location close to the US, Cuba can offer more than only a sun, sand and sea experience. With its unique culture and history, Havana can offer a city trip comparable to any big European city and with its many national parks it can be a big player in the ecotourism industry as well. It therefore can be concluded that Cuba is a destination with a high potential to be market leader in the tourism industry of the Caribbean.

D.3.1 INFLUENCE OF TOURIST PORT HAVANA

Next to the (political) factors stated before, the project Tourist Port Havana can have influence on the future tourism industry as well. An improved cruise terminal, an international ferry terminal and a marina can be an important stimulus with the raised embargo as a condition.

With the rehabilitated Terminal Sierra Maestra, Havana will be able to facilitate four cruise ships at once in a new, modern terminal. Also, the country has a favourable location close to Florida and between the Bahamas and Cayman Islands. At last, with the unique culture of Havana, Cuba can offer a variation to the existing cruise lines. These factors combined, it is to be expected that Havana will be a popular cruise destination, although the exact numbers are hard if not impossible to predict. Considering the advantages of Cuba, it will probably receive passenger numbers between those of the Bahamas and the Cayman Islands. A number between 1.5 and 3 million a year would therefore be a safe guess. However, this would only be in case of political changes that are considered positive by the tourism industry. This

number will also be affected if other locations in Cuba would invest in a cruise terminal, most notably Varadero.

Havana will be able to set up an international ferry connection with for example Key West and Miami, when the ferry terminal is constructed and if the embargo would be raised. This would have two major impacts on the number of foreign visitors. Firstly, Cuban immigrants in particularly Miami will use the ferry connection to visit family and friends on the island. The number of this kind of visitor will of course depend on the possible political changes. Secondly, US citizens will be able to travel to Cuba with their own car, which will stimulate the number of tourists from the United States. Also, a fast ferry service will increase the popularity of Havana for short holidays like a city trip.

A marina in the Bay of Havana could make the city an important player in the Caribbean yachting market. This market has played, despite its small numbers, an important role in the Caribbean tourism industry. A marina is considered an addition to a tourist destination that will attract 'land vacationers' as well. Extra services, like boat hiring and round-trip boats, can also add to the popularity of a destination. Especially in the northern Caribbean, yachting is popular due to the several ports of call within sailing distance. For example, a voyage from Key West to Havana takes about 24 hours with a sailing boat with an average speed of about 4 knots. In this area, many ports use yachting events to position themselves in the yachting market (Zappino, 2005). The premier event in the region is considered to be the Antigua's Sailing Week, which attracts up to 500 yachts. If Havana would be able to organize a sailing event of importance, it could have similar proportions.

Although no information is available about the number of yachts visiting Marina Hemingway the last few years, it is safe to state that the capacity of 170 berths has never been reached. A site visit has shown that only about 30 berths were occupied while the major part of the marina remained unused, see figure D.1. This low intensity is mainly caused by the embargo of the United States which hampers the yachtsmen for visiting Cuba.



figure D.1 – the unused capacity of Marina Hemingway (02/22/2013)

D.3.2 FUTURE SCENARIOS

Considering the above, the conclusion is that the future of tourism in Cuba is hard, if not impossible, to predict. Three main scenarios, that could succeed each other, are considered here.

As long as the current political situation does not change, it is likely that the current growth would not increase. The project of Tourist Port Havana would probably have little impact, as cruise ships will avoid Cuban ports and a ferry connection with Florida is not possible. Considering the current financial crisis in Europe, a yearly growth rate of 5% is assumed. This leads to a number of tourists between 3.0 and 3.5 million in 2015 and 4.0 and 4.5 million in 2020.

A second possible scenario is that the embargo will be raised, but the political system in Cuba will not change. The US International Trade Committee has investigated this situation in 2001 and came to the conclusion that this scenario will have a limited effect on Cuban tourism (US International Trade Commission, 2001). Between 100 and 350 thousand US citizens per year would be expected to travel to Cuba, which is only 6% of the total number of tourists from the USA in the Caribbean. This seems a bit conservative, but could be useful as a transition stage to adapt the numbers of the first scenario. The expected number of tourists would then be between 3.5 and 4.0 million in 2015 and 4.5 and 5.0 million in 2020.

The third scenario is that not only the embargo will be raised, but also the political system in Cuba will change. This last condition is necessary to attract foreign companies to invest in the country. Two studies have been done on this scenario, one by request of the Center for International Policy (Robyn, 2002) and one of the Cuban Policy Foundation (Sanders, 2002). Sanders assumed that Cuba would be able to increasingly restore its market share of US tourism in the Caribbean to 20%,

similar of that in the 1950s. This would come down to a total of 1.0 million US visitors, excluding 100.000 cruise and ferry passengers, in the first year after the political change. This would increase to 2.8 million visitors and 0.5 million cruise and ferry passengers over five years.

Robyn assumed a similar pattern as in the Dominican Republic, concerning the emigrants who would travel back to their homeland, and in Canada, where 1% of the population travels to Cuba each year. The first category would consist of 400 thousands Cuban emigrants, who will most likely travel by ferry, and the second would consist of 2.8 million US tourists.

D.4 ECONOMIC CONSEQUENCES

The inflow of foreign tourists into Cuba, and in particular Havana, will have its consequences on the economy. The positive and negative effects on the economy can influence decision making about possible investments in a marina and ferry terminal. These effects on the economy are evaluated in 'Appendix V: Economic evaluation'.

D.5 CONCLUSION AND RECOMMENDATIONS

D.5.1 CONCLUSION

Considering all uncertainties, it is recommended to not be committed to the stated expectations. Moreover, these expectations are all considering the entire country, and not just Havana. It gives however an important guidance for an estimation for the required capacity. From the above, an expected daily capacity of 1 200 – 1 400 passengers is expected to be required for the ferry connection.

D.5.2 RECOMMENDATIONS

The main recommendation is that an extensive research has to be done in order to determine the expected number of tourists in Cuba, and especially Havana, with more certainty.

It is also recommended that the mentioned future scenarios are used for preliminary designs, as it is difficult to predict the Cuban future.

Appendix E: INFRASTRUCTURAL ANALYSIS

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E.1 INTRODUCTION

In this analysis the land infrastructure around the project area is discussed. For the Tourist Port Havana master plan a good accessibility of the port is essential. This also applies on the marina and ferry terminal specifically. The passengers from the marina must be able to come and go from the marina without creating congestion. With the ferry a large flow of passengers will arrive at the same time. They should be distributed to their final destinations smoothly. To achieve this, a design for these connections is made. This analysis serves as starting point in the search of the best solution for these connections.

In order to investigate the options for the connection of the marina and ferry terminal to the existing network of Havana, the current infrastructure and its problems are evaluated. The scope of this analysis is focussed on the arterial roads around the bay and their connections. The small grid roads are not taken into account because their influence on the distribution from the port is very limited. Paragraph E.2 discusses the current road layout and the facilities for pedestrians and parking. In paragraph E.3 the current traffic situation is elaborated upon. The public transport is discussed separately in paragraph E.4 and paragraph E.5 deals with the safety issues in the traffic in the project area.

Subsequently the development of the traffic around the bay is analysed in paragraph E.6 in order to find out the problems that the solution will have to deal with in the future. This information will lead to the identification of the bottlenecks in the infrastructure, discussed in paragraph E.7. This analysis is concluded in paragraph E.8.

E.2 ROAD LAYOUT

This paragraph will discuss the current road layout; the available infrastructure, containing the number of lanes per direction, sidewalks and parking, as well as the intersections.

There is no data on the exact dimensions of the roads, so for this study only the number of lanes and the possibility to increase this number is taken into account. The analysis firstly focusses on the Avenida del Puerto; the main road along the bay. This road covers the entire bay side from La Punta to Regla. Secondly the main connections of this road to the network of Havana will be discussed. An overview of the roads, parking areas and walking areas is given at the end of the paragraph.

Starting point is the most-west point of the bay, in the corner that is intended to accommodate the marina and international ferry. From here the road along the bay is analysed northwards and subsequently the other main roads in the scope of this analysis.

E.2.1 OVERVIEW

To give an overview of the area, first a few maps are shown here. These maps consist of the roads and the number of lanes, parking areas and walking space. These maps are focussed on the current land infrastructure and therefore do not contain the port infrastructure. A complete overview of the project area can be found in 'Appendix C: Analysis of the surrounding area'.



figure E.1 – overview of the infrastructure in the project area

In figure E.1, the arterial roads in the project area are given.

E.2.2 AVENIDA DEL PUERTO

Part 1: Avenida del Puerto (Avenida Arroyo – La Coubre bus station)

Avenida del Puerto, also called Desamperados (meaning deserted) at this point, is a main road between the bay side and the train rails. This part is situated between the fork with Avenida Arroyo, a main road leading to the west of Havana, and the La Coubre bus station. Currently it is a quiet road with three lanes in the direction of Habana Vieja and a spacious shoulder that doesn't have a paved footpath. In the other direction, towards Castillo de Atarés, there are only two lanes, presumably because of a safety margin with the pillars of the elevated railway track. On this side there is therefore no space for a sidewalk or parking.



figure E.2 – Avenida del Puerto between Arroyo and the bus station. On the left eastwards to Habana Vieja. On the right westwards towards Castillo de Atarés, with the right turn onto Arroyo.

Part 2: Avenida del Puerto (La Coubre bus station – Avenida de Belgica)

Along the Avenida del Puerto there is a bus station; La Coubre. The road layout is continuous here, but the surroundings differ. On the bay side there is a small sidewalk between the road and the terminals of the piers La Coubre and Osvaldo Sanchez. The bus station is on the City side of the road. It contains a terminal and a drive through for the busses. In between the stations drive through and the road there are about 10 parking spots, with an angle of 60 degrees to the main axis of the road.



figure E.3 – Avenida del Puerto between the bus station and Avenida de Belgica. On the left picture looking eastwards in the direction of Habana Vieja and on the right picture looking westwards.

Following the Avenida del Puerto to the east, the road leads to the intersection with Avenida de Belgica, in the form of a roundabout. Towards the roundabout there is a

central reservation with a sidewalk between the lanes in different directions. Along this part of the road the lane configuration remains 3x2 lanes.

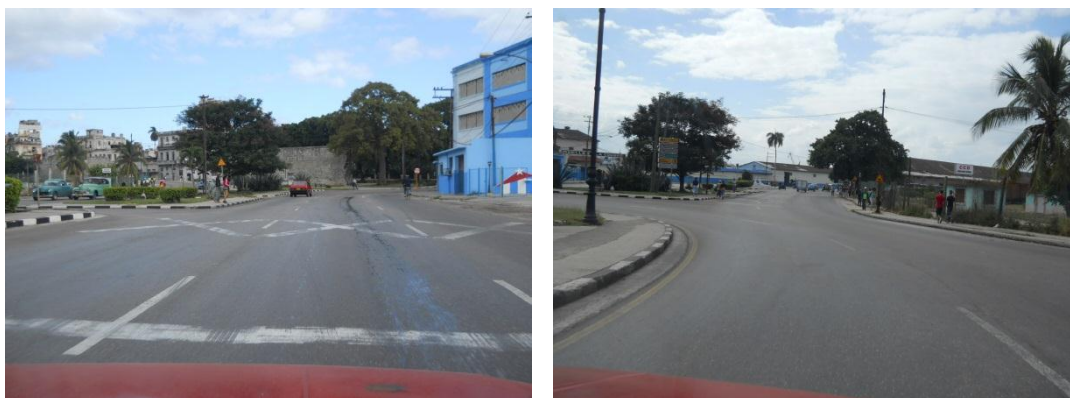


figure E.4 – Avenida del Puerto near the intersection with Avenida de Belgica. On the left eastwards towards the roundabout and on the right westwards, seen from on the roundabout.

Part 3: Roundabout Avenida del Puerto and Avenida de Belgica

The roundabout connecting the Avenida de Belgica to the Avenida del Puerto is a regular two-lane roundabout with an inner diameter of about 50 meters, although the roundabout is not perfectly circular. The outside diameter is approximately 70 meters. The centre holds a part of the old city wall, as mentioned in 'Appendix C: Analysis of the surrounding area'. This roundabout actually passes through two parts of this wall, as another part stands along the Avenida de Belgica. This historic structure therefore limits the boundaries of the roundabout. The sidewalk between the roundabout and the wall is only 1.5 meters wide, on both the inside and the outside of the roundabout. In all three directions there is a central reservation, but on the Avenida de Belgica this reservation is substantially smaller due to the limited space. The trees in the centre and on the reservations, together with the old city wall, make this roundabout a green and peaceful appearance.



figure E.5 – connection Avenida de Belgica to Avenida del Puerto. Top left the overview of the roundabout (Google, 2013). Top right the roundabout seen from the sidewalk on the bay side. On the lower panels the part of old city wall and the little space between the road and the wall.

Part 4: Avenida del Puerto (Avenida de Belgica – Iglesia de San Fransisco de Paula)

As the Avenida del Puerto continues eastwards, it is surrounded by the houses of Habana Vieja, on the city side, and the blue building of the Juan Manuel Diaz pier, the Hines building and the San José shopping centre on the bay side. The lane configuration changed, from the roundabout on, to 2x2 on this part of the Avenida del Puerto. Both sides of the road have a small sidewalk of approximately one meter wide. In front of the Hines building and a small part of the pier buildings there are about 40 parking spaces. In front of the San José shopping centre stand two old train locomotives on non-functional rails as an attraction. Between the locomotives and the road are three bus-parking spots, on which also three cars are able to park. In front of the shopping centre there is also a little more space for pedestrians, but due to the higher number of pedestrians it is still crowded. Crossing facilities are missing, so in order to enter the Habana Vieja quarter people have walk through the traffic.



figure E.6 – Avenida del Puerto between Avenida de Belgica and the Iglesia de Paula, looking eastwards (left) and westwards (right).

Part 5: Avenida del Puerto (Iglesia de San Fransisco de Paula – Sierra Meastra Terminal)

Just east of the San José shopping centre the roads splits up in the two directions, leading around the church. In the direction of la Punta, the road continues along the bay, where the Paula marine board walk will be situated. The present piers are currently being demolished to make room for this new, wooden pier. In this plan the road layout remains the same as in the current situation, which means a 2x3 lane configuration with a central reservation; two lanes in the direction of La Punta and three in the direction of the train station. The central reservation overcomes the difference in height between the directions and holds a line of trees. Furthermore it provides a spacy walking area under the trees and with some seats. In the direction of La Punta there are rails in between the road and the bay. These are out of function and the space is currently used for parking, mainly by buses. This space doesn't have a clear destination in the plans for the marine board walk.

In the other direction there are three lanes leading to the church, but just in front of the church they are reduced to two lanes. Four different roads from Habana Vieja lead on to this road, all of them are relatively small. In front of two blocks about 20 parking spaces are situated.

In the direction of La Punta there is currently no side walk along the road, but this will change with the construction of the marine board walk. In the other direction there is a small sidewalk along the road.

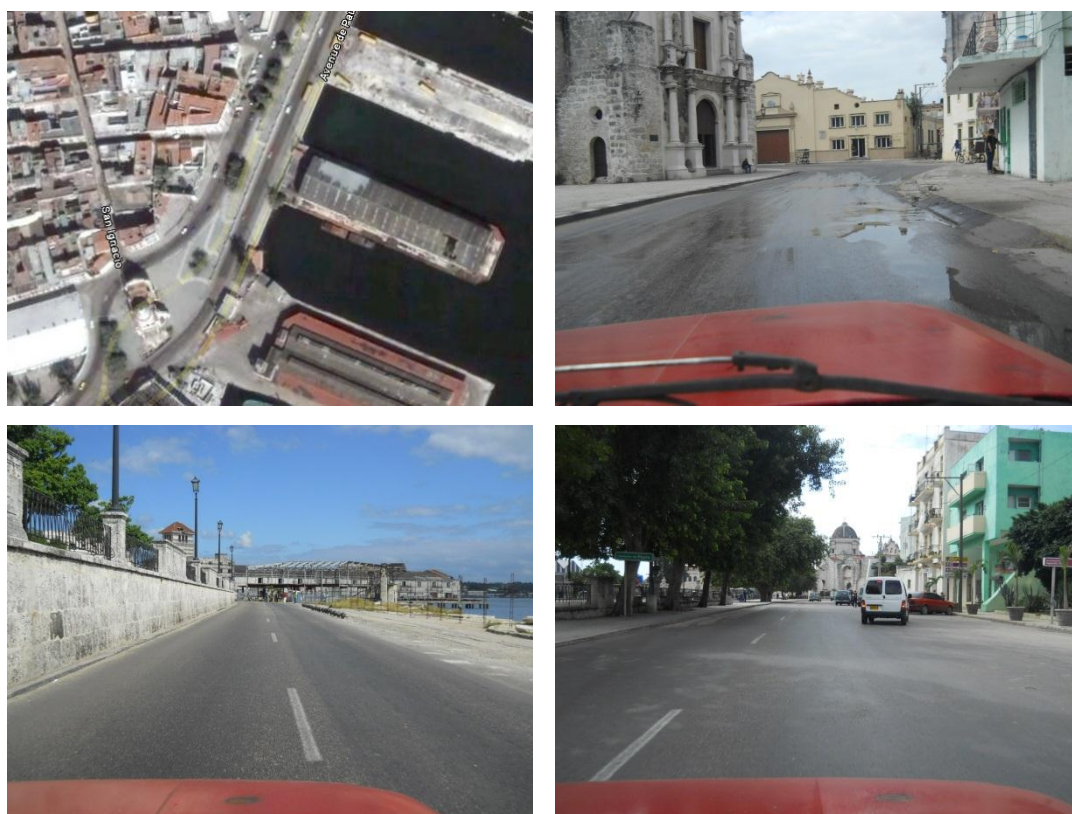


figure E.7 – Avenida del Puerto between the church and the cruise terminal. Top left in top view (Google, 2013). Top right around the church. On the bottom the two directions; eastwards (left) and westwards (right).

Part 6: Avenida del Puerto (Sierra Meastra Terminal)

In Front of the Sierra Meastra Terminal the road layout changes quite dramatically. The road splits up in two different parts. One part leads to the entrances of the terminal and the parking area in front of it, the other part is a 1x1 road for through traffic.

The parking area provides approximately 200 parking spaces for cars and buses, however due to the absent marking there is no clear layout. Tourists arriving from the cruise terminal can enter the bus here immediately after arriving in Havana.

The flow function of the road is drastically reduced. In both directions the road converges from two lanes to only one. Together with the zebra crossing to Plaza de San Fransisco de Assis, on the other side of the road, this part of the Avenida del Puerto can cause much congestion. The merging of tourist buses and pedestrians from the Sierra Meastra terminal is another big part of this problem.

On the opposite side of the parking area there is a small sidewalk along the road. Directly in front of the Sierra Meastra terminal there is another small sidewalk, but together these sidewalks can't handle large flows of pedestrians. This leads to pedestrians walking uncoordinated over the parking area.

The master plan Tourist Port Havana has designated the middle pier to accommodate parking, so that the parking area in front of the terminal can be altered to accommodate other functions. This creates space for a new road layout, in combination with more facilities for pedestrians and tourists.



figure E.8 – Avenida del Puerto at Sierra Meastra. On top the two the split in through road and parking, west of the terminal (left) and the merging traffic on the east side of the terminal (right). On the bottom the road to the east (left) and west (right).

Part 7: Avenida del Puerto (Sierra Meastra Terminal – La Punta)

The part of the Avenida del Puerto between the Sierra Meastra terminal and La Punta is characterized by a lot of parking area. The lane configuration is 2x3; two lanes in the direction of La Punta and three in the direction of the cruise terminal. In between there are parking spaces on the part along the entrance channel of the bay. Closer to the terminal there is the Grit Chamber in between the lanes in different directions. On the bay side there are several parking spaces along the road, where mainly tourist buses are lined up. Besides the parking spaces, the bay side holds some outdoor cafés and a wide walking area. The other side of the road holds a broad sidewalk as well and six roads from Habana Vieja lead onto this road. Along the entire part of the road crossing facilities for pedestrians are absent.

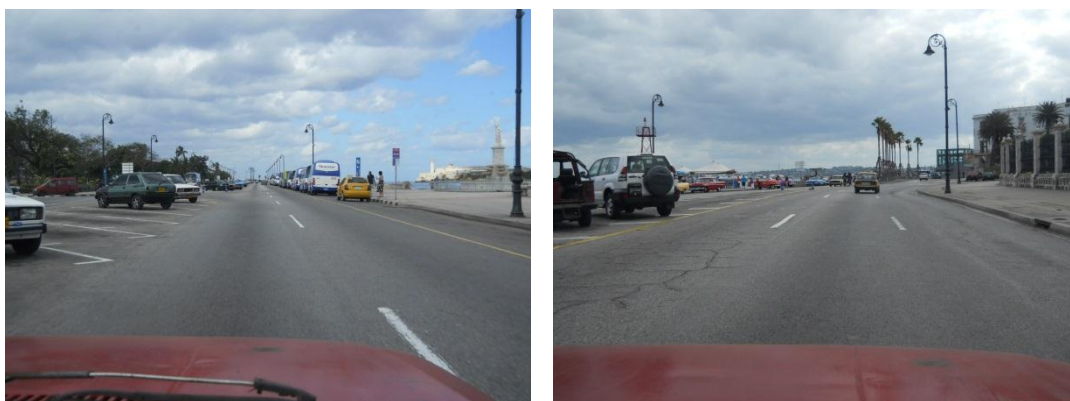


figure E.9 – Avenida del Puerto between the cruise terminal and La Punta. On the left towards La Punta and on the right towards Sierra Meastra.

Part 8: Avenida del Puerto (Arroyo – Jesus Lopez)

Back to the starting point, the analysis continues in the other direction of the Avenida del Puerto, now going south along the bay. This part of the Avenida del Puerto is a quiet part with a 2x2 lane configuration with small sidewalks on both sides until the crossing with Jesus Lopez. There are no connecting roads in between, only a few access roads to the current terminals next to the bay. The location of these terminals is included in the master plan Tourist Port Havana, as possible location for a marina or Ferry terminal. On the other side of the road lies a railway track, limiting the space for expansion of the road.



figure E.10 – Avenida del Puerto between Arroyo and Jesus Lopez. On the left the road along docks next to the bay and on the right the intersection with Jesus Lopez.

Part 9: Avenida del Puerto (Jesus Lopez – bridge)

The connection of Jesus Lopez (also called Primer Anillo del Puerto) with Avenida del Puerto is a T-junction. The Jesus Lopez road, as well as Fabrica, connects the Avenida del Puerto to a main through road of Havana, the Via Blanca. The Avenida del Puerto continues around the bay with the same lane configuration of 2x2 lanes, with small sidewalks on both sides of the road. There are no connecting roads in this part of the Avenida del Puerto, only some access roads to harbour sites.



figure E.11 – Avenida del Puerto beyond Jesus Lopez. Both sides in south-east direction, on the left just past the intersection with Jesus Lopez and on the right near the bridge across the Luyanó river.

E.2.3 MAIN CONNECTIONS

Part 10: Avenida de Belgica

The Avenida de Belgica connects to the Avenida del Puerto at the roundabout next to the bus station. It leads north to the connection with Maximo Gomez (also called Monte), from where on it continues as Avenida de Misiones to La Punta. This road marks the end of Habana Vieja. The lane configuration is 2x2 lanes from the Avenida del Puerto to the T-junction with Arsenal. From this point on north the Avenida de Belgica is a three-lane one-way street in the direction of La Punta. This part of the Avenida de Belgica is very crowded with people, parked cars and containers, making three cars alongside each other impossible. On some parts there is practically only one lane available for through traffic. On both sides there is a sidewalk, but people walk on the street as well.

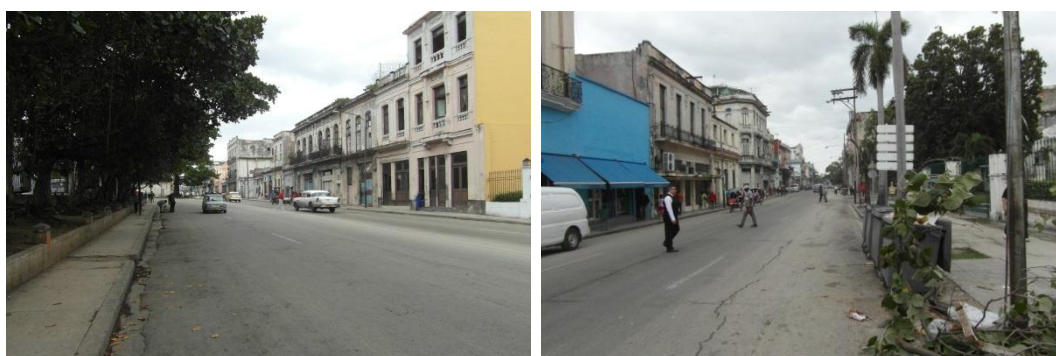


figure E.12 – Avenida de Belgica. On the left between Arsenal and Avenida del Puerto and on the right as one way street beyond Arsenal.

Part11: Arsenal

Arsenal is a side-road from Avenida de Belgica, along the central train station. It is considered as an access road like the smaller screen roads of the city, although it is wider and has a row of parking spaces along the train station. Currently it is really

quiet on the road, since there is not much activity at the train station. Arsenal ends on the other side on the road Factoria, which is also a smaller screen road. Even though it is wide enough for three lanes, or two lanes and a parking lane, the flow function is limited because it only connects smaller roads.



figure E.13 – Arsenal. On the left the road along the railway track, on the right the Central Train station.

Part 12: Máximo Gómez

Maximo Gomez (also called Monte) is another main road through Havana. It connects to Avenida de Belgica and from there on it leads south-east. Just before the connection with Avenida de Belgica, Maximo Gomez forms a complicated and very busy intersection with Avenida Simon Bolivar (also called Reina) and Paseo de Marti (also called Prado). This intersection experiences a lot of congestion because of the high intensities on these three main roads. There is no available data on intensities or congestion on this intersection, so a solution for this junction will be hard to find. In addition, a solution will also be very expensive due to the big surface area and high hindrance of the unavoidable construction works.



figure E.14 – Maximo Gomez (Monte). Top left a top view of the intersection with Avenida Simon Bolivar and Paseo de Marti (Google, 2013). Top right looking onto Simon Bolivar. Bottom left looking onto Maximo Gomez towards southwest and bottom right eastwards.

Part 13: Avenida Simon Bolivar

The Avenida Simon Bolivar (also called Reina) is a main road leading to the east of Havana, connecting the Paseo de Marti to Calle G (Avenida de los Presidentes) and Paseo. The lane configuration is three lanes per direction. At the intersection with Paseo de Marti and Maximo Gomez it has a central reservation between the different directions and there are sidewalks on both sides of the road.



figure E.15 – Avenida Simon Bolivar (Reina)

Part 14: Avenida de Misiones and Agramonte

Avenida de Misiones (also called Monserrate) and Agramonte (also called Zulueta) are two one-way roads in opposite directions, parallel to the Paseo de Marti. They have one block of buildings in between them (with for example the Museo de la Revolution) and they connect Maximo Gomez with the Via Monumental, next to La Punta. Both streets have 3 lanes and sidewalks on both sides. These roads are not very busy and the most right lane is often used for parking.

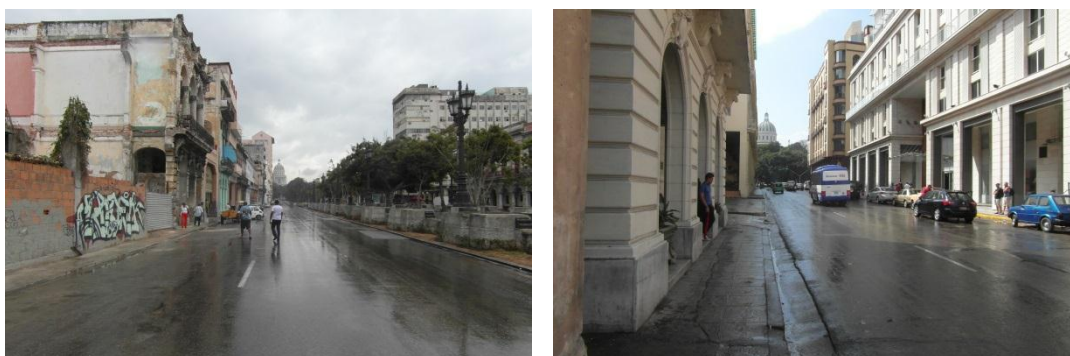


figure E.16 – Avenida de Misiones and Agramonte. On the left Avenida de Misiones and on the right Agramonte, both looking south towards the Capitolio.

Part 15: Paseo de Marti

The Paseo de Marti (also called Prado) is the main road from north to south, separating Habana Vieja from Centro Habana. It connects La Punta with Maximo Gomez and Avenida Simon Bolivar. The Paseo de Marti passes by the Capitolio, making this road a very busy road, filled with tourist busses and taxis. The lane configuration is 3x3 lanes with a double line of parking spaces at 30 degrees in between. These are mainly used by taxis. The most right lane is also often used as parking lane, not in the last place by tourist buses, even though it is a busy street. All the side streets from Paseo de Marti have parking spots, all crowded, indicating that the demand for parking is very high in this area.



figure E.17 – Paseo de Marti. On the left south towards the Capitolio and on the right north, with parking spots and tourist buses.

Part 16: Arroyo:

Arroyo connects to the Avenida del Puerto with a roundabout wherefrom two one-way roads lead on and off the Avenida del Puerto. The roundabout has four lanes and four exits. Clockwise, starting at 12 o'clock; Alambique, Avenida del Puerto, Fabrica and Arroyo. From the Avenida del Puerto, Arroyo leads eastwards where it connects to Avenida de Mexico and Maximo Gomez before it continues as Avenida Zaldo towards Plaza de la Revolution. These are important arterial roads, making Arroyo a significant link for the accessibility of the harbour.

The connection between the roundabout and the Avenida del Puerto is a complicated one, as it crosses two pair of rails at street level and passes many columns from the elevated railway track. This creates a dangerous situation, which is poorly marked in the current situation.



figure E.18 – Arroyo. Top left a top view of the roundabout (Google, 2013). Top right the north part of the roundabout, looking east. Bottom left the southern part of the roundabout, also looking east. Bottom right the connection onto Avenida del Puerto.

Part 17: Fabrica and Jesus Lopez

From the roundabout discussed just above, Fabrica leads south, parallel to the Avenida del Puerto. There it intersects to Jesus Lopez. Fabrica continues to connect to the Via Blanca. Jesus Lopez also connects to the Via Blanca, but more to the west, and also continues to intersect with the Avenida del Puerto.

Fabrica has three lanes in both directions, which looks to be a bit over dimensioned. Even though it is wider than the Avenida del Puerto, it is not as busy. Just north of the intersection between Fabrica and Jesus Lopez there is a driveway with a traffic light leading onto a restricted area. Another driveway is situated a little more to the north, leading to the Castillo de Atarés.

These roads form the main links from the project area to the south, mainly via the connection to the Via Blanca.



figure E.19 – Fabrica. On the left towards the south and on the right towards the north, with traffic lights.



figure E.20 – Jesus Lopez. On the left the intersection with Avenida del Puerto and on the right the intersection with Fabrica.

E.3 TRAFFIC

Besides the road layout, the infrastructure supply, there is the infrastructure demand; the traffic supply. The characteristics of the different traffic modes and their intensities are covered by this paragraph.

E.3.1 TRAFFIC MODES

Cars

Havana is famous for its old-timers, driving everywhere in the city. These jewels from the fifties determine its scene, a unique scene in the world. But these old-timers have quite different characteristics than the modern cars. Many of them are in bad condition and almost every one is repaired with different parts than the original ones. This means that their acceleration and maximum speed is often very limited. Furthermore their ability to take sharp bends is a lot less compared to modern cars and they produce a big black curtain of smoke behind them.

But the street image is currently changing; more and more modern cars enter the roads of Havana. Cubans are allowed to buy cars since 2012 and car rental has become very popular with tourists. This mix of totally different cars on the road decreases the uniformity, which in turn reduces the flow and the safety on the road.

Taxis

The main streets of Havana accommodate a large number of taxis. There are two kinds of taxis, the taxis colectivos and the Cubataxis. The Cubataxis are the regular taxis, often Ladas, and in decent condition. The taxis colectivos are only for Cubans (and international students) and drive rounds on the main roads of Havana. For 10 Cuban pesos the taxi colectivo takes the Cubans to anywhere on the route. All along these routes Cubans enter and leave these taxis, meaning that the righter lane is often occupied by taxis colectivos picking up, or dropping, people.

Buses

The buses in Havana are a big collection of all kinds of different buses from around the world. Buses are numerous in Havana and mostly packed with people. Often they are in bad condition, but for some important lines some long buses in decent condition are available. Most of these are the longer so-called “articulados”, meaning compounds. The bus stops are located on the road itself, blocking the traffic on the most right lane. This lowers the capacity of the road during every stop of a bus.

Trucks

Trucks are rare in the city centre, but are regular at the south-west corner of the bay because of the commercial harbour activities. Most trucks driving here are relatively small, old trucks with an open boot. Articulated lorries are smaller in number, but definitely a factor with their length. Similar to the cars, most trucks have limited acceleration and top speed due to their age.

Cyclists

There are no cycle paths in the project area, so the few present cyclists use the most right lane of the road. In the touristic area around Habana Vieja there are cycling taxis, as well as horse carriages. Just like cyclists, these horse carriages use the right lane as they are slow moving.

Pedestrians

Pedestrians, on the contrary, are everywhere. Around Habana Vieja there are many tourists on foot, walking around the Plazas and through the narrow streets. In Habana Vieja pedestrians walk over the smaller roads. Most main roads have sidewalks where pedestrians are able to walk safely. Crossing facilities for pedestrians are present at some points, but certainly not everywhere. Therefore it is common to see pedestrians crossing a busy road, of sometimes even six lanes, at a random place. Drivers use their horn easily to warn pedestrians, but don't brake or give priority.

Traffic overview of project area

Overall, the area has a difficult mix in traffic. Old and new cars, old buses and new buses, many pedestrians and tourist activities make this area very diverse in its characteristics and its functions. The Avenida del Puerto has a flow function as first road along the bay. Since the traffic from the Habana Vieja quarter is only distributed by the Avenida del Puerto on one side and by Paseo de Marti on the other side, The Avenida del Puerto is an important through road. But with the increase of tourism around the bay, this conflicts with the access functions at the harbour and Habana Vieja. This location is a main touristic area of Havana, with lots of tourists walking on both sides of the Avenida del Puerto. The addition of a marina and a ferry terminal in the south-west part of the bay will extend this problem.

E.3.2 TRAFFIC COUNTS

For an accurate analysis the traffic numbers and the flows on the network are very important. But little can be said about the intensities of traffic on these roads since data is lacking. For most parts only a global impression of the flows can be set out. The only data available are counts of one day at three intersections in the project area. These locations, (1) Avenida del Puerto - Arroyo (Tallapiedra), (2) Avenida del Puerto - Jesus Lopez and (3) Fabrica – Jesus Lopez (Gancedo), are indicated in figure E.21.



figure E.21 – locations of counts (Google, 2013)

The data of locations (1) and (2) have the same set up, containing the number of cyclists, motorcycles, cars, trucks, regular buses and long buses passing, per movement, per five minutes and during twelve hours (7 AM to 7 PM). The data of

location (3) is the same, except for it is counted per half hour instead of five minutes and the counts of articulated lorries instead of articulated buses.³

Since this is the only data available, it is assumed that this data represents the average day. To complete the data of twelve hours to a full day, the Department of Roads of CUJAE University uses the assumption that the day, from 7 AM till 7 PM, holds 70% of all traffic during 24 hours.

The data of the different locations does not match, so the counts are not taken on the same day. This causes inconsistency and decreases the value of these counts.

The data has some gaps. For several movements counts are missing between 1 and 1:30 pm. These gaps are filled by taking the average of the values before and after the gap, i.e. the averages of 12:30 till 1 pm respectively 1:30 till 2 pm.

At the intersection between Avenida del Puerto and Arroyo movement 5 (Arroyo onto Avenida del Puerto towards Regla) is only counted in the afternoon. This data is copied to the morning to create a filled data set. The consequences of these assumptions to fill the gaps are small since it is only a small part of the day, outside the peak period.

The Vehicle Equivalent (VE) is calculated with the factors used by the Department of Roads at CUJAE University, shown in table E.1. These factors are considerably higher than the factors used in, for example, the Netherlands, where the factor for big trucks is assumed to be 1.5 or 2, be it on the freeway. But with the knowledge of CUJAE these factors are better fit for the Cuban traffic, which is quite different as said before.

table E.1 – vehicle Equivalent factors

Vehicle type	VE factor
Cyclist	0
Motorcycle	0.5
Car	1
Truck	2.5
Articulated lorry	4.0
Bus	2.5
Articulated bus	4.0

Intersection Avenida del Puerto and Arroyo (1)

The intersection of Avenida del Puerto and Arroyo is shown in figure E.22. In the schematic representation on the right, the numbers used to assign the different movements are indicated. The raw data is converted from 5 minute intervals to 30 minute intervals to create equal data for all three locations.

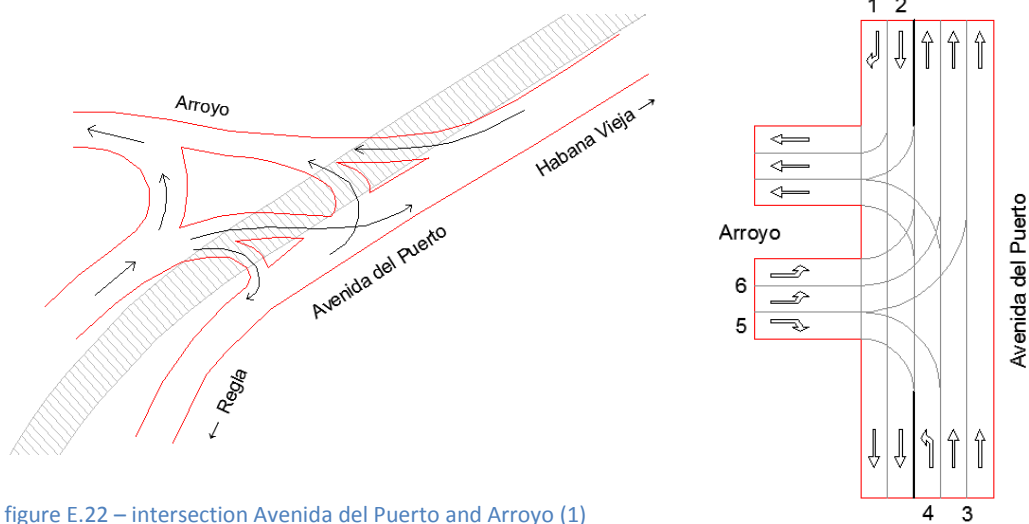


figure E.22 – intersection Avenida del Puerto and Arroyo (1)

The VE per movement indicates that there is quite some truck activity from and to Regla. This can easily be explained by the commercial harbour activities in that direction. Towards Habana Vieja the share of trucks is considerably lower. figure E.23 also shows that there is an important bus line leading from Regla onto Arroyo.

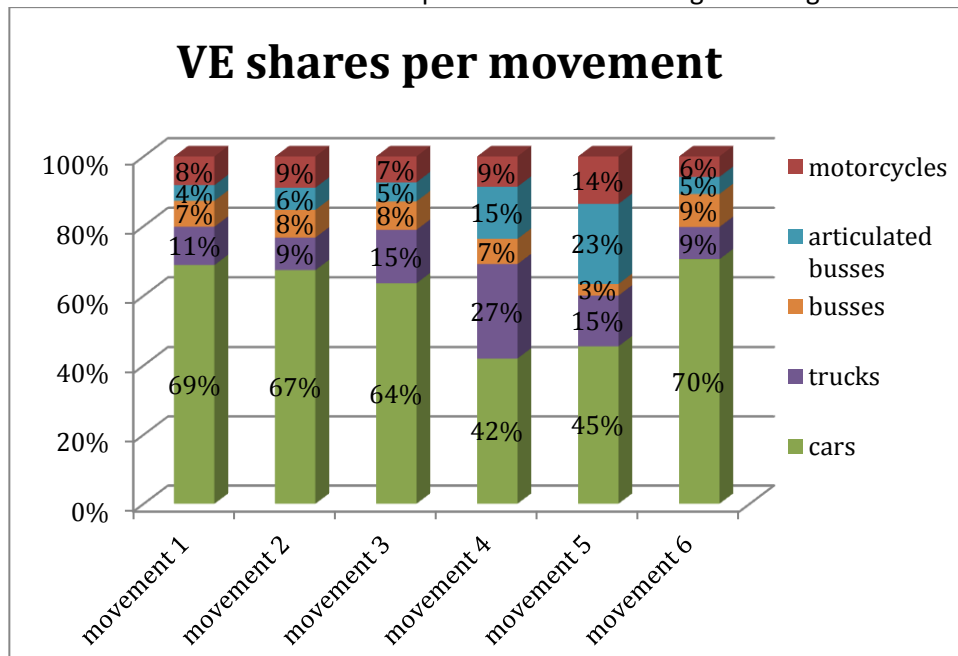


figure E.23 – vehicle Equivalent shares of different vehicle types at intersection Avenida del Puerto and Arroyo

figure E.24, figure E.25 and figure E.26 show respectively the flows per movement (VE per half hour), per direction and per origin (both VE per hour). These graphs show a clear morning peak going from Habana Vieja towards Regla. The evening peak is almost non-existent. This means that this part of the road is either part of a tour consisting of more trips or people take another way back as the one they take

in the morning. It is notable to see that the largest flow is from Habana Vieja towards Regla, while there are only two lanes in this direction and three in opposite direction.

In general the flows are relatively low compared to the capacity. With a maximum of 1 864 VE from Habana Vieja this road does uses little more than half of its capacity. For the capacity of a 50 km/h road the value of 1 549 VE per lane (Nes et al., 2007) per hour is taken. All other directions have considerable lower flows. The only other peak in the flow above 1 000 VE is in the direction of Habana Vieja with 1 080 VE between 6 and 7 pm. The peak of VE on this junction is 3 158 VE between 9 and 10 am.

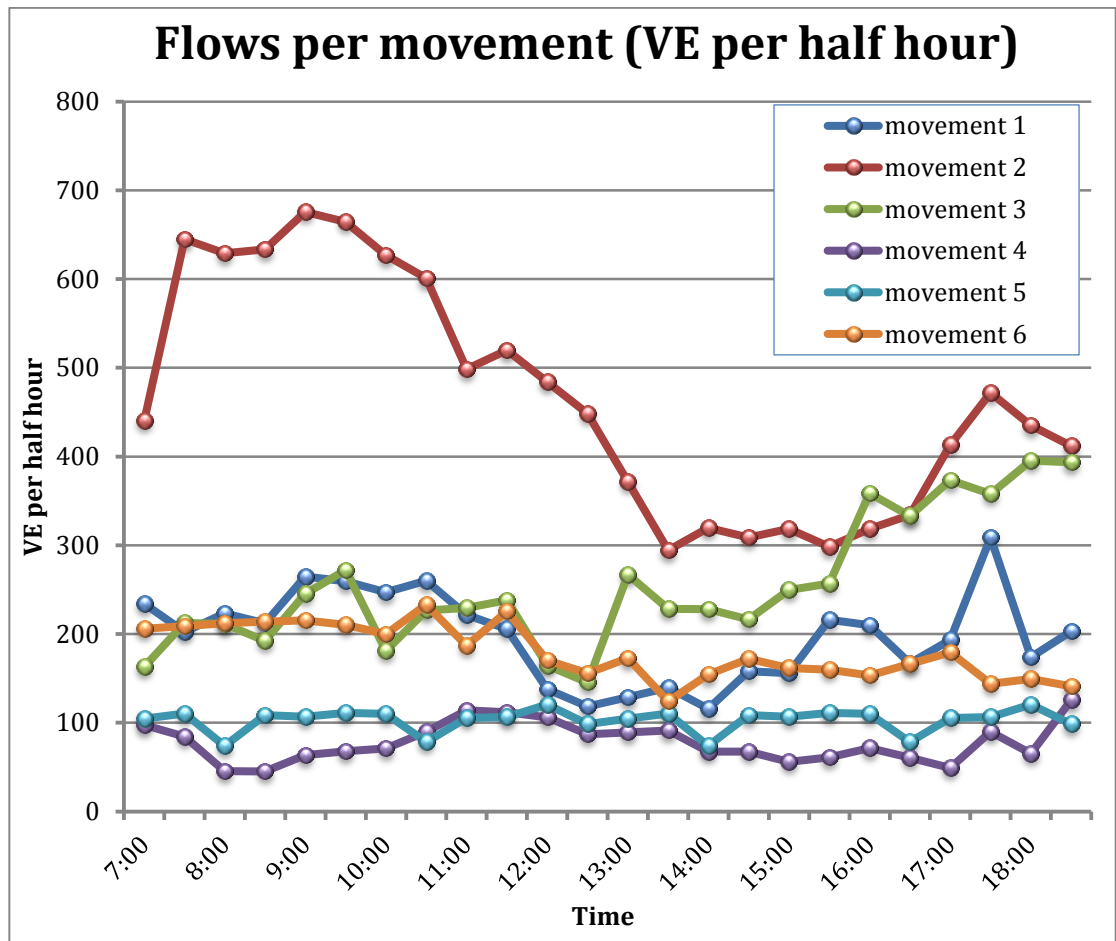


figure E.24 – flows per movement at intersection Avenida del Puerto and Arroyo

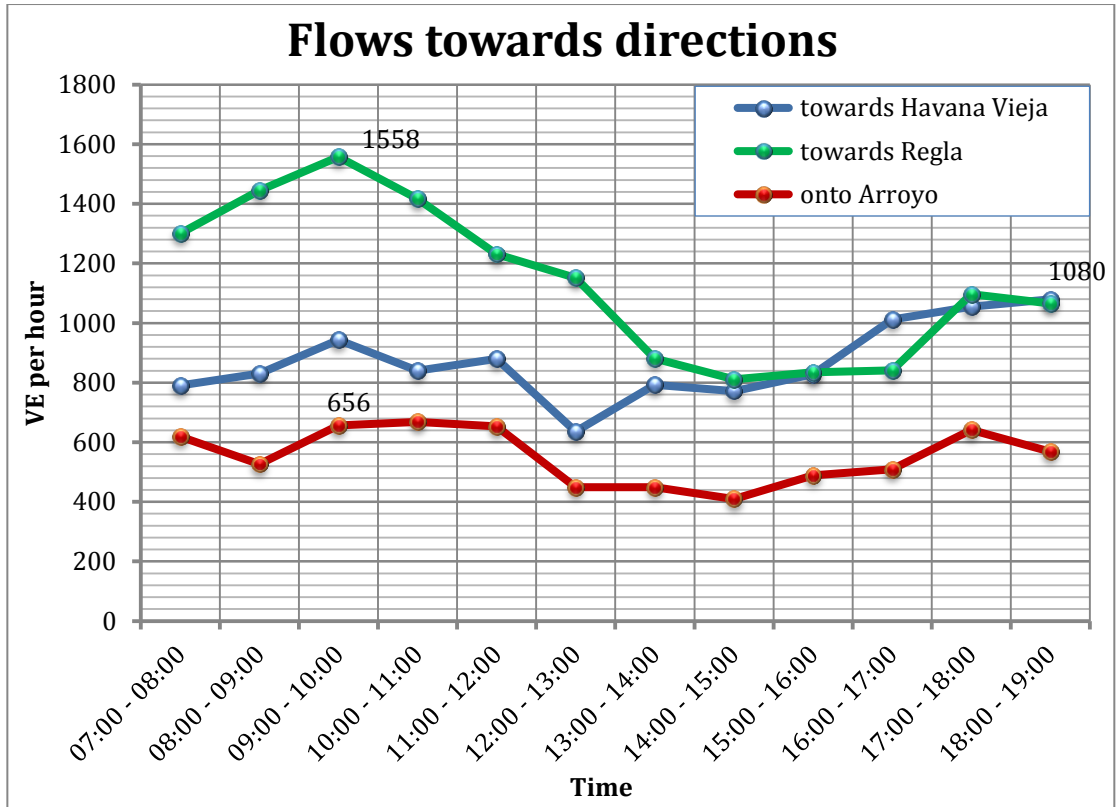


figure E.25 – flows towards the different directions at intersection Avenida del Puerto and Arroyo

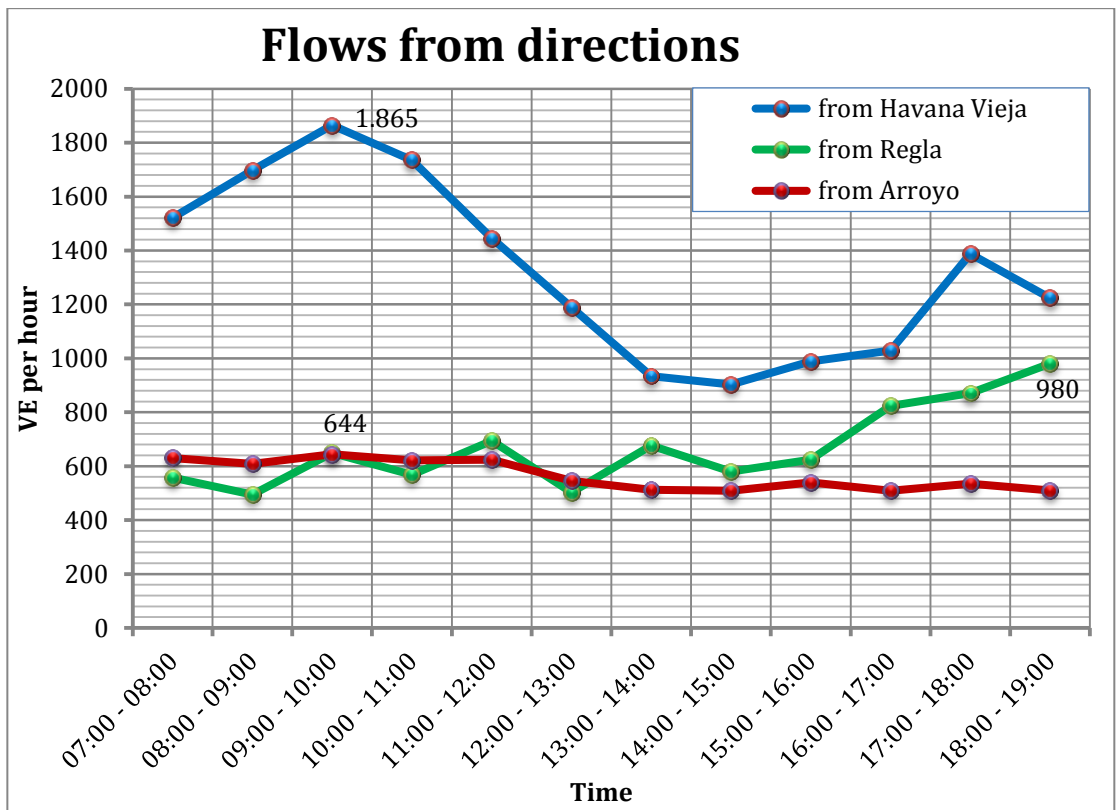


figure E.26 – flows from the different direction at intersection Avenida del Puerto and Arroyo

Intersection Avenida del Puerto and Jesus Lopez (2)

This intersection is a T-junction similar to the intersection between Avenida del Puerto and Arroyo. The directions and movements are illustrated in figure E.27. The available data has the same set up as the data of location (1) so the same conversion and filling method is applied here. In this data there are no day parts missing, but between 1 p.m. and 1:30 p.m. there is often no data. In the numbering of the movements the Avenida del Puerto again is chosen as main direction as shown in figure E.27 on the right.

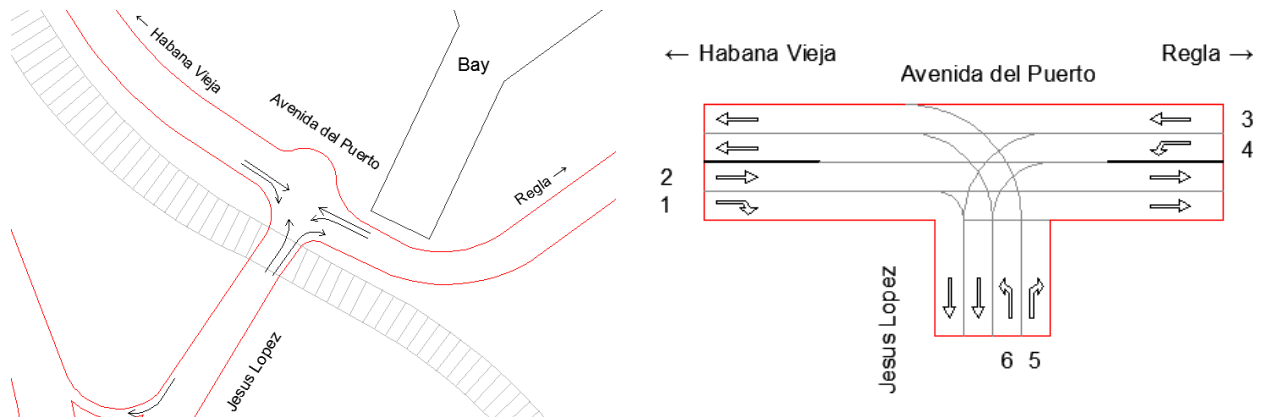


figure E.27 – intersection Avenida del Puerto and Jesus Lopez (2)

The vehicle shares at this intersection are shown in figure E.28. Between Jesus Lopez and the Avenida del Puerto towards Regla there is a high share of trucks. The same conclusion as at the intersection between Avenida del Puerto and Arroyo can be derived here; the commercial harbour activities generate this flow of trucks. In the other directions the car is very dominant in the VE share.

VE shares of vehicle types

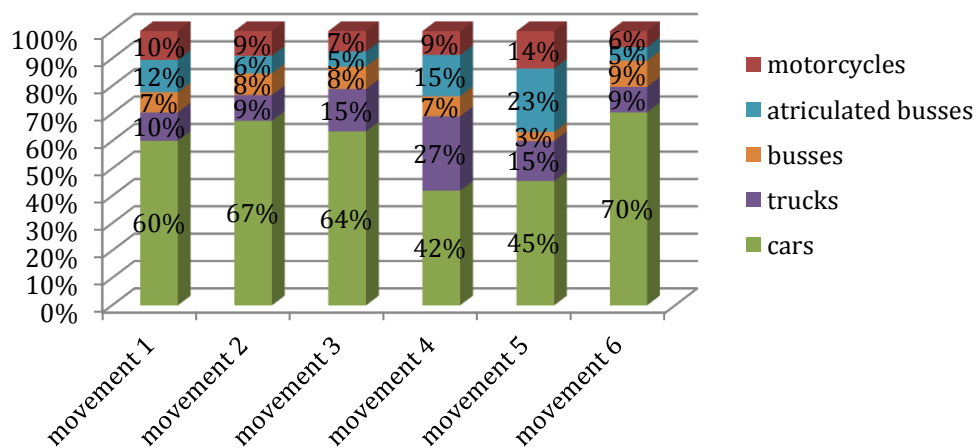


figure E.28 – VE shares of vehicle type at Avenida del Puerto and Jesus Lopez

The flows per movement show a very irregular pattern, just as the intersection between Avenida del Puerto and Arroyo. During the morning the flow onto Jesus Lopez is the largest, mainly originating from Havana Vieja. In the evening this flow is the smallest. The flows towards Havana Vieja and Regla are relatively constant

compared to the flow onto Jesus Lopez, but still the deviation is substantial. In the interval between 1 and 2 p.m. there is a clear drop in the flow, even though the missing data from 1 to 1:30 p.m. is filled. This is due to the incomplete half hour data between 1:30 and 2 p.m. Because there is data noted this is not filled as done with the previous time interval.

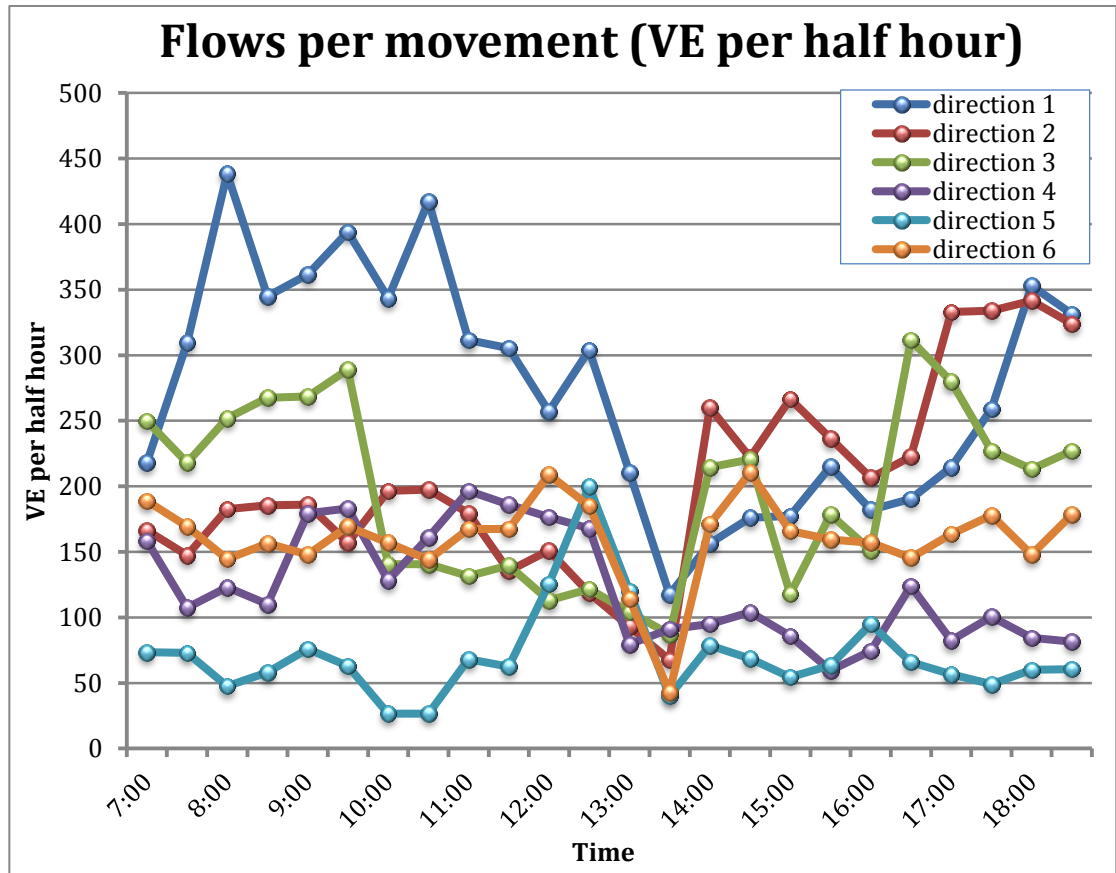


figure E.29 – flows per movement at Avenida del Puerto and Jesus Lopez

The flows from Havana Vieja are the largest and a morning and evening peak are visible in figure E.31. The evening peak has the largest one hour flow of the day between 6 and 7 p.m. of 1 350 VE. The busiest hour on this intersection however, is between 9 and 10 am, when 2 475 VE travels over this intersection.

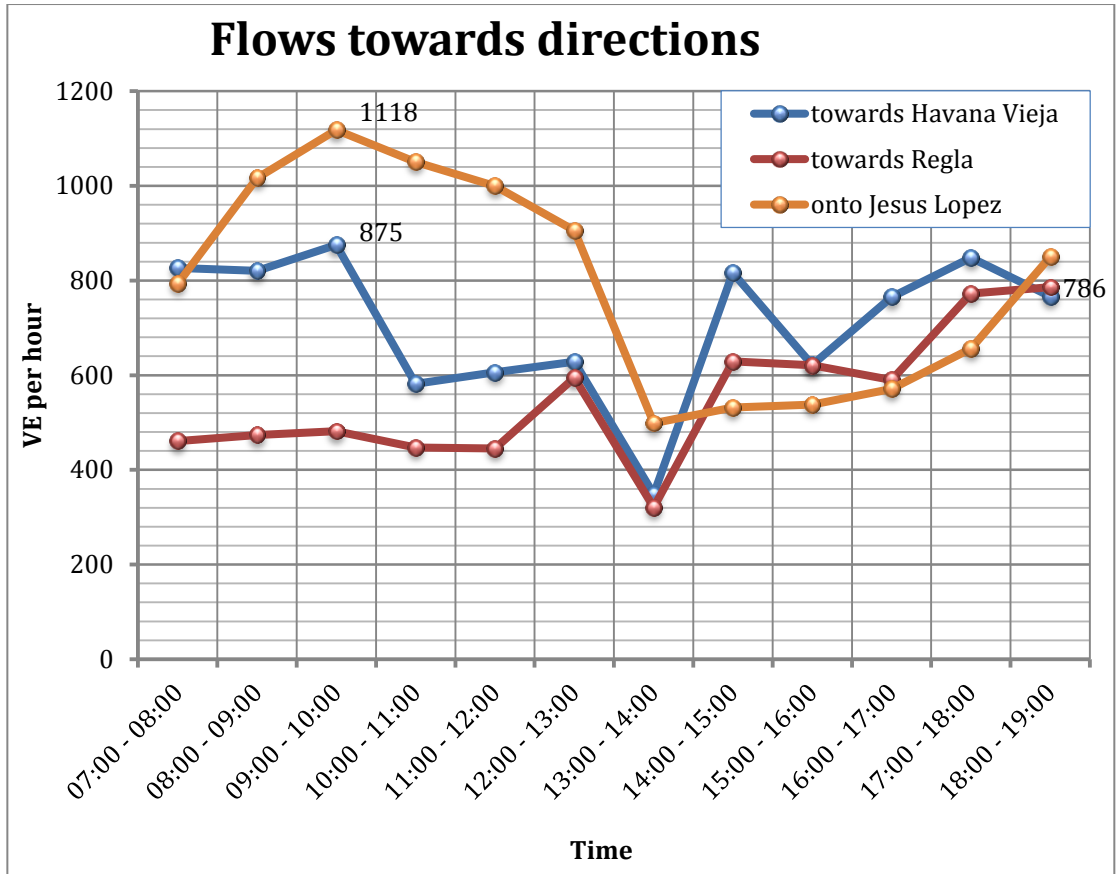


figure E.30 – flows towards directions at Avenida del Puerto and Jesus Lopez

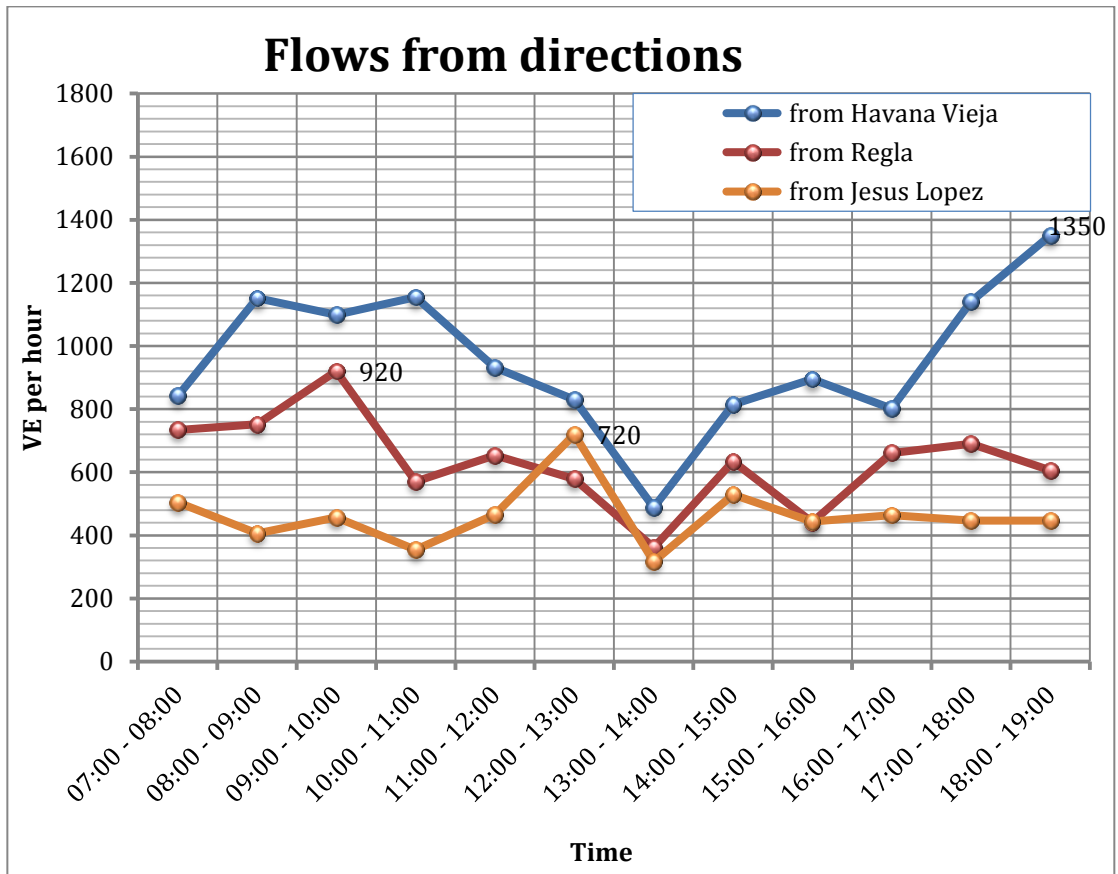


figure E.31 – flows from directions at Avenida del Puerto and Jesus Lopez

Intersection Fabrica and Jesus Lopez (3)

The third location is the intersection between Fabrica and Jesus Lopez. This junction is a four-leg-junction with bypasses to the right from three directions as can be seen in figure E.32 on the left. One of these bypasses is not taken into account in the available data, leaving 10 movements as it is not possible to go left from Fabrica onto Jesus Lopez in the direction of Via Blanca. The numbering of these directions is shown below in figure E.32 on the right.

The data of counts on this junction has a slightly different set-up as the previous locations. Articulated busses are not taken into account, but articulated lorries are. This implies a shift of VE from trucks to busses as articulated busses are now counted as busses and trucks are separated into regular trucks and articulated trucks. For this location the data is already set up with 30 minute intervals and uses VE, so these conversions are not needed. Also this data set does not have any gaps, thus no filling is applied.

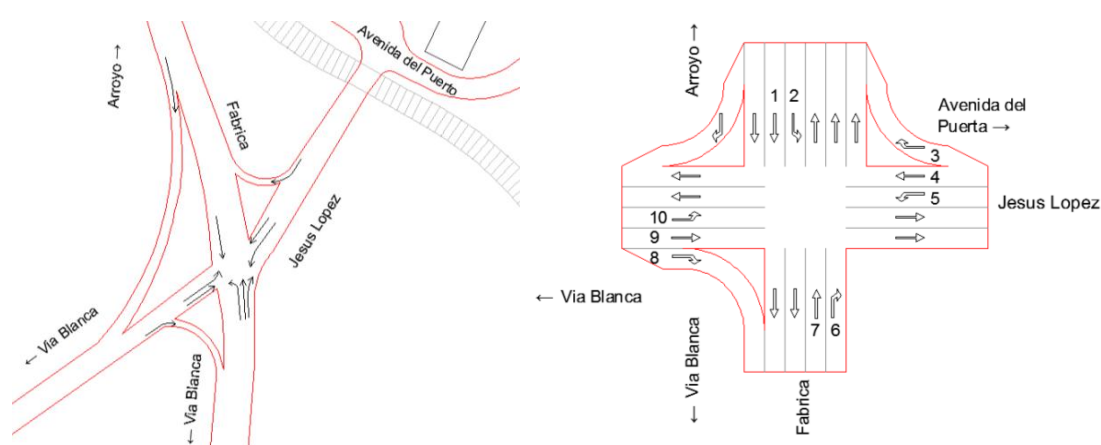


figure E.32 – intersection Fabrica and Jesus Lopez

The shares of VE on this intersection show the same pattern as the previous two intersections. From and to the commercial harbour there is a larger truck movement than in other directions. Especially directions 3 and 8 have high shares of trucks with over 50% of the VE of trucks and articulated lorries combined. The shift from bus to truck as expected from the different set up of the data cannot be seen in figure E.33. The share of busses is slightly higher in comparison to the other two locations but does not cover the entire shift of articulated busses to this category. This intersection is closer to the commercial harbour and is on main cargo routes as many trucks take Fabrica in northern directions instead of Avenida del Puerto.

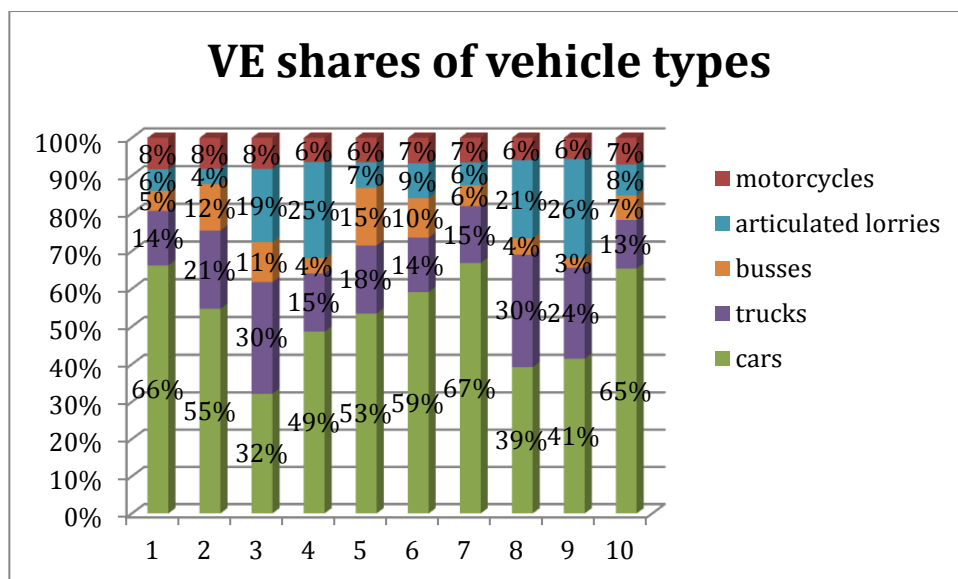


figure E.33 – vehicle Equivalent shares per vehicle type at Fabrica and Jesus Lopez

The flows on this intersection also show a high deviation in time as can be seen in figure E.34. The flows on Fabrica towards Arroyo and Via Blanca have the highest peaks with 1 610 and 1 583 VE respectively. The flow on Fabrica towards Arroyo has peaks in the afternoon, between 1 and 2 pm and 3 and 4 pm, while in the direction of Via Blanca the flow increases until it peaks between 5 and 6 pm. The flows on Jesus Lopez are considerably lower with peaks in the morning between 7 and 8 am, all below 1 000 VE. This confirms the arterial function of Fabrica in this area. The peak of VE on this junction is 4 092 VE between 7 and 8 am, which is considerably higher than the previous two locations. This was to be expected since this junction has a larger setup.

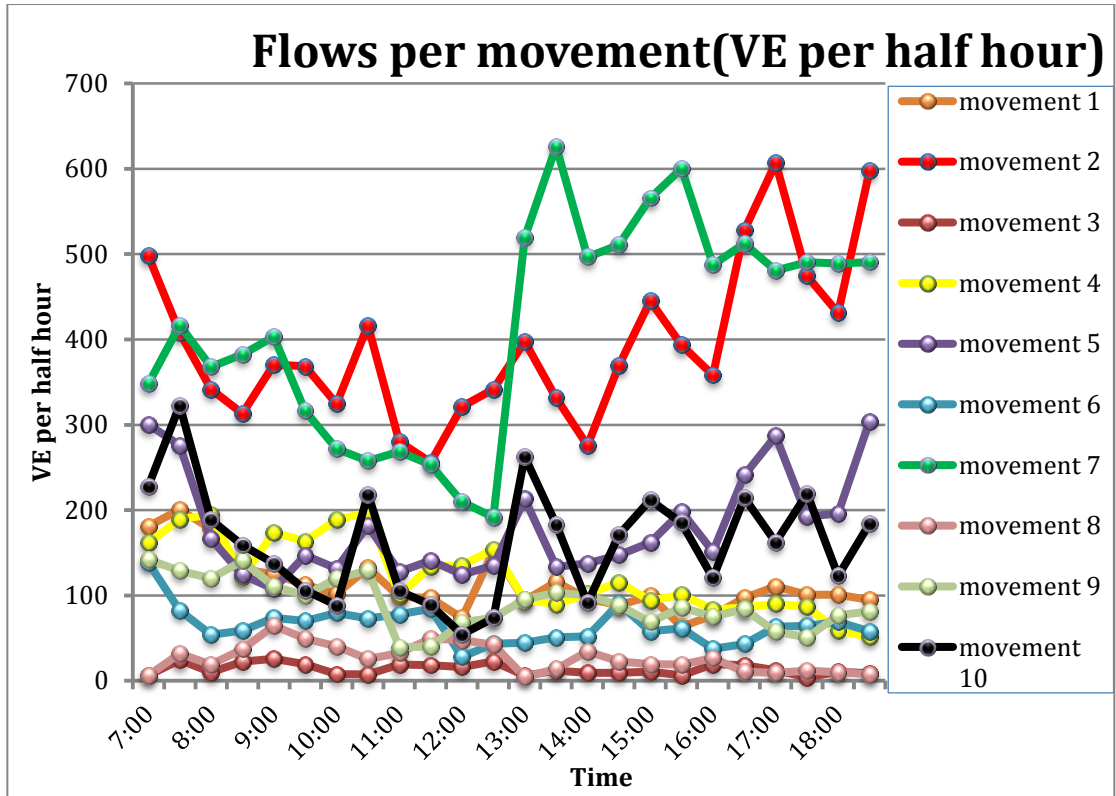


figure E.34 – flows per movement at Fabrica and Jesus Lopez

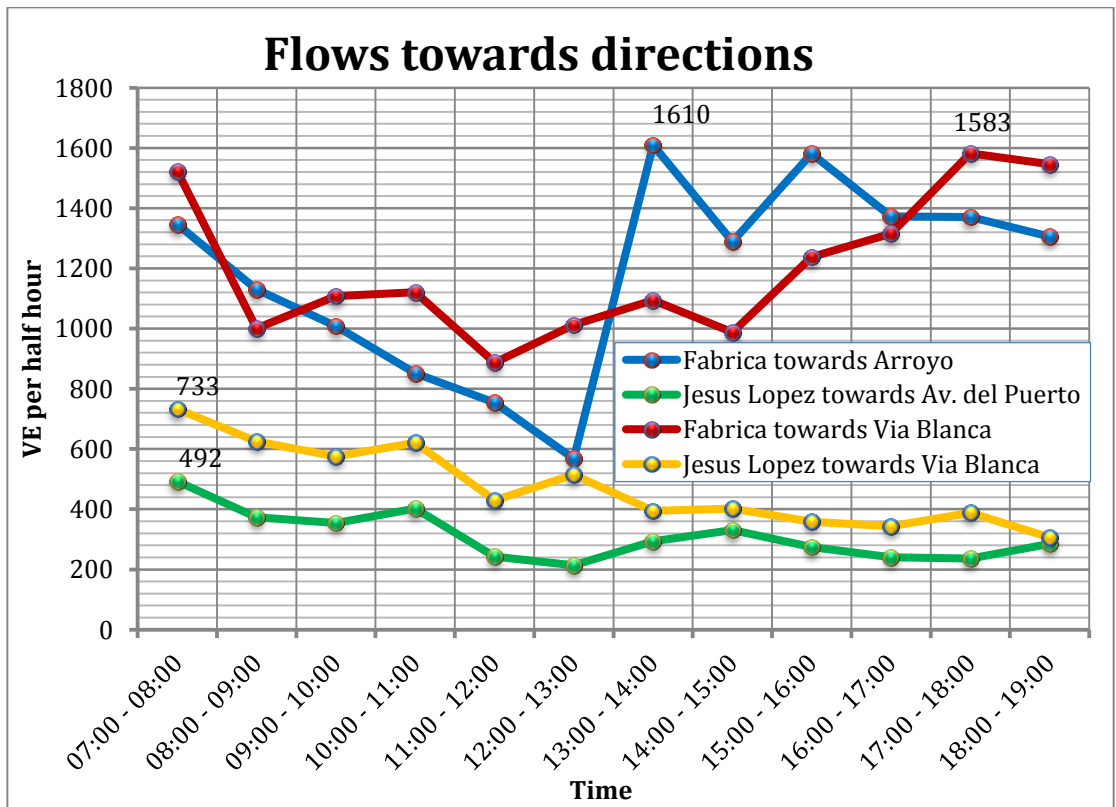


figure E.35 – flows towards firections at Fabrica and Jesus Lopez

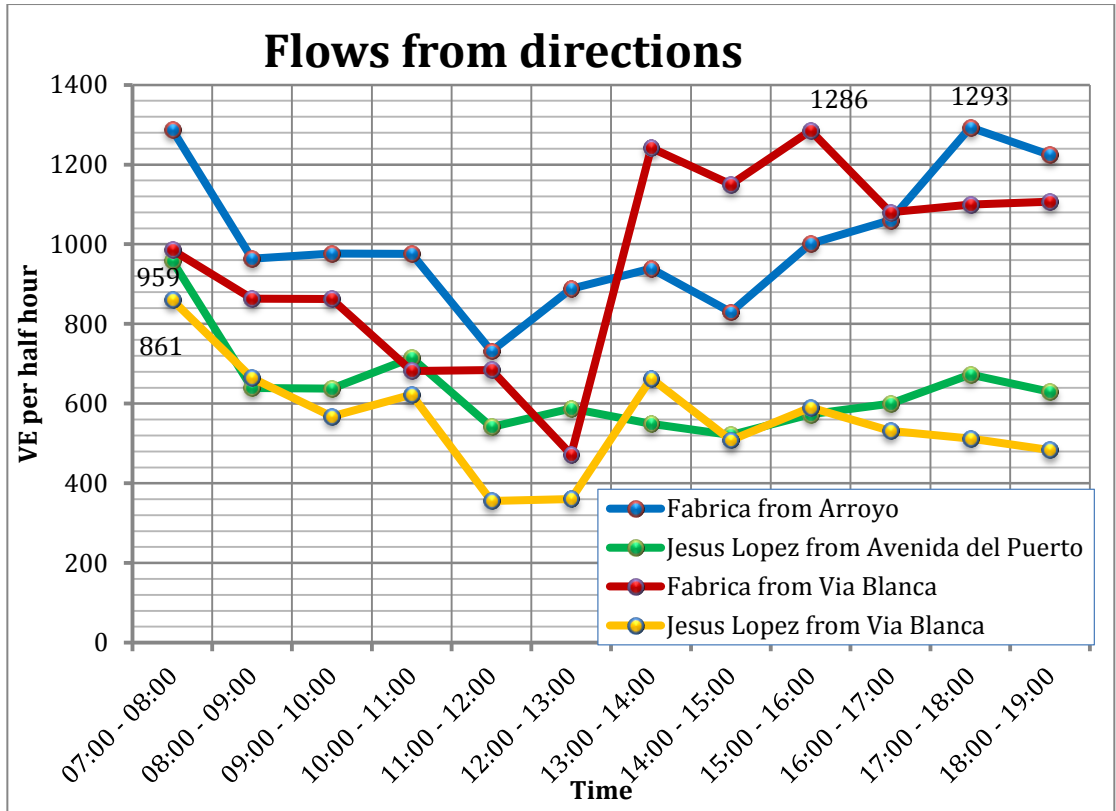


figure E.36 – flows from directions at Fabrica and Jesus Lopez

E.4 TRANSIT

This paragraph discusses the current public transport facilities in Havana and specifically in the project area. The only transit modes available are bus and train, however there are several different types of buses. The city busses consist of two types; new major lines through the city, served with articulated busses, and the smaller lines served with regular busses. Furthermore there are regional and intercity busses for Cubans and separate intercity busses for tourists (Viazul). Then there are the tour buses of Transtur, bringing tourist to all touristic hotspots in the country.

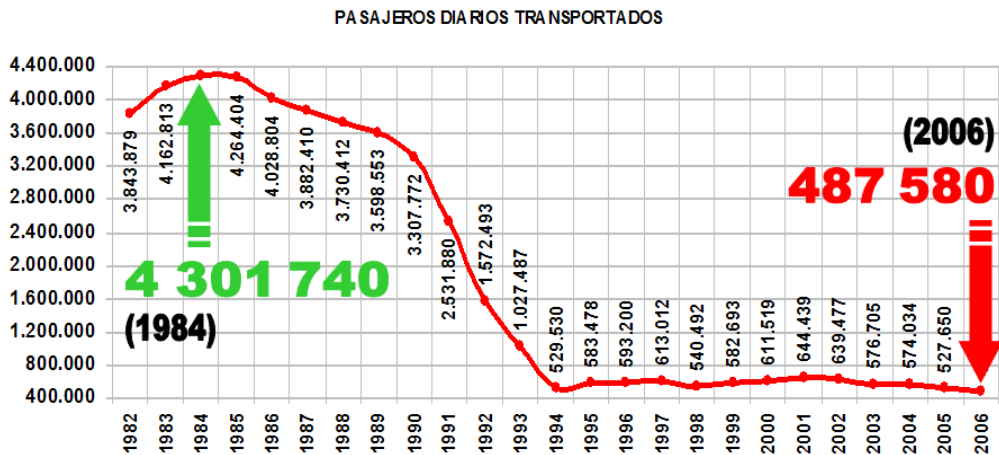


figure E.37 – collapse of the public transport system

The public transport system collapsed in the late 80's and early 90's when the economy came to a standstill after the collapse of the Soviet Union. Figure E.37 shows that the number of passengers transported is almost decimated in 2006 compared to the peak in 1984. But the Cuban government is motivated to rebuild a bus network comparable to the old days since the demand for public transport is enormous. For this, many investments have been done since 2006, of which the new major bus network in Havana is a product.

E.4.1 MAJOR BUSLINES THROUGH HAVANA

The major bus lines are indicated with a P plus the line number. These lines are set up since 2006 and cover the entire city of Havana. Figure E.38 shows the major bus lines in a map and Table E.2 lists all origins and destinations of the lines. This is the only available map of bus lines, meaning there is no precise map of the minor bus lines and no map at all for the smaller lines. These major lines are operated with articulated buses, also called Metro busses, which are relatively new. The intentional six minute interval between the busses is nevertheless not reached by far. Often busses come in pairs. This bunching phenomenon decreases the effectiveness of the line drastically.

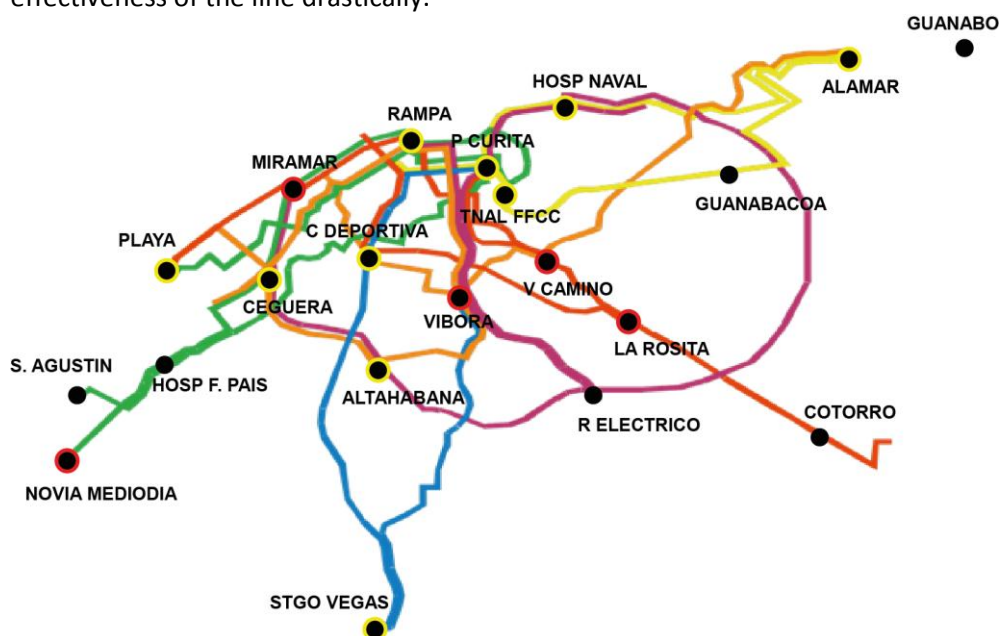


figure E.38 – major bus lines

table E.2 – origins and Destinations of Major bus lines

LINEA	LINEA / RUTA ACTUAL	SERVICIO REGULAR			TRAMOS CON REFUERZO		
		ORIGEN	DESTINO	INT (min)	ORIGEN	DESTINO	INT (min)
P1	P1	V. Camino	Playa	6	V. Camino	Rampa	4 - 5
P2	P2 Mod	La Rosita	Vedado	7 - 8	Vibora	Vedado	5
P3	M3 Ext	Micro X	Miramar	5			
P4	P4	Playa	La Coubre	5			
P5	298 Ext	N. Mediodía	La Coubre	7 - 8	Lisa	Rampa	5
P6	M6	R. Eléctrico	Rampa	6			
P7	M7	Alberro	P. Fraternidad	4	V. Camino	P. Fraternidad	3
P8	NUEVA	R. Eléctrico	Hosp Naval	6			
P9	NUEVA	Vibora	Ceguera	5	Rampa	Ceguera	4
P10	100	Vibora	Playa	9	Vibora	Ceguera	6 - 7
P11	M1	Micro X	Vedado	3 - 4			
P12	M2	Stgo Vegas	P. Fraternidad	4 - 5			
P13	31	Stgo Vegas	Vibora	8	Vibora	Calabazar	6
P14	M4	San Agustín	P. Fraternidad	5			
P15	NUEVA	Micro X	P. Fraternidad	8	Gbaoa	P. Fraternidad	6 - 7
PC	NUEVA	Hosp Naval	Miramar	12			

There is no clear overview of bus lines in the project area, but there is a bus map for Havana Vieja with the major lines. This map is shown in figure E.39 and holds 22 bus stops. It can be seen that in the different directions there are other stops along the Avenida del Puerto. Relevant stops are located at Plaza de Armas, in front of the Sierra Meastra terminal, in front of the shopping centre Almacén San José and at the intersection with Avenida de Belgica. There are currently plans to rearrange the bus lines through the old city, but the actual status of these plans is unclear.

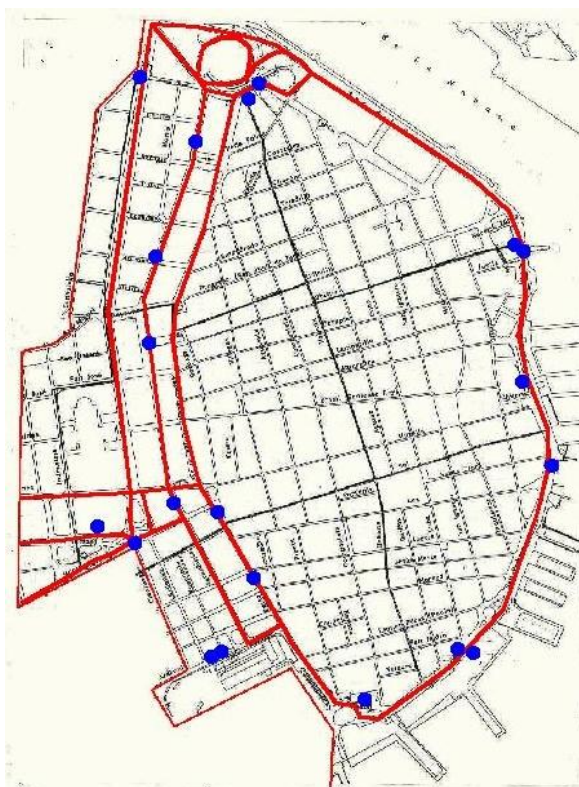


figure E.39 – bus lines in Havana Vieja

E.4.2 REGIONAL BUS LINES

The regional bus lines are shown in figure E.40. This map shows that La Coubre is an important station for the regional bus lines. This is a convenient factor for the connection of the marina and ferry terminal since this station can provide subsequent transportation from the port to the entire province. This advantage can be enlarged by tuning the bus lines and destinations leaving from La Coubre. Currently the station is only used for the bus lines for Cubans. To optimize the connection of the marina and ferry, it should be adapted to handle tourist buses like the Viazul as well.

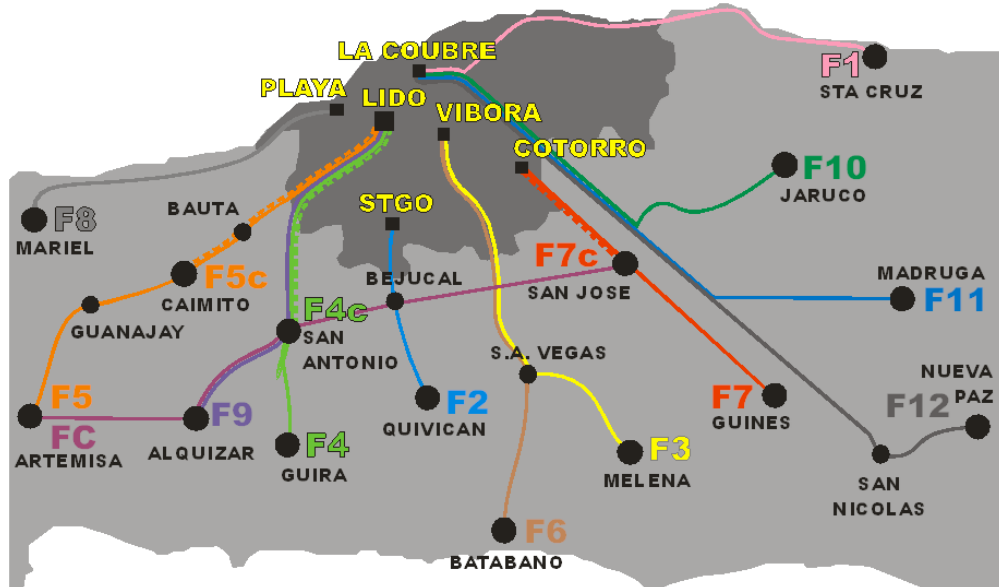


figure E.40 – regional bus lines

Since the bus network is being adapted at the moment and the current situation is vague, the change of the bus network is not included in this project. It is recommended to take the master plan of Tourist Port Havana into account when rearranging the bus lines.

E.4.3 TRAIN

The trains depart from the Central Station of Havana and go to the bigger cities in the country. The station holds seven platforms for passenger transport (and many more for freight) but the frequency of trains is low. The destinations are across the entire country, from Pinar del Rio to Santiago de Cuba. The rails are often in bad condition, as can be seen in figure E.41 on the left. This causes the trains to travel at low speeds and creates delays. Tourists are currently advised to avoid travelling by train, which is a waste of the high potential that passenger transportation via rail has.

To fulfil this potential, a lot of investments in the infrastructure have to be made. This is a very costly operation as the rails are deteriorated for many years. It is recommended to evaluate costs and benefits of these investments to find out if it is worthwhile to renovate the rail infrastructure. This is not done within this project since it is outside the perspective, but it could definitely increase the value of the marina and ferry terminal and the Tourist Port Havana master plan in general.



figure E.41 – bad condition of the rails (left) and low speed (right)

E.5 SAFETY

This paragraph discusses the traffic safety concerns in the project area. First the crash statistics of the period 2003-2008 are analysed to gain an idea of the locations with a high crash risk. Second, the principles of Sustainable Safety⁵ are applied on the current road layout to indicate possible safety improvements. This vision on traffic safety is developed by the Dutch SWOV Institute for Road Safety Research.

E.5.1 CRASH DATA

Crashes don't say everything about safety, as unsafe situations cause drivers to be extra cautious and a perceived sense of safety leads to more risk taking. But despite this psychological phenomenon of compensation, crashes are an important safety indicator.

The available crash data consists of the location of the crash, the number of crashes and sometimes the number of deaths, injured and the costs for material damage. But since this data is far from complete only the location and the number of crashes are used in this analysis. Since the data holds a huge amount of different locations that are not clearly sorted, only the roads that are relevant for the project are analysed. From the total number of 22.821 reported crashes in the province in these 5 years, only 358 crashes are used, which comes down to a humble 1,6%.

A possible error source is the naming of streets. For example, the Avenida del Puerto can also be referred to as Avenida Carlos Manuel Céspedes, Avenida San Paula de Pedro, Desamperados, Avenida la Pesquera or Primer Anillo del Puerto.

The data shows that, within the research area, most crashes occur at the intersection between Avenida del Puerto and Avenida de Belgica. The top 10 is shown in figure E.42. The nearby intersections of Jesus Lopez with Avenida del Puerto and Fabrica are on places 6 and 7, respectively. If they would be taken together, that would put them in first place by far. This is even without the crashes involving a train, as these are mentioned separately in place 5. This is done because of the sometimes unclear reference to the location. Some crashes are indicated at Arroyo and Linea de Ferrocarril, some at Jesus Lopez and Linea de Ferrocarril and some at Avenida del Puerto and Linea de Ferrocarril, of which the last is not an actual intersection. Most of these crashes probably have occurred at the intersection between Avenida del Puerto and Arroyo, as this notation has the larger part of the crashes with the train.

⁵ (www.sustainablesafey.nl)

table E.3 – top 10 crash locations between 2003 and 2008

	Location	Number of crashes
1	Avenida del Puerto and Avenida de Belgica	36
2	Fabrica and Via Blanca	32
2	Arroyo and Avenida de Mexico	32
4	Arroyo and Monte	29
5	Railway track ⁶	28
6	Fabrica and Jesus Lopez	23
7	Avenida del Puerto and Jesus Lopez	16
8	Avenida del Puerto and Arroyo	11
8	Avenida del Puerto and Plaza San Francisco de Assis	11
10	Arroyo between Mexico and Monte	10

Because only the project area and its surroundings are analysed, it is hard to say anything about the relativity of these numbers. These locations probably have the highest crash risk, but more exposure to risk could also be the cause of the higher crash rates. This is probably the case since the flows on main roads are bigger, but without data on the flows this cannot be analysed exactly. Nevertheless, the increase of safety at these locations could save the most lives and damage within the project area. This is especially important when looking at the future, when the traffic will increase and tourism will grow. Both these factors will increase the crash risk considerably as it will be more crowded on the road and tourist are not adapted to the Cuban way of driving. For the development of the port it is therefore important to include safety as a design factor.

⁶ There are two crossings of the railway track taken into account, at Avenida del Puerto and Arroyo and at Avenida del Puerto and Jesus Lopez. Often it remains unclear at which one the crash occurred. (It is indicated as Avenida del Puerto and Linea de Ferrocarril).



figure E.42 – top 10 crash locations

E.5.2 SUSTAINABLE SAFETY

From the five principles of Sustainable Safety only four are applicable for this analysis, as the fifth principle (i.e. State awareness) focuses on the road user and not the road itself. A brief description of the principles is given in table E.4.

table E.4 – the Five principles of Sustainable Safety (SWOV, 2006)

Sustainable Safety principle	Description
Functionality of roads	Mono-functionality of roads as either through roads, distributor roads or access roads, in a hierarchically structured road network
Homogeneity of mass and/or speed and direction	Equity in speed, directions and mass at medium and high speeds
Predictability of road course and road user behaviour by recognizable road design	Road environment and road user behaviour that support road user expectations through consistency and continuity in road design
Forgivingness of the environment and of road users	Injury limitation through a forgiving road environment and anticipation of road user behaviour
State awareness by the road user	Ability to assess one's task capability to handle the driving task

Functionality

The first principle of Sustainable Safety divides the functionality of a road into three categories; flow, distribution or access. Separating the flow function from the access function optimizes both these functions as there are no conflicts between them. Conflicts only occur on distributor roads, where there is an access function at the intersections and a flow function in between them. All the roads that are included in this analysis have a distribution function, although the Avenida del Puerto southwest from the intersection with Avenida de Belgica actually looks more like a through road. This section of the road has little intersections, which are not regulated. When it is busy on the road, which is currently not the case, the access function will be far from optimal.

Homogeneity

The second principle is Homogeneity, which comes down to the separation of speed, mass and direction. This limits the possibility of the most devastating crashes, namely the crashes with most kinetic energy difference between the two vehicles. For through roads this is done by separating mass and speed differences, so a high speed is possible. For access roads this separation is not possible, so speeds are reduced. Tingvall and Haworth (1999) propose safe speeds per conflict situation, as can be seen in table E.5. Currently the speed and mass are not optimally separated as cyclist, with low mass and speed, drive in the same lane as trucks and busses, having high mass and speed. But cyclists are quite rare and there is no cycling culture in Havana, so the question is if cycling paths should be implemented here. The advised speed for a distributor road in urban area is 50 km/h, but this presumes the availability of cycle paths. To reduce speed at intersections it is also possible to implement roundabouts or plateaus. Roundabouts with a proper curve can only be approached at low speed. The same holds for plateaus.

table E.5 – safe speeds in possible conflict situations (Vision Zero; An ethical approach to safety and mobility, 1999)

Road types combined with allowed road users	Safe speed (km/h)
Roads with possible conflicts between cars and unprotected road users	30
Intersections with possible transverse conflicts between cars	50
Roads with possible frontal conflicts between cars	70
Roads with no possible frontal or transverse conflicts between road users	>100

Speed signage is missing, but speeding is rare as most cars are just not able to do so. But the number of modern cars is developing, making the differences between cars bigger. Speed signage is therefore necessary to limit speed differences.

The separation of directions is done with a continuous yellow line between the lanes in opposite direction, which is sufficient for a distributor road with a maximum speed of 50 km/h.

Predictability

The predictability of the road contains two aspects; consistency and continuity. Consistency assures recognizable situations and continuity creates a predictable road course. These factors limit the possibilities for errors by effecting more routine behaviour and predictable behaviour of other road users.

To ensure a good predictability signing and lining on the road are essential. Lining should be clear to indicate the road course and transition between roads. Signing should indicate the maximum speed, as said above, the type of road users allowed and the allowed movements. Also directions should be indicated clearly to limit doubt and to assure drivers take the preferred route at once, keeping the cars on the road as short as possible.

Currently the lining is very vague and needs to be redone. Also the allowed movements and directions are often missing. The signing is absent in almost the entire area. Some existing signs are badly visible as they are places behind obstacles.

To ensure a predictable road layout the lining and signing should be consistent in the whole area, meaning the same lining and signing at all intersections and road sections. This will be increasingly important with the development of Tourist Port Havana since flows will increase and tourists are not adapted to the Cuban traffic.

Forgivingness (forgiving road environment)

The fourth principle is Forgivingness, containing both physical forgivingness of the road environment and social forgivingness towards other road users. For this analysis only the physical forgivingness of the road environment is relevant.

A forgiving road environment decreases the casualty risk of a crash. This is achieved by matted shoulders on the sides of the road, implementing required obstacle free zones and shield obstacles along the road.

Currently the environment is not very forgiving. Just next to the road there are many obstacles as streetlamps, parked cars and columns of the elevated railway track. But with a maximum speed of 50 km/h the risk is relatively low, so this is not a major problem. Nevertheless safety can be improved by shielding the obstacles along the road. Especially at the intersection between Avenida del Puerto and Arroyo the unshielded columns could be dangerous since the road crosses the

railway track at an angle. There is only one column marked at this intersection, but not very clearly. Furthermore, the parking spaces in between the two directions create a lot of movements from cars directly onto the faster lane. The passengers also have to cross the road, which creates many crossing pedestrians along the entire parking area. This is not the safest way of parking so an alternative way to include enough parking places in the area has to be thought of.



figure E.43 – marked column at the intersection between Avenida del Puerto and Arroyo

Concluding, the following concrete points can be applied or improved to increase safety:

- Clear maximum speeds
- Well-organized intersections with Avenida del Puerto
- Roundabouts or Plateaus to decrease speed at intersections
- Cycle paths or lanes
- Consistent lining, indicating;
 - Directions
 - Transition of roads
- Clear signage. Indicating;
 - Directions
 - Transition of roads
 - Maximum speed
 - Allowed movements
- Shielding obstacles along the road
- No parking in the middle of the road

In the variant study the optimal combination of these measures can be investigated. The main issues are the intersections, parking and the implementation of cycle paths.

E.6 EXPECTED DEVELOPMENT

In the absence of growth data, expectations have to be made in another way than by the use of economic models or similar models. This is done by working with different scenarios, based on several sources. This paragraph presents the outcomes of the complete analysis of tourism growth that can be found in 'Appendix D: Tourism analysis'. Furthermore it holds an estimation on the increase of car use and the expected changes on the road due to the implementation of the marina and ferry terminal.

E.6.1 TOURISM GROWTH

There are three scenarios on tourism growth distinguished in 'Appendix D: Tourism analysis', depending on the political developments in Cuba. These scenarios could be successive.

The first scenario considers no political changes and a stagnation of tourism growth at 5% per year. This leads to a total number of tourists between 3.5 and 4.0 million in 2020.

The second scenario assumes a raise of the embargo and no political changes. This leads to a slight increase of tourist numbers due to more tourists from the US. The total number of tourists in 2020 will then be between 4.0 and 4.5 million per year.

The third scenario considers the raise of the embargo and political changes in favour of tourism. This means foreign companies can invest in Cuba to develop tourism. This widens the bandwidth of the expectations since it is uncertain how this development will evolve. The moment of these changes is also a factor for the expectations. In this scenario tourism will grow considerably due to many tourists from the US, leading to a total number of tourists in 2020 between 7.0 and 9.0 million per year.

table E.6 – overview of scenarios on tourism growth

Scenario	Tourists in 2015 (millions)	Tourists in 2020 (millions)
1	3.0 – 3.5	3.5 – 4.0
2	3.5 – 4.0	4.0 – 4.5
3	3.5 – 4.0	7.0 – 9.0 ⁷

The general focus of the master plan Tourist Port Havana is to play an important role in the growth of tourism in Havana. In his study, Sanders (2002) finds a value of 500 000 tourists per year visiting Cuba by cruise and ferry. This is a cautious expectation taking the capacity of the cruise terminal into account. When the master plan is completed, Habana can receive four cruise ships at the same time, bringing a maximum of 10 000 tourists into Habana every day. The eventual contribution of Tourist Port Havana to the national tourism growth is nevertheless highly dependent on the execution of the project and extern factors. Therefore it is not preferable to couple the development of the traffic around the bay to tourist growth directly.

E.6.2 TRAFFIC GROWTH

The traffic growth in Cuba, specifically in Havana, is obviously very important for a design for the road layout around the marina and ferry terminal. Currently the car use is increasing rapidly. The Department of Roads of CUJAE University estimates the current traffic growth at 8% per year. This growth can be explained by several factors. Cubans are allowed to buy cars since 2012, but cars are still very hard to acquire and very expensive in Cuba, so this fact can only explain a part of the growth. Another probable factor is the increasing prosperity in Cuba, causing an increase in demand for fast transport and an increase of the trip rate. This is partly due to the increase of tourist activity, which is on itself another factor in the growth of car use. Car rental has become very popular with tourists and taxis flourish under the increase of tourism.

The car use is probable to continue growing for some time, since Cuba has a very low number of cars per capita: 21 per 1000 inhabitants in 2008 (World bank). This number is a few years old, and does not include recent developments. Furthermore

⁷ In case of political changes at least 5 years before.

the number in Havana, the capital, will of course be bigger than the national average. The Atlas of Havana (ETH Studio Basel, 2007) estimates the number of cars in the city of Havana at 45 per 1000 inhabitants, but states that half of them are not used daily because of the high fuel prices. But still this number indicates that the car availability in Cuba is substantially lower than in other Caribbean countries, as seen in table E.7. In the Caribbean only Nicaragua, one of the poorest countries in the Americas (World bank), has fewer cars per capita.

table E.7 – passenger cars per 1.000 inhabitants (World bank)

	2003	2004	2005	2006	2007	2008	2009	2010
Cuba						21		
Dominican Republic	70	66	71	75	79	84	87	
Haiti								
Jamaica	120	136	135	140			146	144
Bahamas, The								
Puerto Rico		568	565	596	614	608	582	621
Costa Rica	139	146			118	126	130	135
Nicaragua	16	18			17	18	18	17
Panama		77	78	82	85	98	97	102

Even though there is much space for growth, the car use will not grow with 8% for 50 years. That would lead to an increase of traffic with a factor 47, which is implausible. To estimate the car use it could be related to the trip rate, the car availability and the population growth. (Most of the infrastructure is of poor quality but infrastructure quality and availability don't seem to be a factor yet.) Cuba's population growth is negative since 2008, bringing the population in 2011 at the same number as in 2005. Car availability can be compared to similar countries as Cuba. While most well developed countries have between 500 and 600 cars per 1.000 inhabitants, countries like Jamaica and Costa Rica, with a car rate going towards 150, seem to be a better reference for a 50 year horizon. On car trip rate there is no data on the current situation, making growth-factor estimation impossible.

table E.8 – population growth in the Caribbean

	2003	2004	2005	2006	2007	2008	2009	2010	2011
Cuba	11,208,029	0.24	0.17	0.10	0.03	-0.02	-0.04	-0.04	-0.04
Dominican Republic	8,995,398	1.50	1.47	1.45	1.42	1.40	1.36	1.33	1.30
Haiti	9,075,399	1.51	1.46	1.41	1.36	1.33	1.31	1.31	1.31
Jamaica	2,625,700	0.47	0.47	0.48	0.48	0.43	0.31	0.25	0.26
Bahamas, The	310,201	1.46	1.47	1.47	1.48	1.46	1.41	1.34	1.25
Puerto Rico	3,826,095	0.02	-0.14	-0.42	-0.58	-0.58	-0.54	-0.49	-0.41
Costa Rica	4,160,438	1.81	1.74	1.68	1.62	1.56	1.52	1.48	1.45
Nicaragua	5,288,271	1.28	1.28	1.28	1.28	1.29	1.32	1.36	1.41
Panama	3,125,565	1.80	1.77	1.74	1.70	1.67	1.63	1.59	1.55

Without this data an assumption has to be made for the expected generated traffic. The Department of Roads estimates the average growth over 50 years to be far lower than the actual growth of 8%, i.e. at 1.5%. This leads to an increase with a factor 2 over 50 years, which seems to be a bit conservative considering the current

growth. This also implies a constant growth that underestimates the growth in the first years. To give a better estimation of the near future the growth could be assumed as an exponential or a top-lognormal function. The parameters can then be taken in a way that the growth over 50 years is equal to the expectation of the Roads Department of CUJAE. These options are shown in table E.9, where the growth is applied on the biggest peak hour in the current situation (1 865 VE, from Havana Vieja onto the intersection between Avenida del Puerto and Arroyo)

table E.9 – growth functions and parameters

	Function	a	b	c
Exponential	$f_{ab}(t) = a * e^{b*t}$	0.08	-0.09	-
Top-lognormal 1	$f_{abc}(t) = a * e^{(b*\ln^2(\frac{t}{c}))}$	0.08	-1.0	5
Top-lognormal 2	$f_{abc}(t) = a * e^{(b*\ln^2(\frac{t}{c}))}$	0.10	-1.3	5

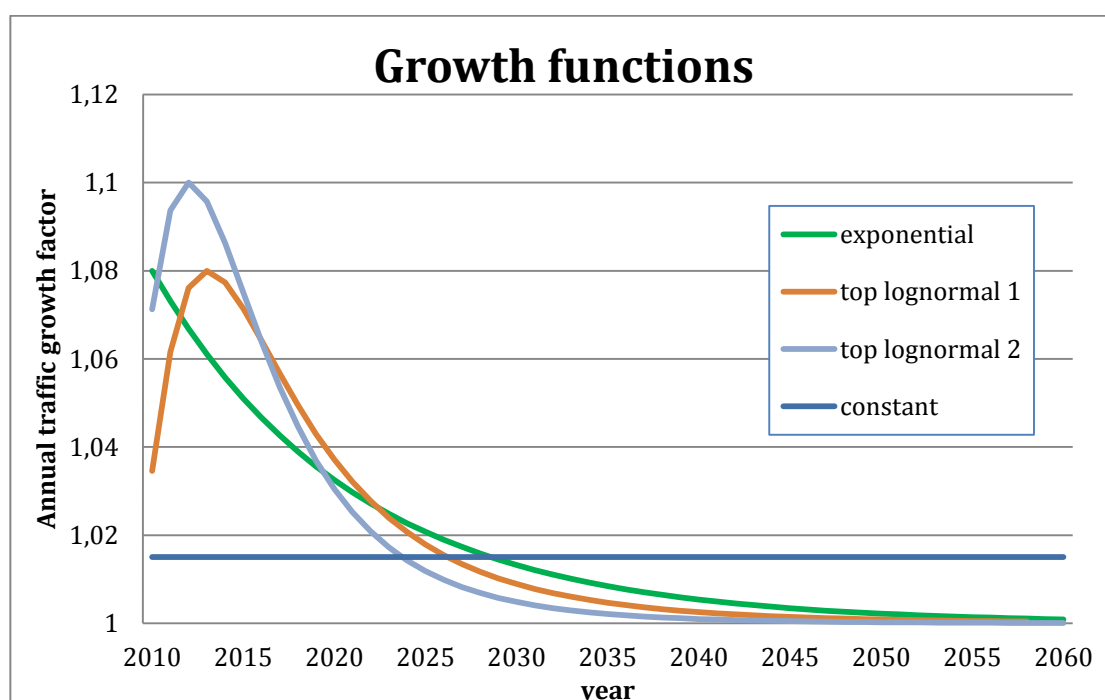


figure E.44 – growth functions

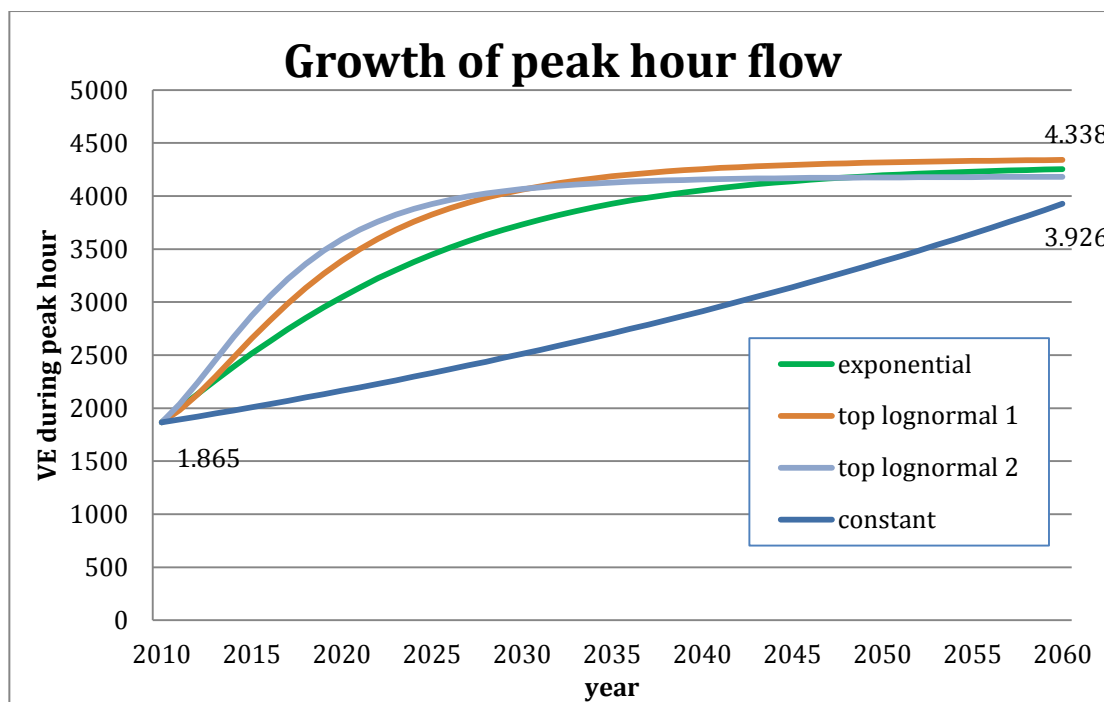


figure E.45 – growth of the peak hour flow

The second top lognormal function is used for the estimation as it is the best fit for the current situation and the expectation for 2060 from the CUJAE Department of Roads. table E.10 shows the estimations for the totals per intersection and their busiest direction. It is clear that the growth is immense. If a capacity of 1.549 VE is assumed, the roads will be able to handle this growth except for the 2 lanes from Havana Vieja towards the intersection between Avenida del Puerto and Arroyo. The intersections, however, are not able to handle this growth. Regular two-lane roundabouts have a maximum capacity of 2 400 VE per hour (Nes, et al., 2007). The capacity of junctions with traffic light is dependent on the number of lanes downstream and the waiting capacity at the intersection. Furthermore the green times are of importance to divide the capacity over the flows. From the estimated peaks in 2060 is it clear that the intersection between Avenida del Puerto and Arroyo and the intersection between Fabrica and Jesus Lopez will have capacity problems if the layout will not be changed.

table E.10 – estimated flows at intersections

location	direction with largest flow	Largest flow (VE)	Estimated flow in 2060 (VE)	Peak at intersection (VE)	Estimated peak at 2060 (VE)
1	From Habana Vieja	1.865	4.181	3.158	7.024
2	From Havana Vieja	1.350	3.003	2.475	5.505
3	Fabrica towards Arroyo	1.610	3.581	4.092	9.101

E.6.3 MARINA

The marina will hold 270 yachts, of which not every yacht owner will have a car available in Havana. Even if it is assumed that the marina will attract one personal car per yacht, the total traffic generated is still very small in comparison to the regular traffic. The cars leaving and arriving at the marina will also be spread out

over the day, making the flow from and to the marina negligible for the intensity over capacity (I/C) ratio.

The marina does have to be connected to the road network properly. This extra connection will influence the flows on the through road as the turning traffic will hinder the through traffic. In the design for this connection this effect has to be minimized.

Furthermore the marina has to be accessible for tankers and trucks for the provision of the marina. These vehicles need a separate access route to the marina, which allows them to turn. This is required so tankers can enter backwards and supply the supply pier with fuel.

E.6.4 FERRY TERMINAL

The ferry terminal will attract larger traffic flows in comparison to the marina. When a ferry arrives all passengers need to be able to leave the ferry terminal fast and smoothly. A departing ferry will also attract traffic as passengers will arrive at the terminal. The departing passengers will be more scattered over time compared to the arriving passengers. On the other hand arriving passengers will first need to go through the customs procedure, spreading the peak flow.

Traffic due to departures

The maximum number of arriving passengers is 660 people and 50 cars per ferry. Since many passengers will not travel alone on the ferry, the average number of passengers per arriving car is assumed to be one and a half. This means that 420 cars will arrive at the terminal in the time before departure. The distribution of these cars is assumed to be 50% in in the hour before departure and the other 50% the hours before that. The 210 cars per hour that will arrive in these conditions are relatively small compared to the regular traffic in this area, but it could become a factor of importance in the peak hours on the Avenida del Puerto. If the distribution would be less favourable, this would increase the capacity problems that could occur.

Some passengers will arrive by car, which they leave at the terminal. Others will be brought to the terminal by a taxi or by a friend of family. If a larger group of tourist will be travelling with the ferry, they could also be dropped off by a bus. Lastly, there is the group that takes the car onto the ferry. For these groups of travellers the functions listed below need to be available at the departure terminal.

Required functions outside the departures terminal:

- Short stay parking
- Long stay parking
- Drop off location for taxis and busses
- Pedestrian crossings
- Access route to the ferry for vehicles to be transported
- Customs services

Traffic due to arrivals

The expected number of arriving passengers is assumed equal to the departing passengers; 660 people and 50 cars per ferry. Many of these passengers will leave the terminal as fast as possible, but with sufficient facilities a considerable number will stick around in the terminal building. It is assumed that 70% of the arriving passengers will leave the terminal within the hour. The remaining 30% will leave in the next hours. Ferries arriving at the same time should be avoided in scheduling

when the intensity of the terminal itself or the road network is close to the capacity at that moment. This might be a problem when more ferries want to arrive in Havana during the morning peak.

The 50 cars are estimated to transport 100 of the 660 passengers. Thus the major part of the passengers will need follow-up-transport from the terminal to their destination. Some of the passengers will be picked up at the terminal by family or friends so short stay parking must be available. The rest of the passengers depend on taxis and busses for transport.

Required functions outside the departures terminal:

- Short stay parking
- Taxi stands
- Bus stands
- Pedestrian crossings
- Exit route from the ferry for transported vehicles
- Customs services

E.7 BOTTLENECKS IN THE NETWORK AROUND THE BAY

This paragraph covers the problems of traffic, found in the project area. The problems are divided into two categories; Intersections and Bottlenecks. The analysis of these conflict situations is done for the current situation, but with eyes on the future, in order to find the transport problems that will have to be resolved when designing the marina and ferry terminal. table E.11 lists the problems in both categories.

table E.11 – overview of bottlenecks

Intersections	Bottlenecks
Avenida del Puerto - Arroyo	Avenida del Puerto at Marina and Ferry
Avenida del Puerto – Jesus Lopez	Avenida del Puerto at Sierra Measta
Avenida del Puerto – Avenida de Belgica	Avenida de Belgica
Fabrica – Jesus Lopez	Arsenal
Avenida de Belgica – Arsenal	Paseo de Marti
Avenida de Belgica – Simon Bolivar – Avenida de Misiones	
Maximo Gomez – Simon Bolivar – Paseo de Marti	

E.7.1 ROADS

Avenida del Puerto at marina and ferry terminal

To connect the marina and the ferry terminal to the road network, the infrastructure will have to be adapted. Currently there is only road along this part of the bay, without any substantial connections from the bay side except a driveway to a dock. The new facilities will attract people and thus traffic, which has to spread out on the network. The development of new traffic at the marina and ferry terminal is discussed extensively in paragraph E.6.

The main focus of the infrastructure part of the project is to optimize this connection of the marina and ferry to the network. This means that this part of the

bay should be easily accessible and arriving passengers are able to leave the harbour smoothly, without holdups.

Avenida del Puerto at Sierra Meastra

As is stated before, this part of the Avenida del Puerto is a major bottleneck with only one lane per direction. The plans of Tourist Port Havana leave space to design a new road layout together with other facilities as a bus stop, taxi stand and tourist facilities. Right next to the cruise terminal and Plaza San Fransisco de Assis, large pedestrian flows can be expected. This will be of big influence on the flow function of the road and therefore it is indicated as the main problem for this location.

The situation at the cruise terminal Sierra Meastra can also be used as a reference from the marina and ferry terminal. Although the scale will be smaller than Sierra Measta, consistency in the design will increase clarity for road users and improve safety.

Avenida de Belgica

The Avenida de Belgica is currently indicated as main road, but can't live up to that status as it is occupied by parked cars and containers on several spots. Nowadays this doesn't cause big problems since it is quite calm regarding traffic. But the development of the bay will attract more traffic. This increase is probable to cause congestion on this part of the network, since it is one of the two roads around Habana Vieja and the direct connection to Paseo de Marti (with the Capitolio) and Avenida Simon Bolivar. The one-way part of the street makes traffic in the direction of the bay dependent on the streets Agramonte and Arsenal, not an ideal situation concerning the flow of through traffic.

Arsenal

The main problem of the road Arsenal is the poor connection to the network. Both sides of this short road along the train station end on a relatively small road. This road could be of importance in the Tourist Port Havana master plan as connection to the train station, but also as tourist attraction, with the Arsenal on the old city wall, the old train locomotives and the building of the Central Station. But as said before, the adaption of the train station is not part of this project, even though it is recommended to include in the bigger master plan Tourist Port Havana.

Paseo de Marti

The Paseo de Marti is one of the main roads for tourists, leading from La Punta along the Capitolio and Habana Vieja to Avenida Simon Bolivar and Maximo Gomez. The increasing focus on tourism in Havana, with an important role for the Tourist Port Havana plan, will magnify the role of this road in the network. The functioning of this road is far from optimal in the current situation as many taxis and buses park on the outer lanes. Furthermore the interaction with Agramonte and Avenida de Misiones is lacking. Those one-way streets parallel to Paseo de Marti are much less crowded while they have the same function.

This part of the network, just as the train station area, will not be included in this project, as it is more a general problem of the city and the master plan than a problem of the marina or ferry terminal.

E.7.2 INTERSECTIONS

Intersection Avenida del Puerto and Arroyo

This intersection at the south west corner of the bay is an important one for the connection between the Avenida del Puerto and the main roads Maximo Gomez and Avenida de Mexico. It is next to the area that is planned to accommodate the marina and ferry terminal in the master plan Tourist Port Havana. This intersection should therefore be tuned to the new situation. Limiting factors at this point are the railway tracks, one at ground level and one elevated. The rails at ground level bring the risk of train collisions, while the elevated track has two columns every twenty meter. Gates and lighting to warn for this intersection are both absent. For those reasons this intersection is an essential part of the connection between the marina and ferry with the city of Havana.

Avenida del Puerto and Avenida de Belgica

The second intersection at Avenida del Puerto, the first one north of Arroyo, is the connection to Avenida de Belgica. This road leads north along the Havana Vieja quarter, a significant destination from the port because of its huge tourist attraction, in the direction of the Capitolio, another tourist magnet. The problem here is not a railway line but consists of two parts of the old city wall, limiting the available space quite rigidly. Together with the two already mentioned, these three intersections form the main connection of the project area to the road network of Havana. Therefore it is essential to adjust these intersections to the changes in demand that will be caused by the development of the harbour

Avenida del Puerto and Jesus Lopez

A little more south along the Avenida del Puerto, the connection with Jesus Lopez is another important intersection with the main road network of Havana. Jesus Lopez leads to the Via Blanca, a major road for the southern part of Havana. At this point there is no elevated railway track anymore, only a track at ground level, but it is very close to the intersection itself. This can be a dangerous combination, also because there are no traffic lights on this big square of asphalt. There is a tower next to the crossing from where surveillance is controlled with an alarm bell when a train is approaching. Just as the intersection with Arroyo, this intersection is an important one for opening up the Tourist Port Havana area, especially for the marina and ferry, which are very close.

Fabrica and Jesus Lopez

This intersection between Fabrica, that runs parallel to the Avenida del Puerto, and Jesus Lopez is really close to the intersection between Avenida del Puerto and Jesus Lopez. It is just on the other side of the railway track. Fabrica and Jesus Lopez have the same function, namely connecting to the Via Blanca. Therefore these intersections should not be designed apart, but should be adjusted to each other.

Avenida de Belgica and Arsenal

North of the train station Arsenal intersects to Avenida de Belgica. This is an important intersection because of the connection with the train station. With the development of the port as an international harbour, the train station will become increasingly important as transport hub to the rest of the country. The development of the train station as transport hub of Havana is no part of this project. Therefore this intersection will be left out of the design for the connection of the marina and ferry terminal. To fully exploit the development of the port it is recommended to

include the train station and its surroundings in the Tourist Port Havana master plan.

Avenida de Belgica – Simon Bolivar – Avenida de Misiones

This intersection of the Avenida de Belgica and Simon Bolivar, where the Avenida de Belgica continues as one way street under the name of Avenida de Misiones, is an important intersection for the connection with the north-eastern part of Havana. Currently this is only a small intersection, but it will become more important as the port will develop and with it the train station. This intersection does not fit in the design range for this project, as it is more a problem of the city network and not of the marina and ferry terminal or the Tourist Port Havana master plan.

Maximo Gomez – Simon Bolivar – Paseo de Marti

As for the previous intersection, this one will experience an increase of traffic due to the development of the port as tourist centre. It already is a source of congestion nowadays, so it is recommended to update this complicated junction, taking into account the developments of the port.

E.8 CONCLUSIONS

From this analysis it is clear that the current traffic is not a measure for the design of the road layout. At the moment the roads in the project area are very quiet, but with the current growth of traffic at 8% per year this will change rapidly. The flows will be doubled in about ten years. But the growth will flatten out eventually, bringing the estimated peak hour flows just above 4 000 VE in 2060. This is of course an estimation, depending on many factors that are uncertain or unknown at this moment. The valuation of the Department of Roads of CUJAE University is leading in this case since their experience in Havana is expert.

The current road layout is not prepared to handle this growth at several locations. The bottlenecks that are identified are listed in table E.11. From these bottlenecks the most relevant for this project are:

- Intersection Avenida del Puerto and Avenida de Belgica
- Intersection Avenida del Puerto and Arroyo
- Avenida del Puerto at Sierra Meastra

The intersection between Avenida del Puerto and Avenida de Belgica is near the entrance of the marina. This roundabout has the most crashes in the project area, from this it can be concluded there is a road safety problem at this location. With the expected growth of traffic and the extra connection of the marina, this problem will only increase. Therefore measures have to be taken to increase safety at this point. The parts of the old city wall in the centre and next to the roundabout are a limiting factor in this location.

The intersection between Avenida del Puerto and Arroyo is near the entrance of the ferry terminal. Here the connection is hindered by two railway tracks, one on ground level and one elevated. This connection is essential to the main network of the city of Havana. Currently it is a very unclear intersection, which will become a problem with increasing flows and more tourists driving in the area.

The Avenida del Puerto at the Sierra Meastra cruise terminal currently only has one lane per direction, making this the bottleneck of the Avenida del Puerto. All along the bay the Avenida del Puerto has at least two lanes per direction, creating a major capacity drop at this point. Furthermore this location also has to contain a lot of other functions as it is located between the cruise terminal and Plaza San Francisco de Assis. The parking area in front of the terminal will be moved inside the middle pier, creating space for functions as a bus stop, pedestrian crossings, tourist information, stalls for food and drinks etcetera.

For these three locations a design has to be made to ensure a good connection of the marina and ferry terminal to the network of Havana. The other nine bottlenecks are advised to take into consideration in the coordinating master plan of Tourist Port Havana but are not direct problems following from the construction of the marina and ferry terminal. The design criteria for these locations hold functional and spatial requirements as well as the intern and extern boundary conditions. These criteria can be found separately in 'Appendix L: Boundary conditions and design requirements'.

Appendix F: ANALYSIS OF EXISTING PORT INFRASTRUCTURE AND FACILITIES

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F.1 INTRODUCTION

The Bay of Havana is currently used for mainly commercial purposes. Therefore, port infrastructure is already available on the location of the future marina and the ferry terminal. These existing facilities can be reused in the design, although the condition of these facilities differs. The dimensions and the current state of the existing port infrastructure are therefore elaborated upon in this appendix.

F.2 PORT OF HAVANA

The Bay of Havana can be divided in three parts: Ensenada de Marimelena, Ensenada de Guasabacoa and Ensenada de Atarés. These three basins are connected with the Straits of Florida by the entrance channel, as can be seen in figure F.1. The Port of Havana is a so-called service port, in which the government owns the land as well as the equipment and provides all services.

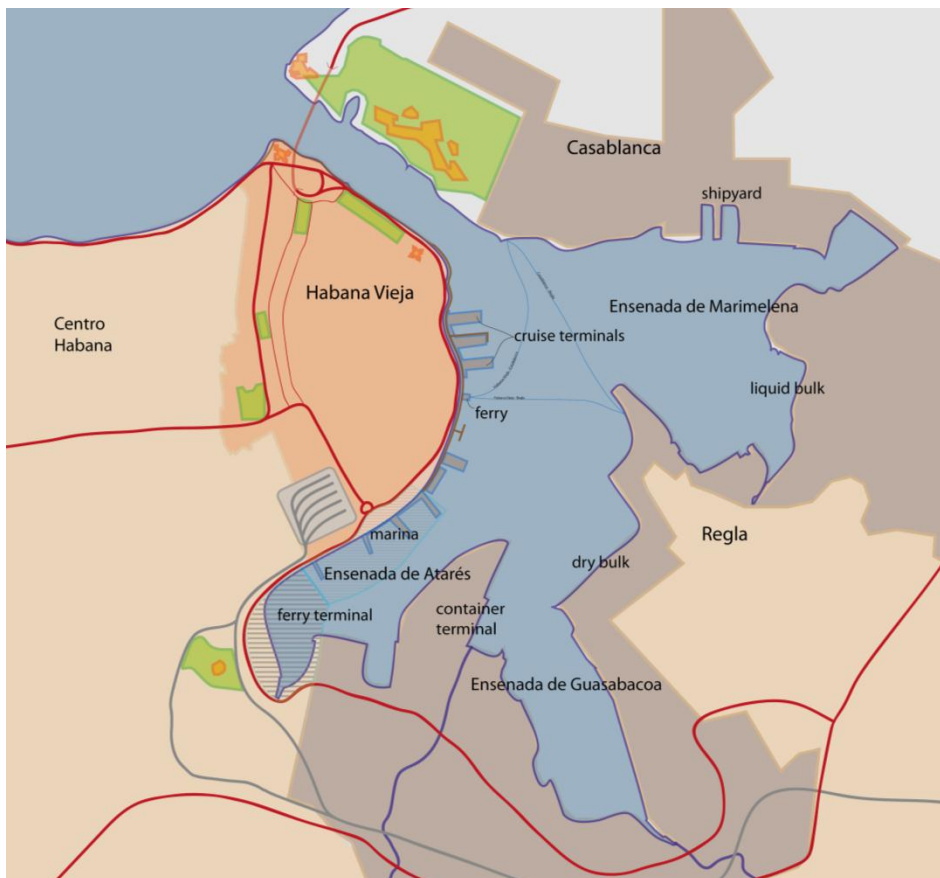


figure F.1 – map of the Port of Havana, north is up

F.2.1 ENTRANCE CHANNEL

The entrance channel has a length of 1530 m with an orientation of 124°. The minimum and maximum width is 220 m and 330 m respectively. The maximum depth of the entrance channel is limited by the tunnel beneath the channel, constructed at a depth of 12.8 m, see figure F.2. According to the current legislation, the maximum draught and length of ships passing the channel therefore is 11.43 m and 270 m respectively. A draught of 11.58 m is allowed with a tidal elevation of at least 0.2 m. This depth is maintained in the bay until the entrances of the three basins, as can be seen in figure F.3. Shipping manoeuvres inside the bay, including the exit or entrance of the channel, are prohibited with winds higher than 5 Bft. The maximum speed of vessels in the bay is 6 kn.

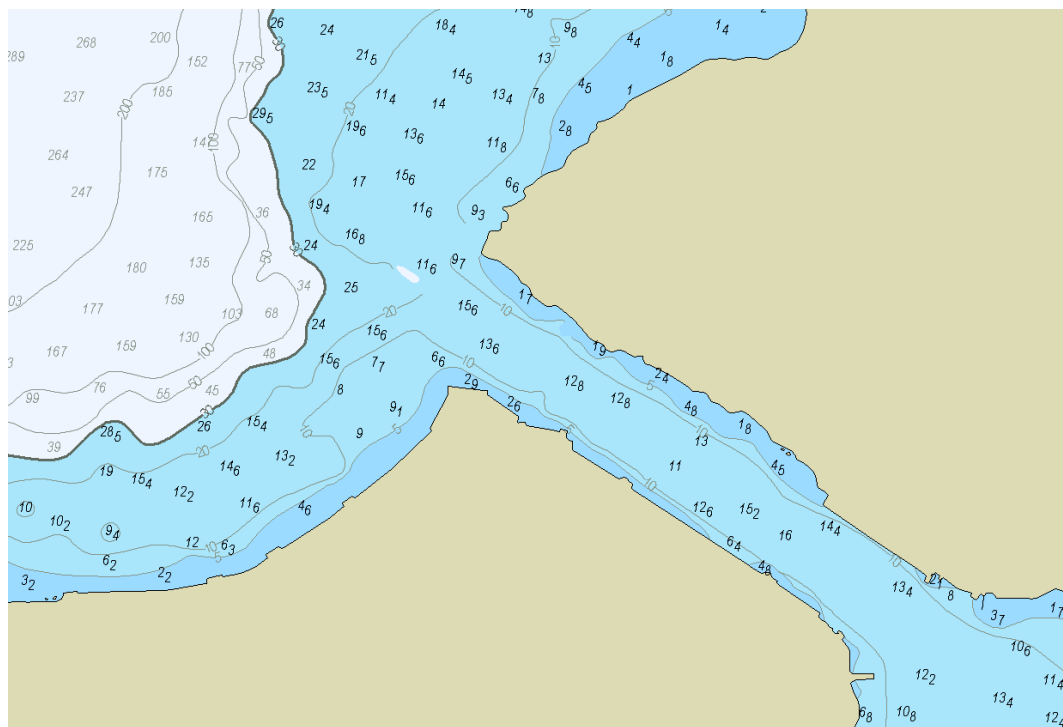


figure F.2 – depth chart of the entrance channel to the Bay of Havana

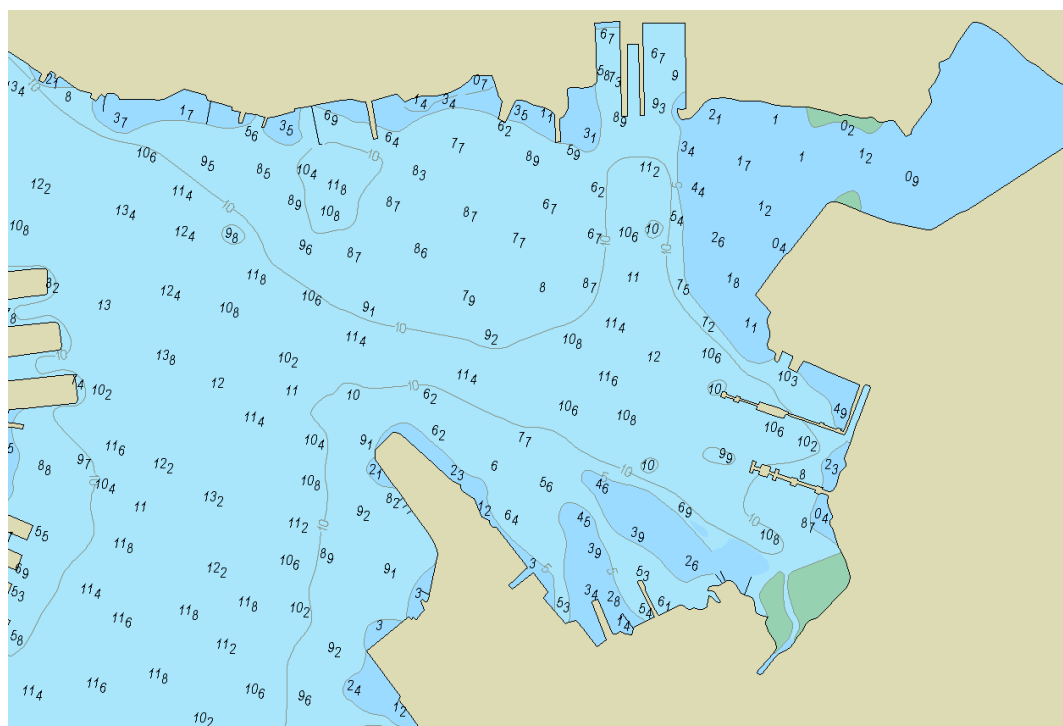


figure F.3 – depth chart of the Bay of Havana

F.2.2 BASINS

In the Ensenada de Marimelena are a shipyard and the liquid bulk terminal ‘Nico Lopez’ situated. The basin has a depth of 10 m at the terminal and 6.7 m at the shipyard. Liquid bulk carriers of no less than 47 000 DWT are reported to have been moored at the petroleum terminal (Valle Benero, 2013).

Three terminals are located in the Ensenada de Guasabacoa: the dry bulk terminals ‘Turcios Lima’ and ‘José A. Echavarría’ and the container terminal ‘TCH’. The

maximum length and draught of ships in this basin are 250 m and 9.75 m respectively.

The Ensenada de Atarés takes up the entire western part of the bay and consists mainly of the future Tourist Port Havana.

Cruise terminal Sierra Maestra

The cruise terminal will have four berths for ships with a maximum length and draught of 245 m and 9 m respectively.

Regional ferry terminal Emboque de Luz

The ferry service has six ferries of 150 BHP in use. Sailing times from one station to the other varies from six to seven minutes. Almost 13 000 persons are transported every day on average.

F.3 FUTURE MARINA AND FERRY TERMINAL

The south-western part of the Ensenada de Atarés will be the location of the marina and ferry terminal, although it is currently used for commercial purposes. The dimensions of the different piers, as depicted in figure F.4, are given below.

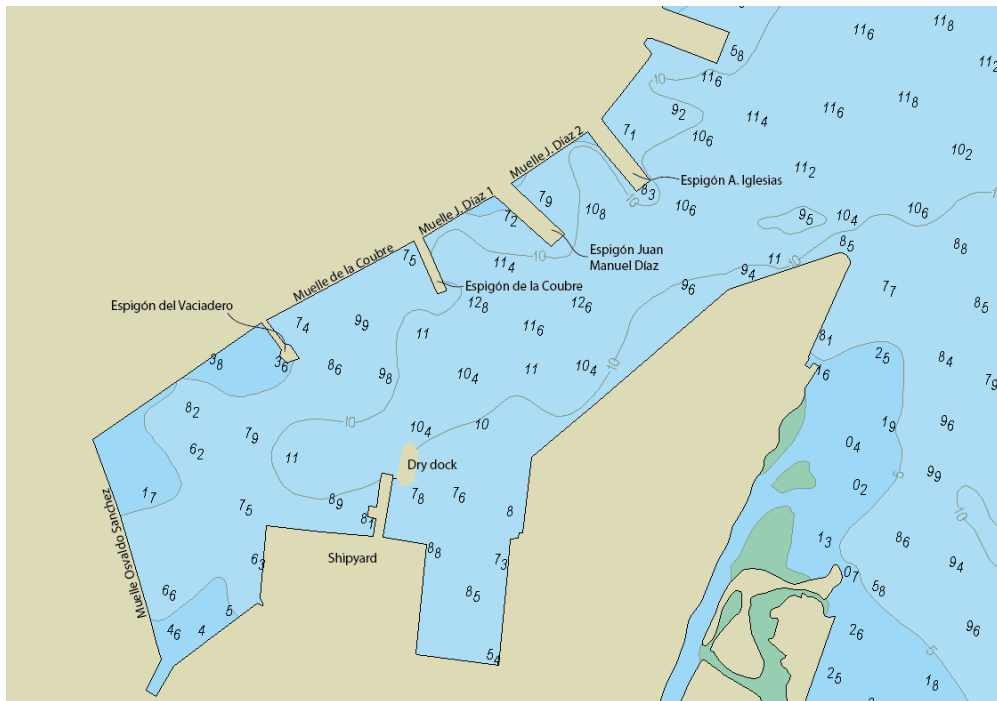


figure F.4 – depth chart of Ensenada de Atarés

Espigón Aracelio Iglesias

Orientation:	142° - 322°
Length:	155 m
Width:	30 m
Maximum draught:	a minimum water depth of 8.3 m
Current status:	Closed for security reasons, see figure F.5.



figure F.5 – the Espigón Aracelio Iglesias as seen from the Almacén San Jose (02/09/2013)

Muelle Juan Manuel Díaz no. 2

Orientation: 55° - 235°
 Length: 187 m
 Width: 20 m
 Maximum draught: 6.40 m
 Current status: Operational for commercial purposes

Espigón Juan Manuel Díaz

Orientation: 131° - 311°
 Length: 150 m
 Width: 40 m
 Maximum draught: 7.60 m, first 15 m of pier limited draught of 3.80 m
 Current status: Operational for commercial purposes

Muelle Juan Manuel Díaz no. 1

Orientation: 59° - 239°
 Length: 147 m
 Width: 10 m
 Maximum draught: 5.00 m
 Current status: Operational for commercial purposes, see figure F.13.

Espigón de la Coubre

Orientation: 156° - 336°
 Length: 130 m
 Width: 15 m
 Maximum draught: A minimum water depth of 7.5 m
 Current status: Closed for security reasons, see figure F.6.



figure F.6 – Espigón de la Coubre

Muelle de la Coubre:

Orientation:	62° - 242°
Length:	330 m
Width:	6 m
Maximum draught:	A water depth of 7.5 m
Current status:	Operational for commercial purposes

Espigón del Vaciadero

Orientation:	145°-325°
Length:	95 m
Width:	8 m
Maximum draught:	A depth of 7.4 m at the east side, 3.6 m at the west side.
Current status:	Dilapidated, closed for security reasons (see figure F.7)



figure F.7 – the dilapidated state of Espigón del Vaciadero (02/09/2013)

Continuation of Muelle de la Coubre:

Orientation:	56° - 236°
Length:	375 m
Width:	7 m
Maximum draught:	a depth of 3.8 m at the east side and 2 m at the west side.
Current status:	Partly operational for commercial purposes, not well maintained, see figure F.8 and figure F.9.



figure F.8 – the current state of a part of the Muelle de la Coubre (03/02/2013)



figure F.9 – the Muelle de la Coubre (03/02/2013)

Muelle Osvaldo Sanchez

Orientation:	163° - 343°
Length:	420 m quay, 485 m total
Width:	25 m
Maximum draught:	2.70 m, after 150 meter a length of 50 meter with a limited draught of 0.60 m
Current status:	Operational for commercial purposes

The interior channel in the basin can be seen as 1250 m long and about 270 m wide, as can be seen in figure F.10. Closer to the Muelle Osvaldo Sanchez the channel is narrowed by the shipyard and the dry dock.

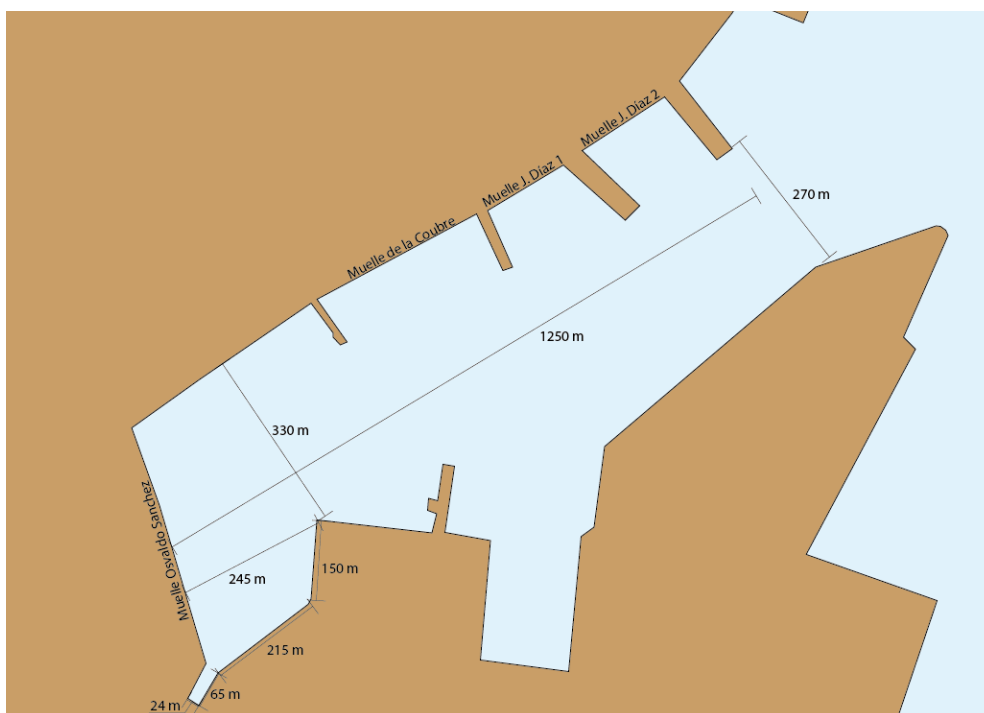


figure F.10 – dimensions of Ensenada de Atarés

F.4 ON-LAND FACILITIES

The terminals are currently dedicated to cargo handling and storage. The existing on-land facilities are therefore built with a commercial purpose. A satellite view of the basin is given in figure F.11, with an enlargement of the area of the future marina in figure F.12.



figure F.11 – satellite image of the Ensenada de Atarés (source: Google Maps)

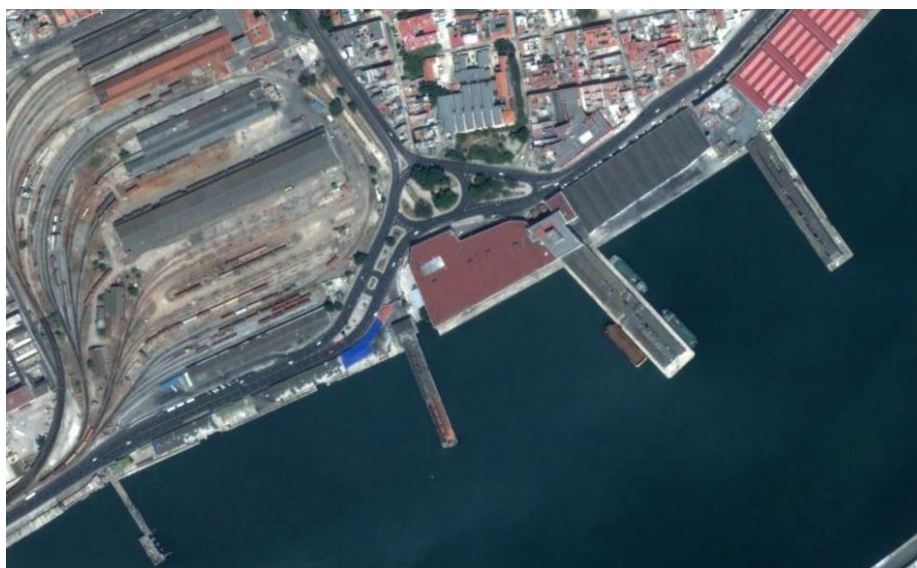


figure F.12 – satellite image of the terminals around La Coubre (source: Google Earth)

All buildings and facilities on the aprons may be rearranged and reused for marina purposes. This specification is interesting to possibly save costs and cultural-historical values. ‘Appendix B: Stakeholder analysis’ shows the companies that are housed in the current buildings can be relocated.

F.4.1 MUELLE JUAN MANUEL DÍAZ NO. 2

A warehouse is located on the quay with an area of 150x55 m². The warehouse is in a reasonable to good state, see figure F.13, and is located directly on the Desamparados street.

Just east of this warehouse, a building is located that currently accommodates the organization ‘Hines’, see figure F.14. The area of this building is 45x25 m² and is located directly in front of the Espigón Aracelio Iglesias.



figure F.13 – terminal Juan Manuel Díaz no. 2



figure F.14 – the Hines building with left the Almacén San José

F.4.2 MUELLE JUAN MANUEL DÍAZ NO. 1

This terminal consists of a four stories building with an area of about 170x70 m² and makes up the entrance to the Espigón Juan Manuel Díaz. The building is in a reasonable state, see figure F.15 and figure F.16.



figure F.15 – the street side of the terminal Díaz no. 1 with left a part of the warehouse of Díaz no. 2 (03/02/2013)



figure F.16 – the south-western side of the terminal Díaz no.1 (03/02/2013)

F.4.3 MUELLE DE LA COUBRE

Multiple relatively small buildings are located on the terrain. The entrance to the pier consists of an entrance gate and a building of about 20x15 m², see . This is the location of the disaster of the French freighter 'La Coubre', which exploded during the unloading of 75 tons of ammunition in March 1960. An estimated 100 people were killed in the attack that is often attributed to the CIA, who wanted to overthrow the new government of Fidel Castro (Fursenko, et al., 1998). Multiple memorials of the disaster were erected: the memorial tablet, which commemorates all victims, is located next to the entrance and a fountain and some remains of the ship are located on the refuge on the road, see figure F.18. On the quay itself, two small warehouses of about 80x15 m² are located. This part is separated from the road by a wall with a height of about 3 m. To the direction of the Espigón del Vaciadero the conditions of the facilities worsen, see figure F.8 and figure F.19. South-west of the Espigón del Vaciadero, the wall changes in a fence, see figure F.9. No more facilities are located on the quay until the Muelle Osvaldo Sanchez.



figure F.17 – the entrance to Terminal La Coubre with left the memorial tablet (03/02/2013)



figure F.18 – the fountain and the remains in front of the Espigón de la Coubre (03/02/2013)



figure F.19 – the remains of structures on the Muelle de la Coubre (03/02/2013)



figure F.20 – the two small warehouses on the Muelle de la Coubre (03/02/2013)



figure F.21 – the wall of the Muelle de la Coubre, with the entrance to the pier (03/02/2013)

F.4.4 MUELLE OSVALDO SANCHEZ

Multiple buildings, warehouses and a factory are located at this terminal, see figure F.22 and figure F.23. The conditions of the facilities are reasonable. The total area of the terminal is estimated to be about 5.5 hectares. Half of the area is occupied by buildings that are in a reasonable state.

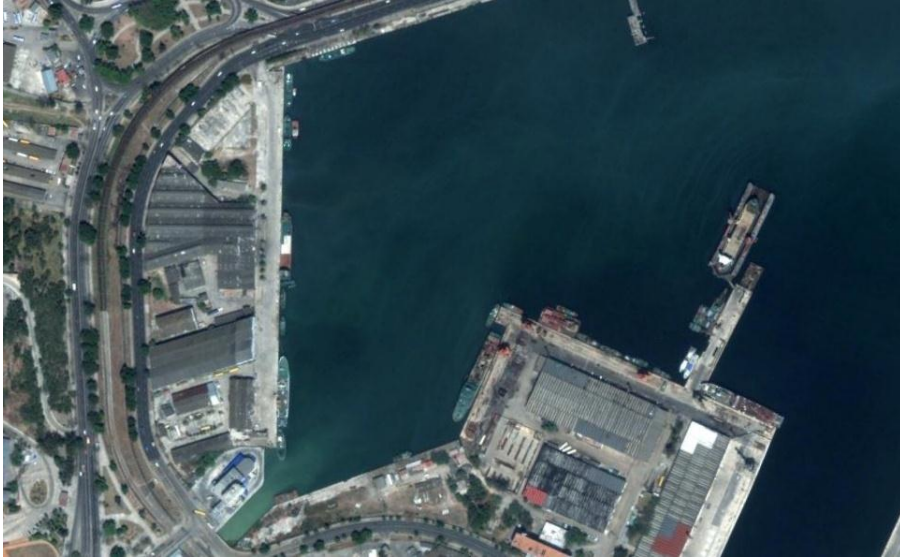


figure F.22 – satellite image of the Muelle Osvaldo Sanchez



figure F.23 – several facilities at the Muelle Osvaldo Sanchez (03/02/2013)

Appendix G: NAUTICAL ANALYSIS

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G.1 INTRODUCTION

The project 'Tourist Port Havana' will cause an expected increase in the traffic intensity in the Bay of Havana. Not only in the number of vessels, but also in the variety of types of vessels. The consequences of this growth are discussed in this appendix.

First, the to be expected vessels are given with the dimensions of a typical or normative vessel, after which the capacity of the Bay of Havana is given. Subsequently, the current intensity of traffic and the expected future growth, which also depends on other ports in the country, are discussed. Finally, the waves and currents generated by a vessel are given.

G.2 VESSEL DIMENSIONS

Different types of vessels will be sailing in the Bay of Havana. The dimensions of a typical or normative vessel are given below. When a name is indicated, the dimensions are of this particular vessel.

Cargo ships

General cargo ship:	170x25x9 m ³
Dry bulk carrier:	160x22x9 m ³
Liquid bulk carrier:	150x22x9 m ³

Service boats

Tug boat:	28.7x10.4x4.8 m ³ (Damen ASD Tug 2810 "Paramaconi", see figure G.1)
Pilot boat:	15.2x4.5x1.2 m ³ (Damen Stan Tender 1504)



figure G.1 – Damen ASD Tug 2810 "Paramaconi"

G.2.1 PASSENGER SHIPS

The maximum dimensions of a cruise ship are limited by the length of the pier of the cruise terminal. The maximum length of a ship the terminal can accommodate is 245 m, so an example of a normative vessel is the "MS Zaandam" with dimensions of 237x32.3x8.1 m³.

Typical dimensions of a regional ferry vessel are 30x10x1 m³.

Considering the sailing times to the international ferry destinations as depicted in 'Appendix A: General perspective of Tourist Port Havana', a ropax (roll-on/roll-off passenger) ferry with a cruise velocity of about 15 kn seems only feasible as an overnight trip to Key West. An example of a small Ropax ferry, suitable for the early stages, is the Damen Ropax 6013 with dimensions of 60.8x12.9x1.8 m³ and a capacity of 350 passengers and 24 cars.

It is however recommended that a fast ropax ferry should be used for the international ferry service. With a top velocity of about 35 kn, a daily connection with Miami and Key West are feasible solutions. With a travel time of about four hours between Havana and Key West, it is even possible to have a service twice a day, one in the morning and one in the evening. Two examples of a fast ferry are given below.

Damen Fast Ropax 5114

Dimensions: 51.3x14.4x1.9 m³
Maximum speed: 36.5 kn
Capacity: 500 passengers and 31 cars

Damen Fast Ropax 6016

Dimensions: 60x16.2x2.0 m³
Maximum speed: 35.0 kn
Capacity: 660 passengers and 49 cars

The Damen Fast Ropax 5114 can be used in the early stages or for a connection with a relatively low required capacity, for example with Tampa or Nassau. The Damen Fast Ropax 6016, see figure G.2, is given its higher capacity recommended for the connection with Key West and Miami.



figure G.2 – the Damen Fast Ropax 6016

A fast ferry, like the Fast Ropax 6016, uses water jets instead of a propeller propulsion system.

G.2.2 YACHTS

The dimensions of yachts that visited Marina Hemingway in 2010 are given in table G.1 and table G.2⁸. It is clear that mega yachts will be normative for the dimensions of a marina. Examples of mega yachts are the Amels 180 with dimensions of 55x9.4x3.4 m³, see figure G.3, or the “Limitless” with dimensions of 97x12x3.7 m³. The national market for yachts in Cuba is currently non-existing as the only habitants with a private boat are fishermen (Valle Benero, 2013). It is therefore expected that the marina in Havana will hardly be used as a homeport.

table G.1 – length of yachts visiting Marina Hemingway (Source: Norma Cubana NC 775-5:2010)

Length	Sailing boats (%)	Motor yachts (%)	Total (%)
< 30' (9.1 m)	9.58	8.03	9.13
30'-60' (9.1 – 18.2 m)	86.53	70.80	81.95
60'-80' (18.2 – 24 m)	3.29	11.68	5.73
> 80' (24 m)	0.60	9.49	3.18
Total	100	100	100

table G.2 – draught and length of yachts visiting Marina Hemingway (Source: NC 775-5:2010)

Draught (m)	Length (m)	Accumulative (%)
< 2.00	< 15	78.70
< 2.50	< 20	95.70
< 3.00	< 23	96.80
< 3.50	> 25	100



figure G.3 – the Amels 180

⁸ Dimensions of newly build vessels tend to increase over time

G.3 CAPACITY

Port dimensions determine for a great part the types and quantities of vessels that the port can accommodate, i.e. the capacity of the port. However, port dimensions are not the only capacity determining factor as capacity is limited by safety and comfort requirements as well. An integral approach on the capacity of a port implies finding the optimum in providing a high call rate while safety and comfort standards are met. These standards cover: sailing speeds, safety margins, required manoeuvring areas and traffic lane configuration.

To illustrate: high sailing speeds, small distances between vessels and a multiple lane configuration will increase capacity. However this approach will cause safety and comfort problems. Capacity is thus limited by at the one hand port dimensions and at the other hand safety and comfort.

The overall port capacity depends on several aspects: entrance channel, turning basins, anchorage areas and berths. These aspects are elaborated on in this section.

G.3.1 REQUIRED DEPTH

The minimum cross section of the channel determines what sizes of vessels are able to enter the port basin. Particularly the depth of the channel is a restriction as it determines the maximum draught of a vessel that can enter the basin. According to 'Appendix F: Analysis of existing port infrastructure and facilities', the maximum draught of a vessel that the port can accommodate is 11.58 m.

Entrance channel

The required minimal depth for the entrance channel is calculated by the following equation (Ligteringen, 2009):

$$d = D - T + s_{max} + r + m$$

with:

- d = guaranteed design depth [m]
- D = draught of normative vessel [m]
- T = tidal elevation above reference level for which no entrance is allowed [m]
- s_{max} = sinkage due to squat or trim [m]
- r = vertical motion due to wave response [m]
- m = safety margin or under keel clearance [m]

The value of T is introduced when a tidal window is used. With this window, ships with a large draught are only allowed to enter the port during a certain period around high water. Currently, the port authority of Havana uses a tidal window in which larger ships can enter the bay during a tidal elevation of at least 0.2 m, which will be taken as the value of T .

The two parameters r and m are estimated on the basis of practical experience. The significant wave height H_s influences r . The maximum wave height which occurs near the (operational) entrance channel is $H_s = 1.3$ m, while the average significant wave height $H_s = 0.8$ m (see J.3.4 'Average wave conditions'). The value of r is now calculated by $H_s/2 = 0.65$ m, or on average $H_s/2 = 0.4$ m. To conclude, m is a safety margin that depends on the type of soil at the bottom. For rock bottoms this margin is set on 1.0 m.

The sinkage due to squat or trim of the vessel can be calculated by the formula (Barrass, 1979):

$$s_{max} = \frac{C_B}{30} * S_2^{\frac{2}{3}} * v_s^{2.08}$$

with:

- v_s = vessel speed [kn]
- C_B = block coefficient [-]
- S_2 = $S/(1-S)$ [-]
- S = blockage factor = A_s/A_{ch} [-]

The block coefficient is estimated by $C_B = \pi/4 \approx 0.79$ (Vrijling, et al., 2011). The vessel's speed is estimated to be around 6 knots near the entrance channel. The blockage factor is calculated by dividing the submerged cross section of the vessel by the cross section of the basin. For simplicity, the ship's hull is schematized as a rectangle. The dimensions are taken for a container vessel with $25 \times 9 = 225 \text{ m}^2$, see also G.2. The wet cross section inside the entrance channel area of $250 \times 12 = 3000 \text{ m}^2$. This leads to a blockage factor of $S = 0.075$ and thus a value of $S_2 = 0.81$. Given all parameters, a sinkage due to squat of $s_{max} = 0.2 \text{ m}$ is found for this container ship.

With a fixed water depth of 12.8 m due to the tunnel beneath the entrance channel, the maximum draught of a ship can be calculated with the values of the parameters given above. With and without a tidal window, this maximum draught is 11.2 m and 11.0 m respectively. When the average significant wave height is taken, these values increase to 11.4 m and 11.2 m respectively, which has only a small deviation with the current legislature given in 'Appendix F: Analysis of existing port infrastructure and facilities'.

Ferry

The required depth of the basin near the ferry terminal can be calculated using the dimensions of the Damen Fast Ropax 6016. The blockage factor can be estimated with the values of $A_s = 16.2 \times 2 = 32.4 \text{ m}^2$ and an $A_c = 100 \times 4.5 = 450 \text{ m}^2$ directly in front of the berthing area, which will lead to $S = 0.07$ and $S_2 = 0.08$.

With an estimated speed of the vessel of 4 kn near the berthing area during the departure, this will lead to a $s_{max} = 0.1 \text{ m}$

The significant wave height with a return period of 1 year has a height of 0.71 m, which yields a value of $r = H_s/2 = 0.36 \text{ m}$.

Given the draught of 2.0 m of the design ferry vessel, this leads to a required minimum depth of 3.5 m.

Marina

The required depth of the main access channel of a marina is given by (de Jong, 2012):

$$h_{req} = D_{max} + 0.5H_s + 0.5$$

The maximum draught is taken to be the draught of a super yacht; about 4 m (see G.2.2). This results in a required depth of $h_{req} = 4.9 \text{ m}$.

G.3.2 REQUIRED WIDTH

The width of the entrance channel determines the number of lanes, and thus the number of vessels, that can be simultaneously accommodated in the channel. This influences the traffic rates inside the channel. The required minimum width of the entrance channel depends mainly on the dimensions of the vessel entering the channel. A difference is made between the outer approach channel and the inner channel, of which the last one is in a relatively sheltered area, i.e. inside the bay.

To determine the possibility for a multiple lane configuration, the equations given below can be used (Ligteringen, 2009). These formulas are applied for each type of vessel. Dimensions of the considered vessel types are given in G.2.

$$W = W_{BM} + \sum W_i + 2W_B, \quad \text{for one-way traffic configuration.}$$

$$W = 2(W_{BM} + \sum W_i + W_B) + \sum W_P, \quad \text{for two-way traffic configuration.}$$

The values for W_{BM} , W_i , W_B and W_P are width components required for safe navigation and depends on several factors.

The value of width of the basic manoeuvring lane, W_{BM} , is a correction for the ship's movement. The basic width is larger than the ship's beam, because a sailing vessel follows a sinusoidal track rather than a straight line, see figure G.4. This is due to the delay in response of the helmsman to the deviation of the intended course and that of the ship in reaction to the change of direction of the rudder.

The increase of the theoretical width depends on ship manoeuvrability and is given in table G.3. A passenger ship, such as a cruise ship or ferry, has a good manoeuvrability. However, in areas with occurring high wind speeds, vessels with high windage characteristics, i.e. high-sided vessels, are advised to be classified as having a poor manoeuvrability (PIANC, 1995). Therefore, cargo and cruise ships will be classified as 'poor', while the ferry and yachts will be classified as 'moderate'.

table G.3 – increase of the basic manoeuvring lane (PIANC, 1995)

Ship manoeuvrability	good	moderate	poor
W_{BM}	1.3B	1.5B	1.8B

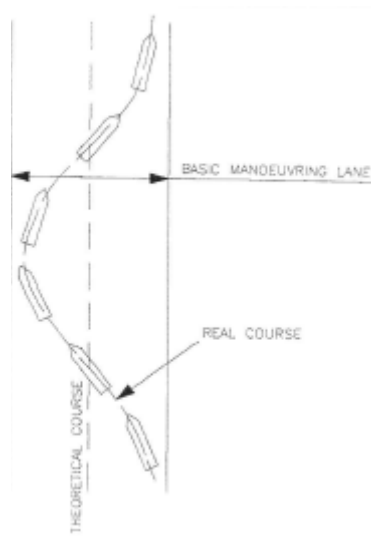


figure G.4 – the sinusoidal course of a ship (PIANC, 1995)

The total additional width is given by the sum of W_i , which depends on for instance wind speeds, wave heights and the vessel's speed. These values are given in table

G.4. The prevailing wind speeds are given in paragraph H.4.2 'Average winds' and are on average about 6 kn and have a maximum of about 22 kn, above which no shipping manoeuvres are allowed. The prevailing significant wave height is on average about 0.8 m, with a maximum of about 1.3 m during the maximum allowed wind speeds.

The maximum velocity of a vessel allowed in the entrance channel is 6 kn. This speed is therefore taken as the input for the values of the width components in table G.4.

table G.4 – width components for straight channel sections (PIANC, 1995)

Width component W_i	Condition	Width [m] outer channel	Width [m] inner channel
Prevailing cross winds	0 – 25 kn	0B	0B
	15 – 33 kn	0.5B	0.5B
	33 – 48 kn	1.0B	1.0B
Prevailing cross current	0 – 0.2 kn	0B	0B
	0.2 – 0.5 kn	0.3B	0.2B
	0.5 – 1.5 kn	1.0B	0.8B
	1.5 – 2.0 kn	1.3B	-
Prevailing long current	0 – 1.5 kn	0B	0B
	1.5 – 3 kn	0.2B	0.2B
	> 3 kn	0.4B	0.4B
Prevailing significant wave height	0 – 1 m	0B	0B
	1 – 3 m	0.5B	-
	> 3 m	1.5B	-
Aids to navigation	VTS	0B	0B
	good	0.1B	0.1B
Seabed characteristics	if $d > 1.5D$	0B	0B
	smooth	0.1B	0.1B
	hard	0.2B	0.2B
Cargo hazard	low	0B	0B
	medium	0.5B	0.4B
	high	1.0B	0.8B

For steep and hard embankment, such as rock or fortresses as occur in the Bay of Havana, the value of $W_B = 0.5B$. The additional width for passing in two-way direction, the values of W_p , are given in table G.5. The current traffic density of the Port of Havana is 'light'.

table G.5 – additional width components for passing in two-way direction (PIANC, 1995)

Width component W_p	Condition	Width [m] outer channel	Width [m] inner channel
Vessel speed	5 – 8 kn	1.2B	1.0B
	8 – 12 kn	1.6B	1.4B
	> 12 kn	2.0B	-
Traffic density ⁹	light	0.0B	0.0B
	moderate	0.2B	0.2B
	heavy	0.5B	0.4B

⁹ Traffic density is defined as 'light' for a density of less than one vessel per hour and as 'heavy' for a density of more than three vessels per hour

Given these values, the required minimum width for each type of vessel can be calculated with the results given in table G.6. It is stressed that for the two types of cargo vessels the dimensions of a typical vessel are used; the required width of the channel for the normative vessel will be slightly larger.

table G.6 – required channel widths for the entrance channel

Type of vessel	One-way		Two-way	
	Width (m)	Length (m)	Width (m)	Length (m)
Container	4.1B	102.5	8.4B	210
LNG	5.1B	112.2	10.4B	228.8
Cruise	4.1B	132.0	8.4B	270.5
Ferry	3.6B	58.3	7.4B	119.9
Mega yachts	3.6B	43.2	7.4B	88.8
Yachts (2m width)	3.6B	7.2	7.4B	14.8

From the calculations above, it can be concluded that cargo vessels and cruises cannot be accommodated in a two-way configuration in the current entrance channel. Ferries and yachts can use the channel in a two-way configuration. Note that ferries and cruises will usually never arrive and/or depart at the same time since these lines make use of a strict time schedule. Besides, it is not expected that more than a single mega-yacht will arrive at the same time. It is therefore assumed that in the current situation:

- Cargo vessels always sail in one-way traffic configuration.
- Cruises, ferries and mega-yachts will sail in a one-way traffic configuration.
- Yachts of average dimensions can sail in two- or even more way configuration.

G.3.3 BERTHING FACILITIES

The port of Havana has currently few terminals that are able to receive tourist related vessels. Only the cruise terminal with one pier in use can receive tourists. The general plan of 'Tourist Port Havana' requires different berths for several types of tourist vessels in future, see also 'Appendix A: General perspective of Tourist Port Havana':

- 6 regional ferry berths; two at each ferry station
- 2 mega yacht, 60 super yacht and 210 smaller yacht berths
- Multiple international ferry berths, the exact number will be discussed in 'Appendix P: Design of the ferry terminal'.

The number of currently operational commercial berths in the port at present is the estimated present capacity. These berths provide a daily service.

- Liquid bulk: 4 berths
- Dry bulk: 3 berths
- General cargo: 15 berths
- Container: 2 berths

Accumulated, this is a total of 24 commercial berths in the whole bay. This capacity is currently not reached. Only the container terminal receives vessels on a contract basis: three set days a week a container vessel calls. The liquid and dry bulk terminal do not receive on such contract basis, the calls therefore show a very irregular pattern.

In the bay there is sufficient space to increase the number of commercial berths. In order to do so a reorganization of the different activities is recommended. Also more operational quay length and thus berths can be provided by dredging shallow areas in the bay. It is assumed that about 14 berths can be created in these ways, to provide a total of around 38 berths in future.

G.3.4 TURNING BASINS

Turning basins provide space for vessels to change direction. This manoeuvring takes also time and will therefore disprove the traffic flow. It is therefore preferred to design spacious turning basins, but at the same time they should not block other traffic. When an increase of vessel traffic and vessel dimensions is expected, also wider turning basins are expected. The diameter of a turning basin has a minimum of $1.8L_s$, with L_s the length of the design vessel (PIANC, 1995), although a minimum diameter of $2L_s$ is recommended (Ligteringen, 2009).

G.3.5 ANCHORAGES

An exterior anchorage area is located about 250 m north of the Castillo del Morro with a capacity of five ships with a maximum length of 150 m, see figure G.5. The water depth is between 12 and 15 m and the soil consists of gravel, vegetated with sea moss. The area accommodates a safe anchorage, but it cannot be used as a refuge for high waves and winds.

Two anchorage areas are located in the bay: Fondeadero la Tasajera and Fondeadero de Casablanca. La Tasajera has a capacity of five ships with a maximum length of 230 m; Casablanca has a capacity of four ships with a maximum length of 165 m. Both anchorages can be used until winds of 5 Bft.

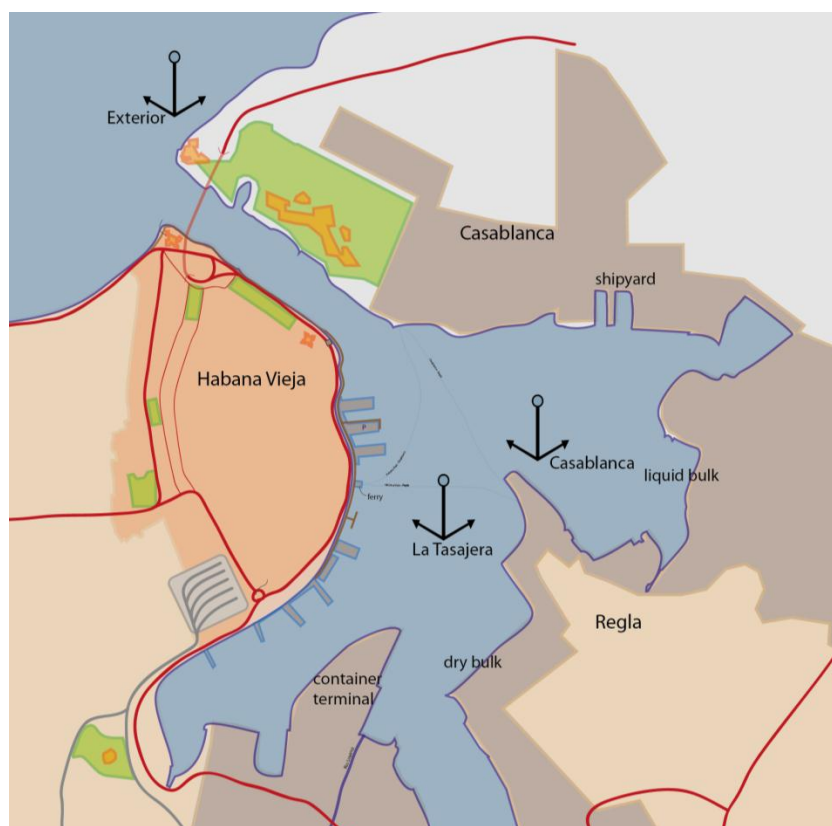


figure G.5 – anchorages in the Bay of Havana, current situation

G.4 INTENSITY

Little is known about the current intensity in the Bay of Havana. Only the container terminal has regular calls with three times a week. By account of the traffic control service, on average one liquid and one dry bulk vessel arrives per week. In general, two or three vessels arrive at the port on an average day.

G.4.1 FUTURE GROWTH

The to be expected economic growth in Cuba, especially after the possible lifting of the embargo, will lead to an increase in commercial activities in the country and possibly the Bay of Havana. Moreover, as a result of Tourist Port Havana, an increase in traffic of tourist related vessels is to be expected. The overall harbour activities will as a result probably intensify, and thus more calls and traffic is expected.

In order to become successful, it is vital that the port can accommodate future tourist supply in a safe and comfortable way. Conflicts must therefore be prevented by providing sufficient capacity and/or a traffic control system. Hindrance of tourism and commercially related vessels must be minimized as much as possible.

The above shows the importance for future traffic intensities expectations. These future traffic intensities are based on economic growth of Cuba and Havana in particular. It is hard, if not impossible, to predict the exact economic growth of the country, see also 'Appendix U: Financial evaluation' and 'Appendix V: Economic evaluation'.

G.5 OTHER PORTS IN THE REGION

The to be expected intensity of traffic in the bay partly depends on the development of other ports on the island. Cargo ships can be attracted by other ports in Cuba because of for example better equipment, shorter sailing distances, shorter service times or to avoid waiting times. As a result, the number of calls in the Port of Havana could be negatively affected. Cuba has a total of seven major ports: Havana, Mariel, Santiago de Cuba, Cienfuegos, Matanzas, Antilla and Nuevitas (Acher mann, 2007).

Marinas in other parts of the country can conversely cause an increase of the number of calls of yachts in Havana. With multiple marinas in the country, Cuba would be a more attractive destination for yachts as it would make a trip around the island possible. Marinas in the close proximity of Havana will of course have a negative effect on the number of calls in the future marina in the bay.

G.5.1 COMMERCIAL PORTS

Mariel

Located 40 km to the west of Havana, the Port of Mariel is currently under construction. Dubbed as Cuban's most complex development project that can boost investment and foreign trade by President Raul Castro (Dredging Today, 2013), Mariel will be able to handle cargo ships with a draught up to 15 m. With this maximum draught, the port authority anticipates on the enlargement of the Panama Canal after which vessels with such a draught are able to pass the canal. The project includes a container terminal with a berth length of 700 m, which would mean an annual capacity of about one million TEU (Port Technology, 2011). Compared to the current capacity of 350 000 TEU of the Port of Havana, the construction will allow Mariel to become the principal gateway of Cuban foreign

trade (Dredging Today, 2013). If the U.S. government will decide to (partly) lift the embargo, Mariel could become an attractive hub port of the U.S. and Caribbean region thanks to its strategic location.

Partly financed by a Brazilian investment company, the container terminal is expected to be operational by the end of 2013 after which it will be operated by a Singaporean port operator.



figure G.6 – map of Cuba with the seven major ports indicated in blue

Santiago de Cuba

Currently the second city and port of Cuba after Havana, Santiago is located at the south-east corner of the island. The Bay of Santiago is the largest natural harbour in the Caribbean. This southern location makes Santiago an attractive destination for trade ships coming from South-America.

Moreover, a ferry service located in Santiago can connect Cuba with countries like Jamaica, Haiti and the Dominican Republic.

Cienfuegos

The port of Cienfuegos is located on the southern coast, about 250 km south-east of Havana, in the natural Bay of Cienfuegos. Sugar is the main cargo product shipped which makes Cienfuegos the centre of the sugar trade of the country.

A possible ferry connection can be made between Cienfuegos and the Cayman Islands.

Matanzas

The port of Matanzas is located in the Bay of Matanzas, about 90 kilometres east of Havana. The port mainly provides services for liquid bulk cargo.

Antilla

Located in the north-east of the country, the port of Antilla handles mainly the export of minerals like nickel and the trade in sugar.

Nuevitas

The port of Nuevitas can be seen as the regional hub of the north-eastern part of Cuba.

G.5.2 MARINAS

Marina Hemingway

The main marina of Havana is currently Marina Hemingway and located near the western end of the city, on a distance of approximately 15 km from Habana Vieja. The marina is sheltered from the sea and has a possibility of 400 moorings, although only 170 are suited for living on board. A free bus service connects the marina to the city centre thrice a day. Multiple excursion, for instance for diving, sport fishing or for a round trip, are organized from the marina.

Marina Tarará

In the east of the city, close to the Playas del Este, is the small Marina Tarará located. The marina has a capacity of 20 moorings and a maximum draught of 1.3 m.

Varadero

The main tourist destination of Cuba, Varadero accommodates multiple resorts fitted out with all conveniences. A new large marina is currently constructed near the eastern end of the peninsula. The Marina Gaviota will be able to accommodate about 2000 yachts and will provide other services, such as restaurants, a five star hotel and shops, as well. The construction began in 2002 and the marina is expected to be operational in 2015. The location of 140 km to the east of Havana makes Varadero an attractive sailing destination from the capital.

If Cuba will become a cruise destination of importance, Varadero could become an attractive location for a cruise terminal, for example near the Marina Gaviota, as well.

G.6 VESSEL INTERACTIONS

A sailing vessel generates waves and currents that may influence the berthing conditions in the marina.

G.6.1 RETURN CURRENTS

The water displacement of the ship causes a return current to the stern of the vessel in order to 'refill' the space behind the ship. This current also causes a 'sinkage' of the vessel, or more specifically a decrease of the water level next to the ship. After all, the velocity height has increased. This water movement can be seen as a wave with a wavelength equal to the length of the ship, see figure G.7. This wave is called the primary wave induced by a vessel and influences the conditions in the marina in the bay.

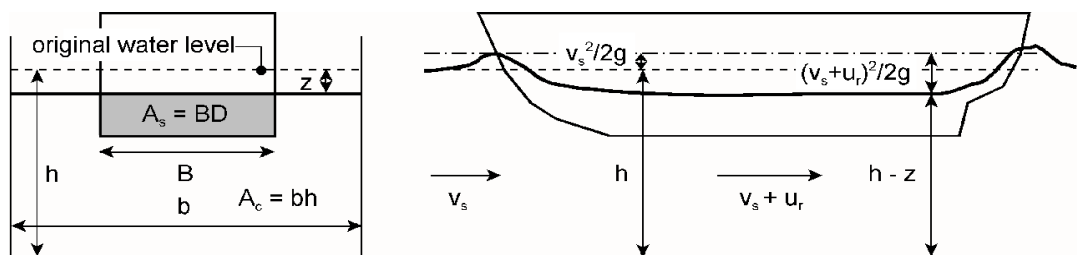


figure G.7 – the primary wave induced by a vessel (Schierreck, 2006)

Therefore, the sinkage and return current of a vessel are determined from the 'Schijf diagram', figure G.8, or by the equations given below (Schierreck, 2006). The

width of the channel in the Ensenada de Atarés can conservatively be taken as 270 m at the Espigón Iglesias (see 'Appendix F: analysis of existing port infrastructure and facilities'). When a ship sails in an eccentric position, with a distance y from the axis of the channel, z and U_r should be corrected. This eccentricity is conservatively taken as $y = 35$ m, in the case a vessel passes the Espigón Iglesias at a distance of $s = 100$ m. Eventually the height of the stern wave is approximated as this forms the design primary wave.

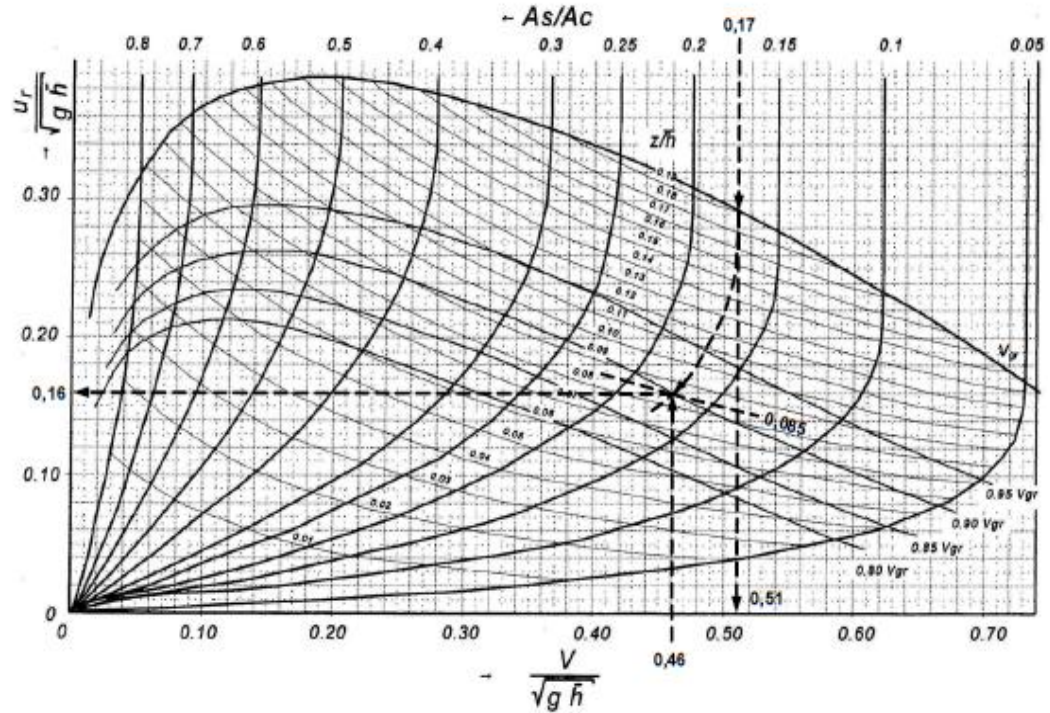


figure G.8 – Schijf diagram

Froude equation:

$$Fr = \frac{\frac{2z}{h} \left(1 - \frac{z}{h} - \frac{A_s}{A_c}\right)^2}{1 - \left(1 - \frac{z}{h} - \frac{A_s}{A_c}\right)^2} = \frac{V_s}{\sqrt{gd}}$$

Return flow equation:

$$U_r = V_s \left(\frac{A_c}{b(h-z) - A_s} - 1 \right)$$

Correction for eccentric position of ship in the canal:

$$z_{ecc} = \left(1 + \frac{2y}{b}\right) z \quad \text{and} \quad U_{r,ecc} = \left(1 + \frac{y}{b}\right) U_r$$

Height of stern wave:

$$z_{max} = 1.5z_{ecc}$$

The eventual results are given in table G.7. The dimensions of two different ferries are used with a sailing speed of 6.0 knots (3.1 m/s).

table G.7 – return current and sinkage

	Damen Ropax 6013	Damen Fast Ropax 6016
D (m)	1.8	2.0
B (m)	12.9	16.2
A_s (m ²)	23.2	32.4
h (m)	10	10
b (m)	270	270
A_c (m ²)	2 700	2 700
A_s/A_c	0.009	0.012
Fr (-)	0.31	0.31
z (cm)	1.0	1.3
z_{ecc} (cm)	1.3	1.6
z_{max} (cm)	1.9	2.4
U_r (cm/s)	3.0	4.2
$U_{r,ecc}$ (cm/s)	3.4	4.7

G.6.2 VESSEL GENERATED WAVES

The bow and stern of a sailing ship generates diverging waves, which move out from the vessel's sailing line, and transverse waves that propagate behind the vessel, see figure G.9.

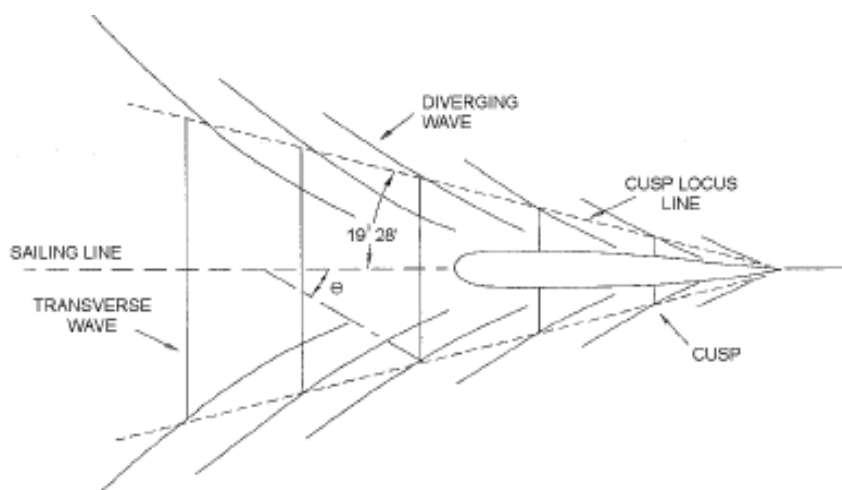


figure G.9 – vessel generated waves (Coastal Engineering Manual, 2006)

The angle of propagation θ depends on the Froude number of the vessel (Weggel and Sorensen 1986) and can be calculated by:

$$\theta = 35.27(1 - e^{12(Fr-1)})$$

Consecutively, the wave celerity, period and length can be calculated by:

$$c = V_s \cos \theta = \frac{gT}{2\pi} \tanh \frac{2\pi d}{cT}$$

$$L = cT$$

Wave heights of the cusps have to be determined experimentally or by means of comparisons with quasi-empirical studies of similar vessels. The wave height also depends on the sailing speed, water depth and the distance to the sailing line. An approximation of the relation of these experimental data of other vessels can be given by (Schiereck, 2006):

$$\frac{H}{h} = \zeta \left(\frac{s}{h}\right)^{-1/3} Fr^4$$

The value of ζ depends on the geometry of the vessel, but $\zeta = 1.2$ gives a reasonable upper limit for the collection of experimental data, see figure G.10. Because little is known about the exact relation between the geometry and the value of ζ , this upper limit will be taken as a conservative value.

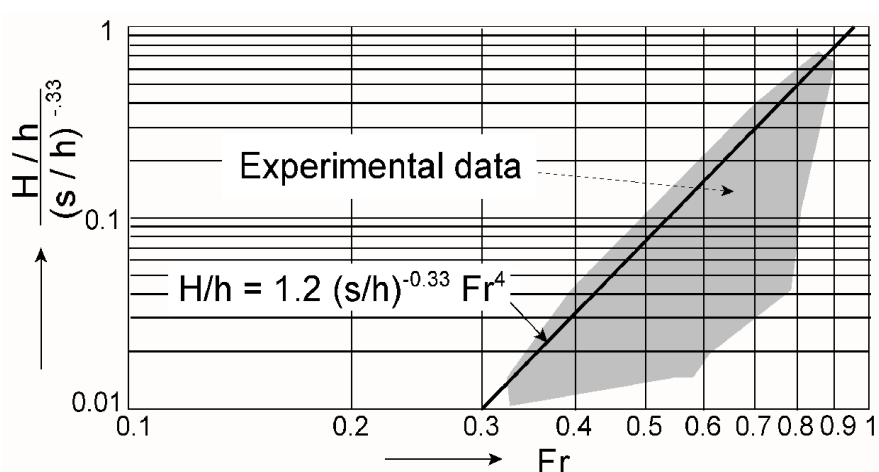


figure G.10 – experimental data of secondary wave heights induced by vessels (Schiereck, 2006)

The results of three different sailing speeds are given in table G.8. The depth of the channel in de Ensenada de Atarés can conservatively be taken as 10 m (see also figure F.4 – depth chart of Ensenada de Atarés) and the distance to the sailing line as $s = 100$ m.

table G.8 – secondary vessel generated wave

V_s (kn)	4.0	6.0	8.0
V_s (m/s)	2.1	3.1	4.1
Fr (-)	0.21	0.31	0.41
ϑ (-)	35.27	35.26	35.24
c (m/s)	1.7	2.5	3.4
T (s)	1.1	1.6	2.1
L (m)	1.9	4.0	7.1
h (m)	10	10	10
s (m)	100	100	100
ζ (-)	1.2	1.2	1.2
H (cm)	1.1	5.1	15.7

Significant waves occur with a sailing speed of 8 kn, but this speed is actually prohibited in the bay. Although vessels will probably sail with maximum speeds of 4 kn close to the marina, a speed of 6 kn can occur with a departing ferry. Therefore, waves occurring with a sailing speed of 6 kn are taken as the design limit.

G.6.3 PROPELLER WASH

The flow behind a ship generated by the propellers of a vessel is of importance when a ship is near a berthing structure and has the characteristics of a jet (Schiereck, 2006). It is influenced by the diameter of the propeller R , the distance from the jet in the centre of the flow line x , the radial distance from this centre r and the initial flow of the jet U_0 . This initial flow depends on the power of the engine P and is given by:

$$U_0 = 1.15 \left(\frac{P}{\rho d^2} \right)^{1/3}$$

With $d = 0.7R$ for a normal propeller or $d = R$ for a propeller in a jet tube. When the diameter is not known, R is estimated as 70% of the ship's unloaded draught.

After this, the flow can be calculated by:

$$U = \frac{2.8U_0}{x/d} e^{-15.7\left(\frac{r}{x}\right)^2}$$

The differentiation of this equation to x gives the location of the maximum velocity at $x = 5.6r$. Substituting this gives:

$$U_{max} = 0.3U_0 \frac{d}{r}$$

The results of these equations for several types of ferries are given in table G.9. Three scenarios are taken with different distances to the propeller. The first one gives the propeller wash close to the quay wall during berthing or when leaving the berth. The second scenario is the maximum velocity in the marina. At last the maximum velocity at the bottom is calculated.

table G.9 – propeller wash of vessels

	Damen Ropax 6013			Damen Fast Ropax 6016		
P (kW)	559			2 880		
ρ (kg/m ³)	1 025			1 025		
R (m)	1.7			0.75		
d (m)	1.2			0.75		
U_0 (m/s)	7.2			19.66		
r (m)	0	100	7	0	100	7
x (m)	1	560	39.2	1	560	39.2
U (m/s)	24.3	0.026	0.37	41.3	0.045	0.64

G.7 CONCLUSIONS AND RECOMMENDATIONS

G.7.1 CONCLUSIONS

The Damen Fast Ropax 6016 will be used as a design vessel as it is the recommended ferry considering its capacity and velocity.

The entrance channel has sufficient width for the design vessel of both cargo and passenger transport ships. The depth of the channel, restricted by the tunnel beneath, limits the maximum draught of particularly cargo vessels like bulk carriers. This is however a relatively small limitation considering the current demand, but may become a problem in the future.

It can be concluded that the Port of Havana is currently operating far below its capacity, but it is impossible to say when the capacity will be reached or if it will be reached at all. This also depends on the development of ports in other cities, most notably the currently constructed port in Mariel, Santiago or Varadero.

The capacity of the port will also be limited by the diversification that the project Tourist Port Havana will bring to the bay. With the presence of yachts, other vessels may become hindered in its manoeuvrings; a traffic control system is therefore recommended to limit these problems. Moreover, other, larger vessels can be a hazard for the safety of the relatively small yachts. The waves generated by a passing vessel have some influence on the wave climate in the marina, but this will only be in the order of magnitude of several centimetres with normal sailing speeds.

G.7.2 RECOMMENDATIONS

Considering the results of the nautical analysis, the following recommendations are made:

Required capacity of the ferry

A market research has to be performed in order to know the demand for a ferry connection between Havana and other cities. This research not only determines (with a higher degree of certainty) the type of vessel that will have to be used, but also the required number of berths at the ferry terminal and the expected frequency of the ferry service.

Expected intensity

A research has to be done about the expected traffic intensity in the future. Not only the cargo forecast should be taken into account in this research, but also the expected demand of cruise line operators and yachtsmen for Havana as sailing location. The results of this research are important for the port planning operations, i.e. to answer the question whether the capacity of the port should be increased or not. The increase in traffic also causes safety issues that will have to be accurately predicted to be anticipated on in time. The results are also of importance for the design and construction planning of the marina.

Capacity cruise terminal

The current cruise terminal, Sierra Maestra, can accommodate cruise ships with a maximum length of only 240 m. The current operating cruise ships in the Caribbean are larger than this capacity. If Havana wants to play a major role in the cruise market, the terminal should be able to accommodate larger cruise ships. As the cruise ship “MS Zaandam” is already the current design vessel considering the beam, this will of course change when the capacity of the cruise terminal will increase.

Appendix H: HYDRODYNAMIC ANALYSIS – PRELIMINARY INVESTIGATION - FLOW

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H.1 INTRODUCTION

In this appendix, the focus will be on flow and current patterns that occur in the Havana Bay and especially in the entrance channel. This information is wanted for two reasons. Firstly, the flow velocities need to be quantified in order to gain more insight in the navigability of the entrance channel. For example, it may be possible during a storm surge or a normal tidal cycle that the flow velocities become too high for shipping. This depends entirely on the system characteristics, e.g. storage area, length of inlet channel, tidal elevation etcetera.

Secondly, this information is needed if one wants to carry out a hydrodynamic study of the Havana Bay

This means that the goal of this appendix is to gain more insight in system characteristics and the corresponding flow velocities in an analytical way. From this, some preliminary conclusions can be taken about flow velocities near the location of the marina and ferry terminal.

Firstly, the system characteristics will be evaluated in chapter H.2. In this chapter, also a tidal analysis will be given. Secondly, a simple approach will be given to determine the flow velocities in the entrance channel; the ‘basin storage approach’. In chapter H.4, the wind conditions will be evaluated in order to quantify different wind situations. After this analysis, different scenarios will be created that will be analysed in ‘Appendix I: Hydrodynamic analysis – Delft3D-FLOW.

H.2 SYSTEM CHARACTERISTICS

The Bay of Havana (figure H.1) is situated on the north side of the island of Cuba, facing the Straits of Florida, which connect the Gulf of Mexico to the Atlantic. It is a natural bay, consisting of an inner basin with a surface of about 5.2 km², which is connected to the open ocean through a narrow entrance channel.

H.2.1 DIMENSIONS AND CHARACTERISTICS

Offshore

Key West in Florida is located about 150 km to the north of Havana. Between Havana and Key West the Straits of Florida are located, which have a maximum depth of about 1800 m (Buker, 1993). This means that within a few kilometres of the coast, the depth rapidly increases.

Nearshore

The 200 m depth contour is around 1 km offshore (directly opposite the entrance channel), resulting in a relatively steep cross-shore profile.

Entrance channel

The entrance to the bay is a narrow channel with a length of 1.2 km. The width varies from 330 m at the mouth, down to 220 m at its most narrow point. The depth of the channel is limited by a tunnel connecting Havana West to Havana East, resulting in a maximum depth of 12.8 m (relative to MSL). Other sections of the channel have depths of up to 17 m, but mostly depths vary between 11 and 15 m.

Bay

The bay contains the largest body of water, with a surface-area of 5200 ha. The natural basin has been increasingly used for port activities over the years, which can be seen by the occurrence of many piers and quay walls. The bay can be divided into three sections or smaller basins; 'Ensenada de Marimalena' in the east, 'Ensenada de Atarés' in the west and 'Ensenada de Guasabacoa' in the south. The average depth of the bay is approximately 10 m. The bottom of the basin is rock, covered with a thin layer of mud, implying that erosion and sedimentation can be neglected for this study.

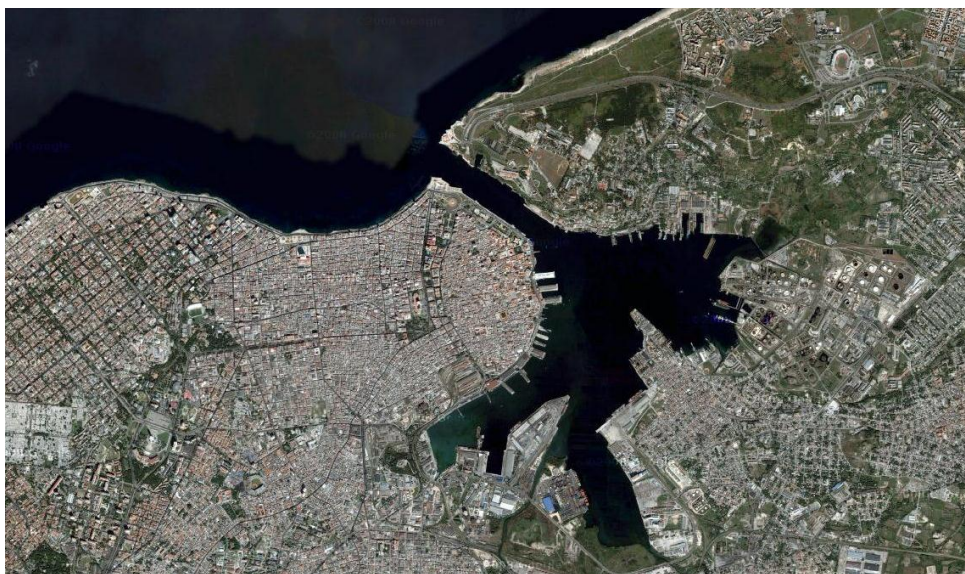


figure H.1 – Havana Bay and its surroundings

With the information above, a first approach can be made about the bay characteristics. The basin is small (order of kilometres) for the water surface to rise and fall uniformly (co-oscillate) in response to its forcing, the ocean tide. This is true if the tidal period is long compared to the time required for a shallow-water wave to propagate from the inlet to the farthest point in the bay (Coastal Engineering Manual, 2006). This means that the following should apply:

$$T \gg \frac{L_b}{\sqrt{gd_b}}$$

in which:

- L_b = the greatest distance from inlet to the end of the bay (about 5 km)
- d_b = average depth of the bay (entrance channel - end of bay; about 12 m)
- T = tidal wave period (semidiurnal tide; wave period approximately 44 400 s)

In this case, the tidal wave propagates in circa 460 s through the system; a value much smaller than the tidal wave period. This means that there is almost no phase lag ($460/44\ 400 \approx 1\%$) between the tidal forcing and the water level at the farthest point in the bay.

Furthermore, the inlet has a substantial large water depth (well over 10 metres), so it is possible that the tidal wave is not hindered at the entrance when entering the bay.

H.2.2 SEA LEVEL RISE

In the lifetime of the marina and ferry, the sea level is predicted to rise significantly due to global warming. This increase in water level has to be added to the design water level. It is very difficult to determine the rate of sea level rise, because of the many factors that play a role in this process.

For instance, estimations of possible temperature rise show large uncertainties and hence the amount of melt water coming from the South Pole is uncertain.

In 2007 the United Nations Intergovernmental Panel on Climate Change presented their Fourth Assessment Report (IPCC, 2007). In this report a sea level rise for the 21st century has been estimated using a low and high scenario. These scenarios are based on different assumptions on economic development, changes in human population and emissions of greenhouse gasses. The low scenario, which is the most eco-friendly scenario, results in a sea level rise of 18 – 38 cm (average of 28 cm). With the high scenario, the most pessimistic one, a sea level rise of 26 – 59 cm is expected (average of 42.5 cm). For the design of the marina and the ferry terminal, the average has been taken of these two scenarios, which results in a sea level rise of 35 cm. This is a prediction for 100 years, so in the total lifetime of the marina and the ferry terminal, the sea level rise is assumed to be **17.5 cm**.

H.2.3 TIDAL ANALYSIS

Maximum tide:

Predicted tidal date (Nautical Software Inc., 1994) is used for an analysis of the tidal situation in Havana. The results are visible in figure H.2, which shows maximum tidal ranges for the year 2013. Springtide ranges are the most interesting, as maximum flow velocities are expected to occur during a springtide period.

The tidal range has been defined as the largest difference in water level between successive high and low waters. From it can be seen that the largest ranges occur in June and July.

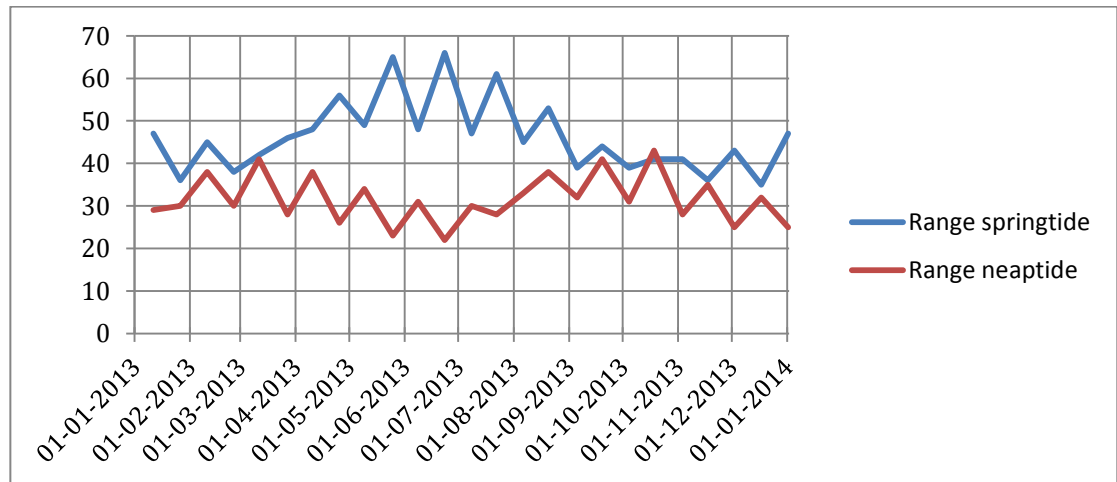


figure H.2 – maximum tidal ranges, levels relative to MLLW (predicted, 2013)

The predicted tidal signal for June 25th can be seen in figure H.3. It is a semidiurnal tide, with a maximum range of **0.66 m**. Because it is not expected for the tidal signal to differ much over the years, this signal presents a valuable design input.

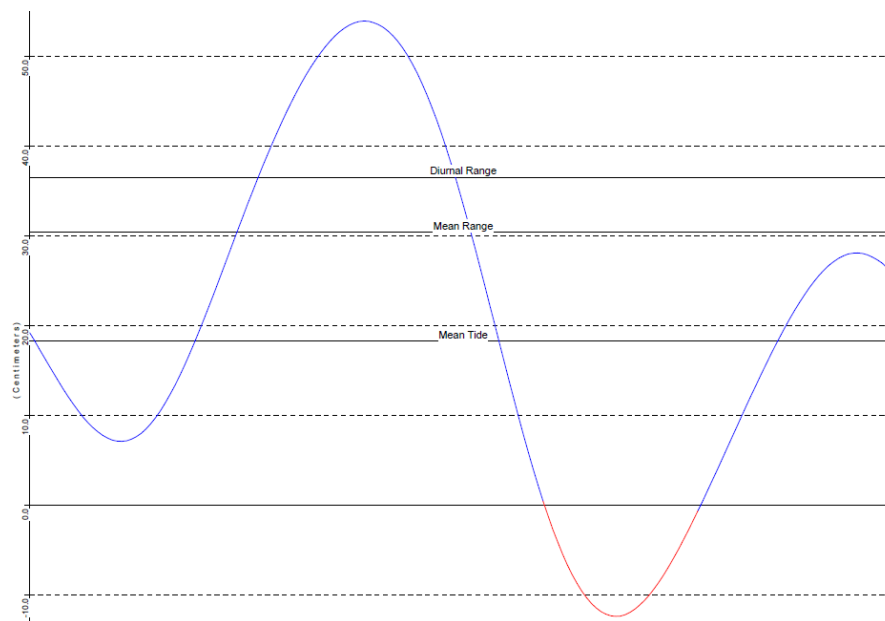


figure H.3 – predicted springtide signal for Havana, June 23th 2013 (24h)

Regular day

For simulation purposes, a fitting tidal signal that can be considered regular is required. To achieve this, two random days have been chosen, the 14th and 15th of October. The resulting signal is displayed in figure H.4. The tidal range is roughly **35 cm**, with a maximum water level of 47 cm.

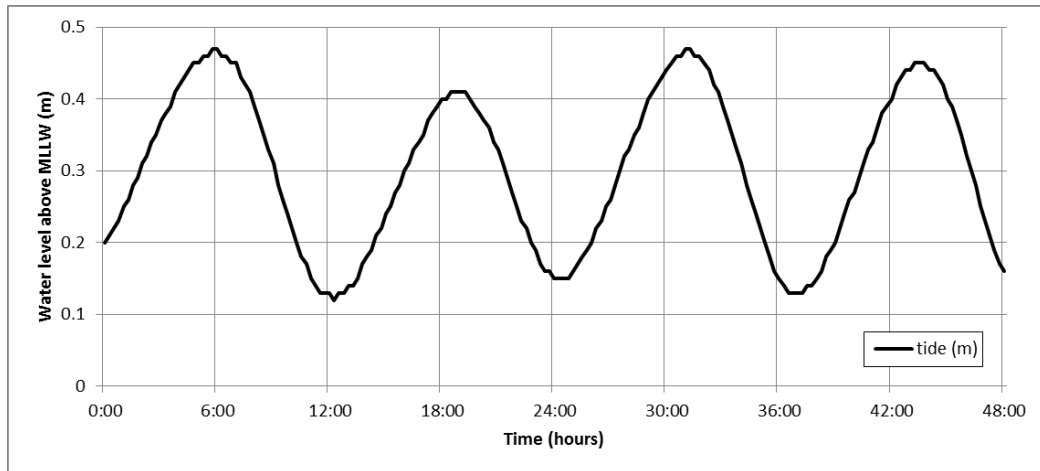


figure H.4 – Havana tidal signal (Nautical Software Inc.)

H.3 INLET HYDRODYNAMICS

Many approaches are available for evaluation of inlet hydrodynamics; analytical expressions, numerical models and physical models for instance. In this chapter, a simple analytical approach will be given to determine average velocities in the cross section of the entrance channel due to the ocean tide.

H.3.1 INTRODUCTION

First it is important to determine the cause of the velocities in the channel. In case of a co-oscillating tidal system, the tide in the bay will rise and fall equally and simultaneously with the rise and fall of the ocean tide. This will be the case if the inlet is wide and deep in proportion to the area of the bay. The tidal wave in the near shore can then be seen as a translation wave; the total water body moves in a horizontal way. Then hydraulic currents will be *small* and tidal wave propagation is the dominant factor (Coastal Engineering Manual, 2006).

This is a very different situation when compared to a system with a small inlet with respect to the bay area. The wave propagation will then be small, resulting in a hydraulic head between ocean and bay. This means that the water surface will have a slope, causing a flow which results in substantially higher flow velocities than the co-oscillating system. In the previous section, the Havana Bay was characterised as a co-oscillating system, so no hydraulic head is expected and tidal propagation will be the dominant factor. In the next section, an approach will be given to obtain flow velocities in an analytical way.

H.3.2 'BASIN STORAGE' APPROACH

The 'basin storage' approach is a very simple approach to get a first impression on flow velocities. Because of this simplicity, no detailed information is known about flow velocities, e.g. the current patterns near the marina. Hence, this approach will only be used for the entrance channel and to obtain the order of magnitude of the flow velocities. In this approach, the Havana Bay will be schematised as a large bay with a small and narrow inlet channel which connects the bay to the sea.

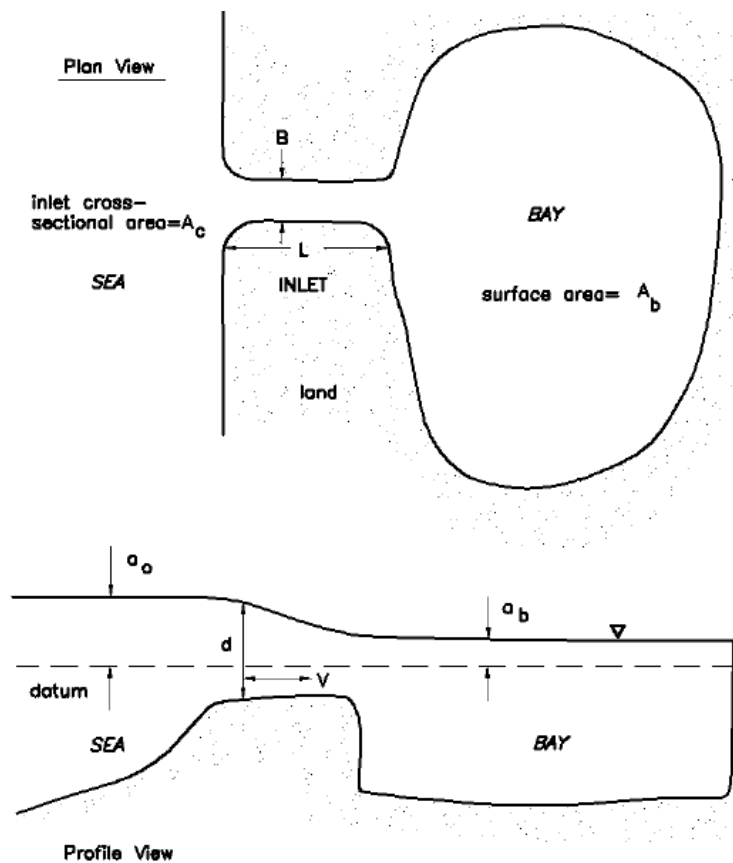


figure H.5 – schematisation of the Havana Bay (Coastal Engineering Manual, 2006)

This approach can only be used if the basin is much smaller than the wavelength of the tidal signal. The tide signal near Havana is semi-diurnal (Tide book Cuba) with an approximated period T of 12 hours and 20 minutes (44 400 s). In this case, a normal tidal range will be used (regular tide of 0.35 m), see chapter H.2, system characteristics. This value is close to the mean tidal range of the system and the corresponding flow velocities will therefore represent average values.

The celerity of a tidal wave can be calculated with $c = \sqrt{gh}$. With an average water depth of 200 m in the coastal zone, this results in a wave celerity of 44 m/s. Using this information the wavelength L can be calculated with $L = cT$, which yields a wavelength of 1967 km. The maximum length of the basin, l , is about 5 km. In this case $l \ll L$, so the water levels in the basin can be assumed to be constant in space and will only vary in time. In that case only storage of water is important and a formula for this system is shown below:

$$Q = A_b \frac{dh_b}{dt}$$

in which:

Q	Discharge of water through the channel [m ³ /s]
A_b	Storage area of the Havana Bay [m ²]
dh_b/dt	Rate of change of water level

As mentioned in section H.2, the bay of Havana has a total storage area of 5.2 km². This area will be affected by a tidal wave (time dependent only) that will be schematised as follows:

$$h_b(t) = \eta(t) = \frac{H}{2} \sin\left(\frac{2\pi}{T} t\right) = \frac{0.35}{2} \sin\left(\frac{2\pi}{44400} t\right)$$

Differentiating with respect to time results in:

$$\frac{dh_b}{dt} = \frac{2\pi H}{T} \cos\left(\frac{2\pi}{T} t\right) = \frac{2\pi}{44400} \frac{0.35}{2} \cos\left(\frac{2\pi}{44400} t\right)$$

The water elevation due to the tide will fill up the bay area, and the total amount of water will flow through the entrance channel, which in case will be schematised as a rectangular channel with an average width of 250 m and an average depth of 12 m. This results in an A_s (flow-through area) of $250 * 12 = 3000 \text{ m}^2$. The velocity in the entrance channel can be calculated with the simple formula $v = Q/A$.

The computations for one tidal cycle have been carried out with a spread sheet and the result is shown in figure H.6.

t (s)	Q (m ³ /s)	v (cm/s)	t (s)	Q (m ³ /s)	v (cm/s)			
0	128.78	4.29	22800	-128.31	-4.28	Depth entrance channel:	12	meter
1200	126.92	4.23	24000	-124.62	-4.15	Width entrance channel:	250	meter
2400	121.42	4.05	25200	-117.35	-3.91			
3600	112.42	3.75	26400	-106.69	-3.56	As entrance channel:	3000	meter ²
4800	100.19	3.34	27600	-92.97	-3.10			
6000	85.08	2.84	28800	-76.58	-2.55			
7200	67.52	2.25	30000	-57.98	-1.93			
8400	48.02	1.60	31200	-37.71	-1.26			
9600	27.13	0.90	32400	-16.36	-0.55			
10800	5.47	0.18	33600	5.47	0.18			
12000	-16.36	-0.55	34800	27.13	0.90			
13200	-37.71	-1.26	36000	48.02	1.60			
14400	-57.98	-1.93	37200	67.52	2.25			
15600	-76.58	-2.55	38400	85.08	2.84			
16800	-92.97	-3.10	39600	100.19	3.34			
18000	-106.69	-3.56	40800	112.42	3.75			
19200	-117.35	-3.91	42000	121.42	4.05			
20400	-124.62	-4.15	43200	126.92	4.23			
21600	-128.31	-4.28	44400	128.78	4.29			
22200	-128.78	-4.29						

figure H.6 – calculated velocities in the entrance channel

According to this computation, the flow velocity has a magnitude of 4.29 cm/s. This is only due to a tide, so no storm surges or fresh water discharges are present. Local measurements in the Havana Bay show an average SE-orientated flow velocity of 7.33 cm/s under normal circumstances (Lázaro, 2006). This value is a flow velocity measured near the water surface, hence this is not depth averaged. It is assumed that this higher value near the surface is caused by wind patterns and that the average velocity in the channel is lower. The depth averaged velocity is about 0.85 times the velocity at the surface with an error of approximately 15% (Méndez, et al., 1989). If we apply this rough estimation to this case, the depth averaged velocity of the measurements becomes 6.23 cm/s. It can also be stated that it was possible that a different tidal range was active during this measurement, which resulted in a different flow velocity. In chapter '1.5 Conclusions and recommendations', a more detailed conclusion will be made.

H.4 WIND CONDITIONS

H.4.1 DETERMINATION DESIGN STORM

The design storm, for which the structure will be designed, is related to the economic lifetime of the structure (Verhagen, et al., 2009). According to this source, a common lifetime for a breakwater is in the order of 50 years. For designing the marina, also a lifetime of 50 years will be chosen. This may seem short for a marina, but it is assumed that in the 50 years little maintenance is necessary. Of course, after the design lifetime the marina will still be operational.

The determination of the probability of occurrence of the event requires some more explanation. In this case the probability of occurrence is equal to failure of the structure. The actual choice of parameter p depends largely on the purpose of the structure and on the risk involved. If it is a purely economic problem, the acceptable value can be larger than the situation when human lives are involved. In the case of the marina, no human lives are involved and any possible damage is purely economic. Also, damage is allowed during storm events when the marina is not operational. So, in this case, a value of 20% will be chosen for parameter p .

The probability of damage during the lifetime of the marina is given by the Poisson distribution. With the values $T = 50$ and $p = 0.20$, the resulting frequency of the event per year is $1/225$.

$$f = -\frac{1}{T} \ln(1 - p) = -\frac{1}{50} \ln(1 - 0.20) \approx \frac{1}{225}$$

in which:

p = probability of occurrence of an event one or more times in period T

T = considered period in years (lifetime of structure)

F = average frequency of the event per year

This approach is useful for the determination of the design storm for a breakwater, because external forcing is directly linked to failure of the breakwater. However, for the design of a marina and ferry terminal, this link is rather weak. When applying a $1/225$ per year storm for the design, the marina will not be in use during this storm and damage, from an economic point of view, is acceptable. Because of the relatively low construction costs, the design itself does not have to withstand the $1/225$ per year extreme event as reconstruction is more profitable than the expensive realization of a construction that is able to resist such storms.

Instead, the design itself will be much more focused on the usability of the marina and the ferry terminal during normal circumstances, rather than during extreme events.

For a hydrodynamic analysis however, the $1/225$ per year storm is relevant, because it can be considered as an extreme event and for instance, information about occurring wave heights and water levels is wanted from a hydrodynamic point of view. For that reason, the $1/225$ per year value will be used in further analysis and wave heights and wind speeds with a return period of $1/225$ per year have to be determined.

H.4.2 AVERAGE WINDS

For the average annual winds in the Havana Bay, data is available from Windfinder¹⁰ at the ‘Casa Blanca’ measuring station. Data has been gathered from the period September 2005 – December 2012, roughly seven years.

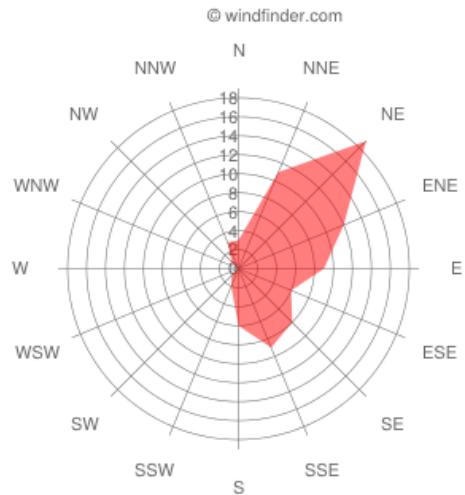
It shows that the annual average wind speed is 6 knots, which corresponds to **3.1 m/s**. The dominant wind direction is NE with an 18% yearly probability. The full data and monthly averages can be seen in figure H.7.

Casa Blanca/La Habana (Habana)

Statistieken gebaseerd op waarnemingen van 9/2005 - 12/2012 dagelijks van 7u tot 7pm lokale tijd.

Maand van het jaar	Jan 01	Feb 02	Mrt 03	Apr 04	Mei 05	Jun 06	Jul 07	Aug 08	Sep 09	Oct 10	Nov 11	Dec 12	Som 1-12
Overheersende windrichting	↙	↗	↗	↗	↗	↗	↗	↗	↗	↗	↘	↗	↗
Wind waarschijnlijkheid > = 4 Beaufort (%)	19	27	35	35	21	19	13	8	11	16	14	21	19
gemiddelde Windsnelheid (Knots)	7	8	9	9	7	7	6	5	6	6	6	7	6
gemiddelde luchttemperatuur (°C)	23	22	24	26	28	29	29	29	28	27	24	24	26
Selecteer maand (Help)	Jan	Feb	Mrt	Apr	Mei	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jaar

Wind dir. distribution Casa Blanca/La Habana all year



Windrichting verdeling (%)
figure H.7 – Windfinder data

¹⁰ @Windfinder, www.windfinder.com

H.4.3 DATA FROM GEOCUBA

The information in this chapter is obtained from the report ‘Oceanic Characterization of the Havana Bay (2006)’, developed by the Cuban Institute ‘GeoCuba’ and main author Lázaro J.

Cuba’s climate is classified as tropical with two distinct seasons; dry season (November to April) and rain season (May to October).

Typically heavy weather events in this region are hurricanes, severe local storms, strong cold fronts and ‘Sures’:

- Hurricanes are part of the most heavy weather category (tropical cyclones) and their corresponding season begins June 1 and ends November 30. The occurrence of hurricanes in Cuba is highly variable with a range from zero to five events per year. In the last century (1901 – 2000), there were 32 years when Cuba was not affected by a hurricane, but in 1933 a total of five hurricanes were active in this region.
- Local storms are associated with local thermal convection in the warm and rainy season and these storms may occur throughout the year, but the highest frequencies are reached from June to September.
- The predominant winds in Cuba are from the northeast – east and these winds are known as trade winds. During cold fronts, which are generated in the Gulf of Mexico, these winds are interrupted and change their direction to the first and fourth quadrant (NW – NE). Cold fronts can occur from May until October with a yearly probability of 99%.
- From September until May, also ‘Sures’ can occur and these strong winds have a mainly southern component. They are generated during the advance of a frontal system and can include tornados.

With a dataset of wind speeds from a period of 21 years, return periods have been calculated by using a Gumbel distribution. These wind speeds are obtained by using measurements from the meteorological station Casablanca, which is located near the Havana Bay. A distinction has been made between blast of winds and three hour averages; this can be seen in table H.1.

table H.1 – return periods and corresponding wind speeds

Return Period (years)	Wind speed (m/s) Blast of wind	Wind speed (m/s) 3 hour averaged
1	23.31	21.74
10	36.82	33.88
25	40.92	38.11
50	43.96	41.23
100	46.98	44.31
200	49.98	47.36
500	53.95	51.36

With table H.1 and figure H.8, a 3 hour averaged wind speed of $4.743 * \ln(225) + 22.4 = 48.09 \text{ m/s}$ has been found using a logarithmic interpolation.

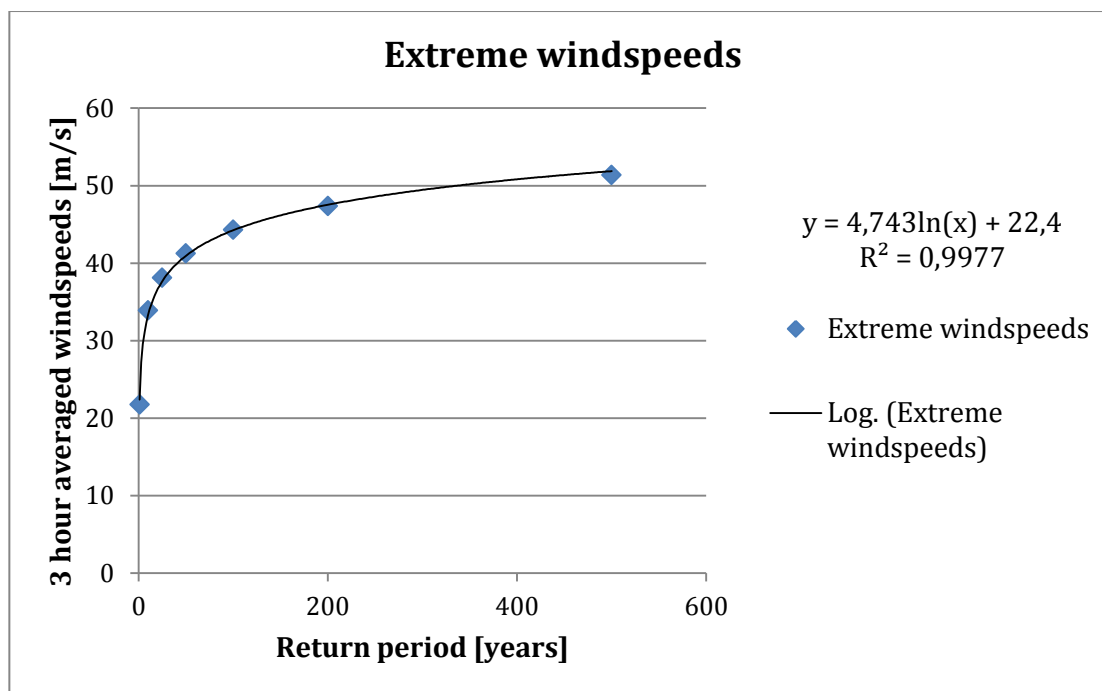


figure H.8 – logarithmic extrapolation of extreme wind speeds

In table H.2, averages of the maximum annual wind speeds are presented from the same dataset that has been used for determining the return periods. This means that from every year in the 21 year dataset, the maximum value has been chosen and then averaged over these 21 values. As can be seen, the predominantly direction is south and south-southwest, which is mainly associated with extratropical systems, local storms and tropical cyclones.

table H.2 – averages of maximum annual wind speed per direction (dataset 21 years)

Direction	NNE	NE	ENE	E	ESE	SE	SSE	S
Frequency of occurrence (%)	3.2	3.2	2.1	2.1	2.1	2.1	7.4	37.9
Average (m/s)	27.4	26.8	22.7	22.7	23.8	29.8	35.3	28.8

Direction	SSW	SW	WSW	W	WNW	NW	NNW	N
Frequency of occurrence (%)	15.8	6.3	1.0	5.3	1.0	5.2	2.1	3.2
Average (m/s)	29.3	31.6	30.6	27.6	22.4	28.0	27.5	26.2

H.4.4 ARGOSS DATA

With the use of ARGOSS data, a wind rose has been created (figure H.9). The ARGOSS data covers a period of 20 years and contains measurements of wind speeds and wind directions obtained every three hours.

It must be stated, that the location of the ARGOSS data is approximately 90 km north of the Havana Bay and that for that reason the figure differs from figure H.7. In this situation, it is reasonable to assume that the mainly easterly winds in the Straits of Florida are coming from the northeast near the Havana Bay.

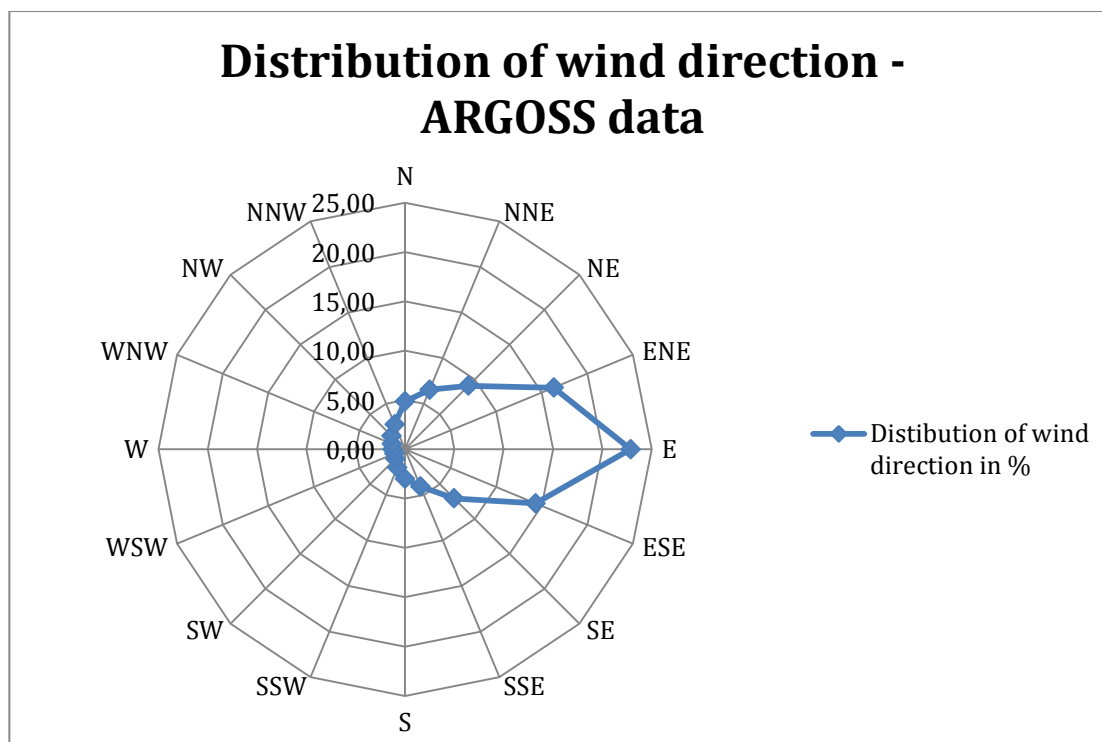


figure H.9 – distribution of wind direction, ARGOSS data.

With this dataset, consisting of 58 432 records, one can easily obtain the occurrence of a certain wind speed (table H.3). This is, for instance, interesting for the design of a marina and ferry terminal, because with this information it is possible to determine the downtime for both facilities.

Note: the ARGOSS data shows a higher average wind speed compared to the average wind speed of Windfinder (6 m/s compared to 3.1 m/s). This is understandable since the ARGOSS data is measured in an offshore oceanic region and the Windfinder data is obtained from measuring station Casablanca in the Havana Bay. Therefore, the values in table H.3 can be interpreted as a conservative upper value. It can be stated that large values of U_{10} , have a better match with the windfinder data.

table H.3 – probability of occurrence for different wind speeds

Beaufort scale	U_{10} (m/s)	Number of records	Probability of occurrence
>1	0.3	58 158	99.5 %
>2	1.6	56 047	95.9 %
>3	3.4	48 386	82.8 %
>4	5.5	33 376	57.1 %
>5	8.0	14 634	25.0 %
>6	10.8	2 977	5.0 %
>7	13.9	346	0.59 %
>8	17.2	79	0.14 %
>9	20.8	33	0.056 %
>10	24.5	11	0.019 %
>11	28.5	6	0.010 %
>12	32.7	2	0.003 %

H.5 SCENARIOS TO BE INVESTIGATED

H.5.1 REGULAR DAY

The situation on a regular day will be investigated to find out if there are any navigational problems for shipping due to high velocities in the entrance channel or near the marina. An ordinary day is useful to study, because the marina is only operational during regular days. In extreme events or storms, sailing is for example not allowed.

The information that is used in this scenario has been obtained in the previous sections and will be the input for the more detailed study with Delft3D.

Tides:

When simulating an ordinary day, a tidal range of 35 cm will be used (chapter H.2, tidal analysis) that occurred on the 14th and 15th of October. This value is close to the mean tidal range and this day is therefore a good representation of an ordinary day.

Winds:

In chapter H.4.2, a yearly averaged wind speed of 3.1 m/s has been found. The dominant wind direction is from the Northeast.

Rainfall and river discharges:

Two rivers discharge into the bay, the Luyanó and the Martín Pérez. Next to these two rivers, a small stream named Tadeo, discharges into the bay. At normal circumstances, the combined discharge of these three sources is 103 310 m³/day (Espinosa, et al., 1983), or 1.2 m³/s. Therefore, in this scenario, the river discharges will not be accounted for.

Other sources of freshwater discharge are sewer drains and ships. Their influence however is limited because they are spread over the whole perimeter of the bay.

Sea level rise:

For simulating a day in the present, there is no need to take global sea level rise into account.

H.5.2 HURRICANE WILMA

Wilma was a hurricane that was formed over the north-western Caribbean Sea on October 15th 2005 and travelled in northerly direction around the west tip of Cuba before cutting across Florida towards the Atlantic (figure H.10).

For Havana it was one of the fiercest hurricanes in recent history, mainly because it produced high storm surges. It is also one of the few hurricanes of which there is some data available concerning water levels, making it possible to reconstruct the water level signal for the days when the surge was highest. This reconstructed water level signal can be used as input to simulate currents caused by Hurricane Wilma.

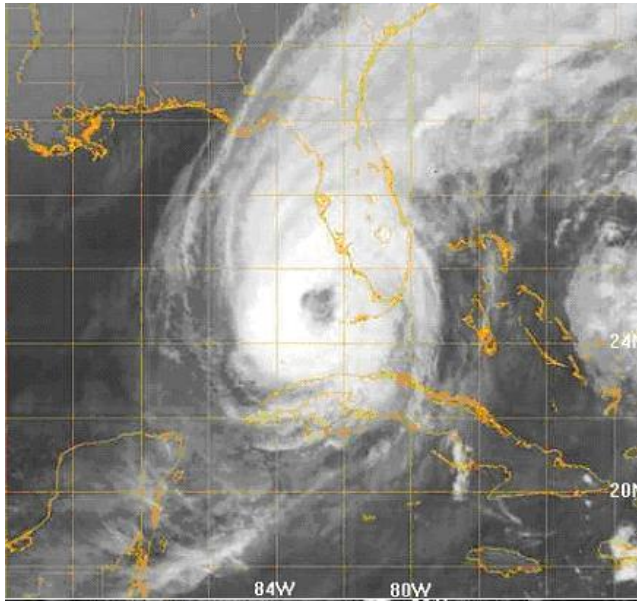


figure H.10 – Hurricane Wilma. Image from satellite GOES 12 on Oct. 24th 2005 at 06:45 UTC

Tides:

The tide forms the basis for the water level signal. Tides for the period of Oct. 19th until the 25th are available as predicted astronomical tides. When Hurricane Wilma was affecting Havana the most, around 3:00 AM on the 24th, the tidal elevation was 0.45 cm (figure H.11)

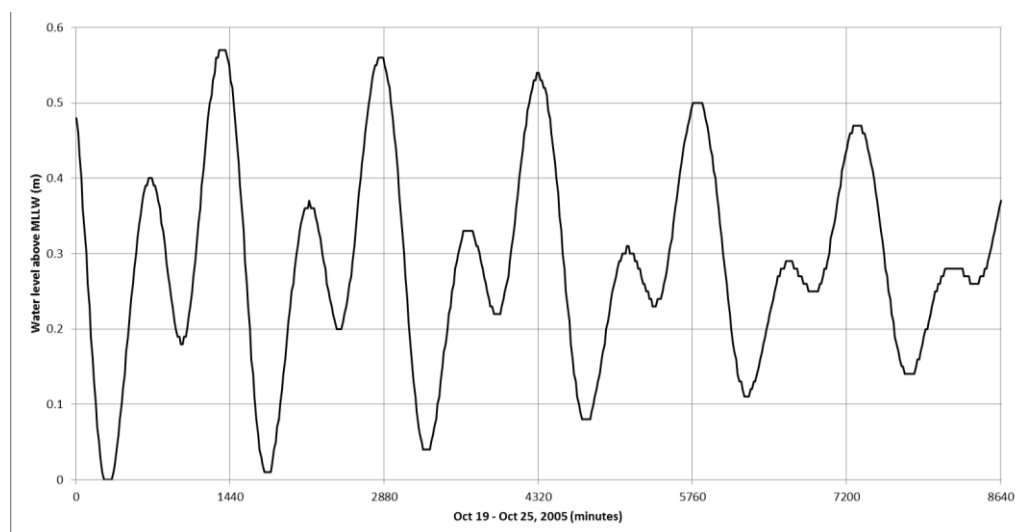


figure H.11 – predicted tidal signal during Hurricane Wilma (Nautical Software Inc.)

Winds:

Wind is a very important factor to consider when one wants to model the effects caused by a hurricane. As wind is the main factor contributing to the storm surge level, it is also an important factor when considering surface currents.

Wind data from Hurricane Wilma for the city of Havana is not abundantly available. Only one document provides a ‘sustained velocity’ of 115 km/h, with gusts of 136 km/h (Cuban weather report on Hurricane Wilma, source unknown). In considering wind induced currents, the most important direction is northeast. Therefore, to simulate Wilma, it is assumed that during the peak hours of the hurricane, a wind with a velocity of 32 m/s from the Northeast occurred.

Rainfall and river discharges:

As there are two small rivers discharging into the bay, it can be interesting to include a hurricane discharge. During regular circumstances the rivers do not have any significance, but hurricanes produce above average levels of rainfall which can increase the discharges.

Measured rain intensities (table H.4) during Hurricane Wilma can only give an idea towards the possible intensities in the Havana area, since no actual measurements are available for the city. Considering the intensities in the cities in Pinar del Río, an estimated 120 mm of rainfall in 24 hours for the Havana area seems reasonable.

table H.4 – rain intensities during Hurricane Wilma (Cuban weather report)

Day	City and province	mm/24 h
15	Jatibonico, Guantánamo	161.5
15	San Antonio del Sur, Guantánamo	128.0
15	Imías, Guantánamo	103.0
15	Caimanera, Guantánamo	101.0
17	Pilón, Granma	151.0
17	Uvero, Santiago de Cuba	200.0
17	Grillo, Santiago de Cuba	145.0
17	Charco Mono, Santiago de Cuba	136.0
17	El Cobre, Santiago de Cuba	131.0
17	Presa Parada, Santiago de Cuba	121.5
17	Vista Alegre, Santiago de Cuba	116.0
20	Mal País, Isla de la Juventud	107.4
20	Paso Real de San Diego, Pinar del Río	116.6
21	Mantua, Pinar del Río	425.5
21	La Bajada Pinar del Río	204.0
21	Isabel Rubio, Pinar del Río	131.0
21	Ciudad de Pinar del Río, Pinar del Río	131.2
21	San Juan y Martínez	112.6
22	Isabel Rubio, Pinar del Río	214.4

To translate rainfall intensity into a river discharge, it is necessary to consider the catchment area of the two rivers. A very rough estimate of the combined area of the two rivers provides a catchment area of 40 km². The combination of intensity and catchment area leads to a discharge of 28 m³/s per river (if the discharge is split evenly among the two rivers). This value can be considered to be small, but if it is compared to the yearly average of 1.2 m³/s it is a relevant contribution.

Sea level rise:

As Hurricane Wilma happened in 2005, climate change may have caused sea level rise in the last years. It can be argued that it is a factor that can be taken into account. However, due to the combination of a lack of solid data and the estimation that sea level rise over a few years plays a minor role, sea level rise will not be taken into account.

Atmospheric pressure:

During hurricanes, low atmospheric pressures can cause storm surges. As the atmospheric pressure decreases, the water level responds by rising. A drop of 1 mbar will cause a rise in water level of 0.01 m (Coastal Engineering Manual, 2006).

Hurricanes are categorized according to table H.5, depending on central pressure and wind speed. Following this system, during the period of 1800 – 2010, 39 hurricanes occurred that affected the province of Havana (MeteoService, 2012).

table H.5 – Saffir-Simpson hurricane scale (Simpson, 1974)

<i>Category</i>	<i>Central pressure (mbar)</i>	<i>Maximum continuous wind speed (km/h)</i>
1	980	118 – 153
2	965 – 979	154 – 177
3	945 – 964	178 – 209
4	920 – 944	210 – 250
5	< 920	> 250

In table H.6, a selection of data about hurricanes is presented. The table shows pressures from a selection of hurricanes, during a phase when they came close to Havana (coordinates: 23.1, -82.3).

table H.6 – selection of hurricane data (MeteoService, 2012)

<i>Hurricane name</i>	<i>Latitude</i>	<i>Longitude</i>	<i>Velocity (knots)</i>	<i>Pressure (mbar)</i>
Kate (1985)	22.7	-80.2	90	971
	23.2	-81.9	80	976
	23.9	-83.5	85	972
Floyd (1987)	23.0	-84.0	60	994
	24.0	-82.9	65	993
Georges (1998)	23.9	-81.3	90	982
Irene (1999)	23.1	-82.6	60	988
	23.8	-82.2	65	988
Rita (2005)	23.9	-81.6	85	975
	24.1	-82.7	95	967
Wilma (2005)	24.0	-84.3	95	958

As hurricanes travel, their characteristics change every hour. The lowest possible value that occurred near Havana was during Hurricane Wilma, 958 mbar. Standard atmospheric pressure (1.0 atm) is 1013 mbar, it should therefore be taken into account that a hurricane like Wilma could result in a maximum rise in water level of 0.55 m in its centre.

As figure H.12 shows, the pressure away from the eye of the hurricane decreases with space. Hurricane Wilma was approximately 200 km (125 miles) distanced from Havana, which according to the figure, can result in an increase in atmospheric pressure of roughly 100 mbar. This would mean that the inverted barometer effect, due to a hurricane far away, would not be directly noticeable in Havana.

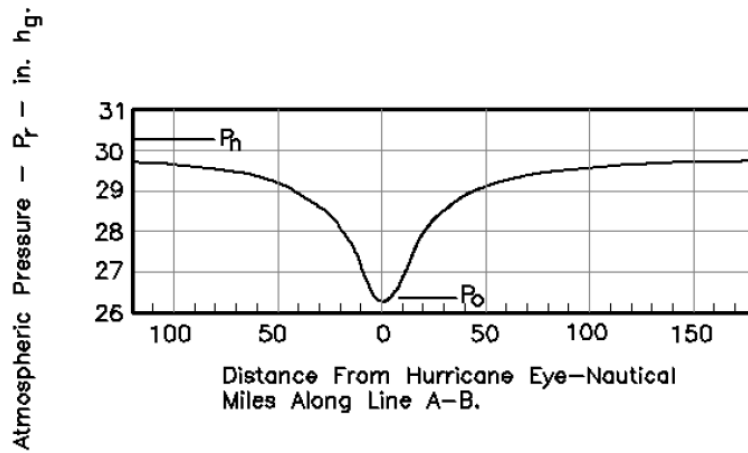


figure H.12 – pressure differences from hurricane eye outward (Coastal Engineering Manual, 2006)

Note:

Normally a statistical method can be used to extrapolate the available measurements to compute design values in case of an extreme event. In this case, data is very limited and extrapolating is not advisable. Besides, hurricane Wilma can be considered to be an extreme event.

Another point to consider is the combination of effects contributing to a surge. The highest rise in water level, due to a low atmospheric pressure, occurs when the centre of a hurricane is closest. But in this situation the fetch for a wind setup decreases as the hurricane approaches.

Storm surge:

- Hind casted storm surges

Specialists from 'Meteorología Institute' have analysed the storm surge level that occurred during Hurricane Wilma with a mathematical model. They state that during the hours of 2:00 AM and 4:00 AM a maximum storm surge level of 1.53 m occurred. During these hours the hurricane was classified as a Category 3 on the Saffir-Simpson scale, blowing winds with a maximum velocity of 195 km/h.

It is unfortunate that the report does not share information about surge levels following or preceding this maximum, taking into account the duration of the surge.

Two other hurricanes have been analysed, the results of which are shown in table H.7. They follow from the same model but give an insight into the severity of Hurricane Wilma.

table H.7 – hind casted set-up levels (MeteoService, 2012)

Tropical cyclone	Date	Calculated surge due to wind (m)	Wave set-up (m)	Astronomical tide (m)	Total elevation (m)
Kate	Nov 11, 1985	0.4	0.41	0.31	1.12
Rita	Sep 21, 2005	0.9	0.31	0.4	1.61

- Hurricane Ivan

A record from Hurricane Ivan taken at Panama City Beach, Florida (figure H.13) shows a surge level signal which provides a basis for what must also have happened in Havana during Wilma. The figure shows a normal predicted tide signal, but during approximately 48 hours there is a clear peak in the water level.

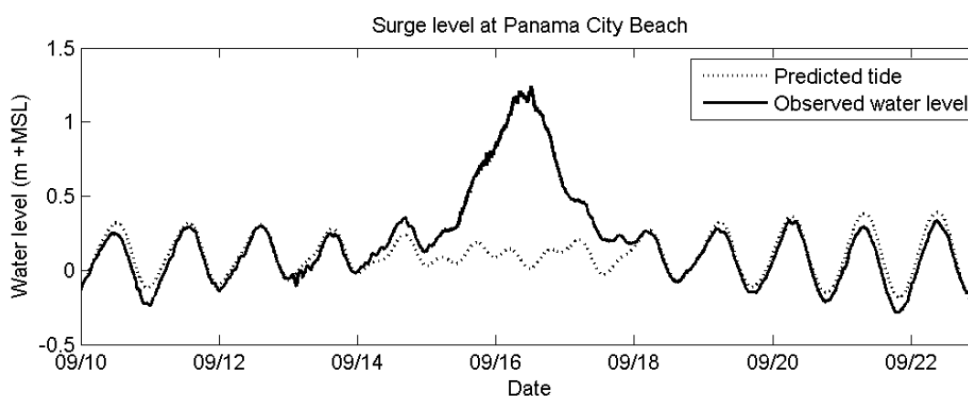


figure H.13 – measured water level (solid line) and predicted astronomical tide (dotted line) at Panama City Beach (Deltares, 2009)

However, the tracks of Ivan and Wilma (figure H.14 and figure H.15) are incomparable if storm surge duration is taken into account. The main difference between the two is that the track of Hurricane Ivan was almost straight towards the Panama City Beach tidal station. Hurricane Ivan passed in front of the coast of Cuba, thereby having less time to produce the storm surge.

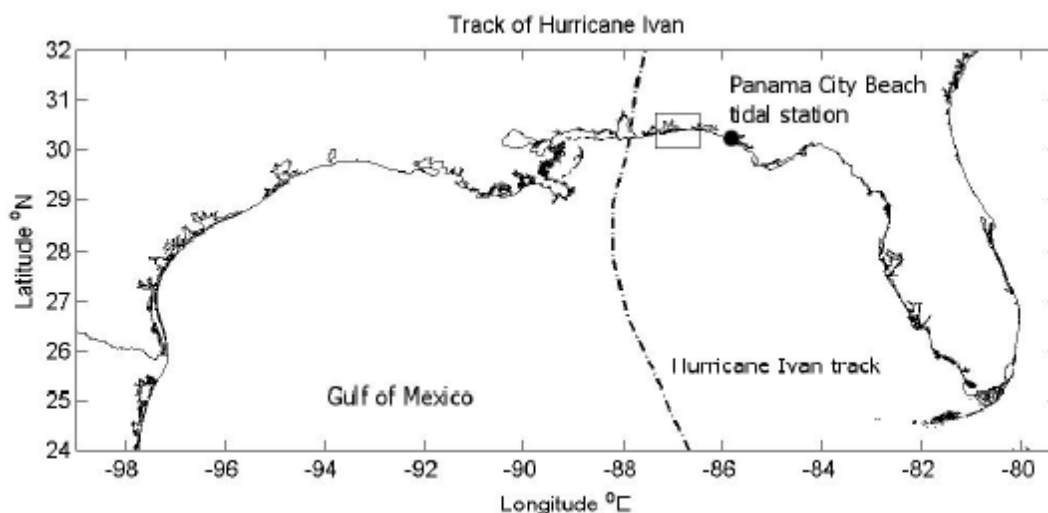


figure H.14 – Hurricane Ivan track (Deltares, 2009)

- Hurricane Wilma

The track of Hurricane Wilma can be seen in figure H.15; it originated in the Caribbean Sea, and travelled across the Yucatan Peninsula towards the seas North of Cuba. A reconstruction of the duration of the storm surge is possible if the track is combined with records of wind directions.

The meteorological station in Casa Blanca recorded three gusts of wind with a velocity of 136 km/h, coming from a south(south)easterly direction. The times these blasts occurred are at 22:30 UTC, 00:40 UTC and 01:20 UTC (Oct. 24th). These records form a basis to state that, concerning the direction and counter clockwise rotation of the hurricane, at 01:20 UTC the hurricane was not able to generate a storm surge.

The maximum storm surge occurred between 02:00 UTC and 04:00 UTC (24th), which means that over a time span of approximately 160 minutes the storm surge was generated.

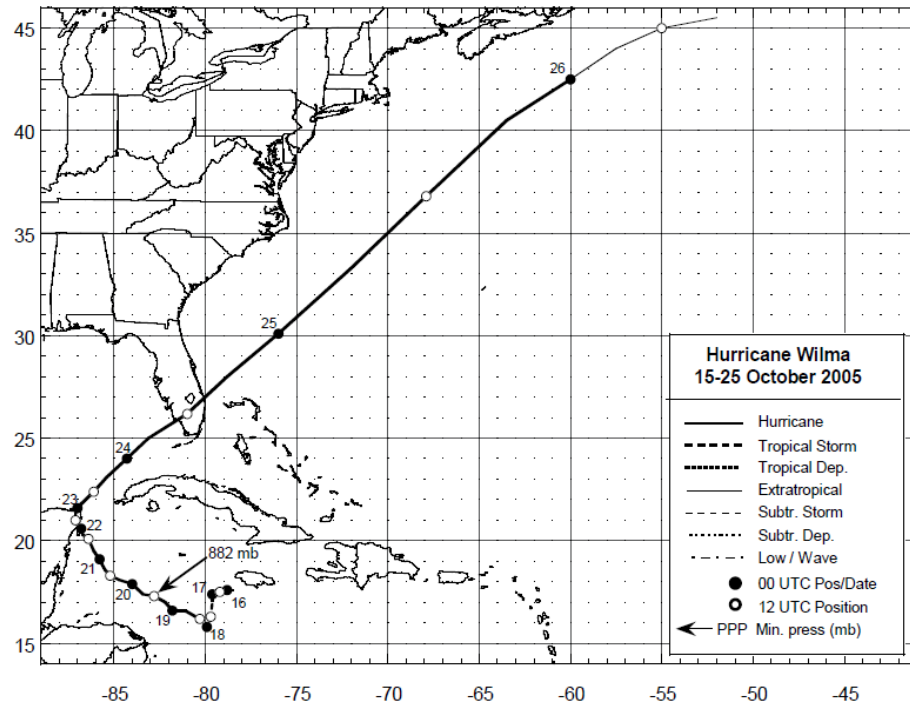


figure H.15 – Hurricane Wilma track (Pasch, et al., 2006)

Wave induced set-up:

Wave induced set-up is difficult to reconstruct as there is uncertainty surrounding the values. MeteoService reported a contribution of 77 cm due to this phenomenon, but calculations made using a SwanOne model with an accurate cross shore profile and using the offshore conditions during Hurricane Wilma, give a lower value of 33 cm (Córdova, 2013).

Next to an uncertainty in water level, there is also uncertainty in timing. Since wave propagation speed exceeds storm translation speed (Coupling of surge and waves for an Ivan-like hurricane impacting the Tampa Bay, Florida region, 2009), the peak caused by wave induced set-up arrives before the storm surge peak. This may mean that the reported 77 cm set-up was not a maximum level, as the maximum must occur in advance of the storm surge maximum. A likelier explanation is an error in computation due to a lack of data. This explanation is corroborated by the SwanOne model results, using correct wave and bathymetry data.

For the wave induced set-up, a peak value of 45 cm is chosen as a compromise between reports. The shape is similar to the peak due to storm surge, but with a shorter time period and steeper slope.

Summary:

All the above contributions are visualised in figure H.16. The continuous black line gives the summation of the predicted tide, storm surge and wave induced set-up water levels.

It is obvious that the storm surge has an important contribution to the total water level, whereas the wave induced set-up has a smaller contribution, peaking in advance of the storm surge peak.

The highest water level of **2.23 m** occurs on 3:00 AM on the 24th of October, when there is a tidal elevation of 0.45 m.

The physical input for this scenario is given below:

- The wind during this hurricane is schematized as a constant wind of 32 m/s (115 km/h) and is coming from the northeast, i.e. 315° from the north.
- Rainfall (120 mm in 24 hours) is translated to a river discharge by estimating a catchment area of 40 km². This combination leads to a discharge of 28 m³/s per river.
- At the location of the Havana Bay, a raise of water level due to a low atmospheric pressure did not occur during hurricane Wilma.
- Sea level rise will not be taken into account.

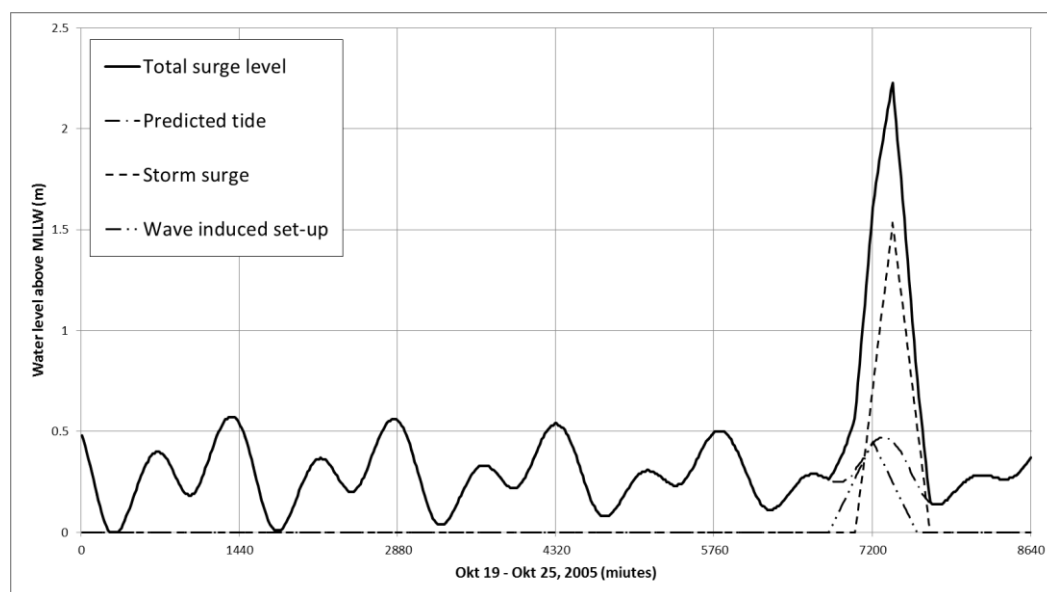


figure H.16 – reconstructed total water level due to Hurricane Wilma for six days

Appendix I: HYDRODYNAMIC ANALYSIS – DELFT3D-FLOW

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I.1 INTRODUCTION

This appendix will focus on the use of the mathematical modelling suite Delft3D – Flow¹¹ (provided by Deltares). To describe FLOW, it is best to quote its user manual: *“Delft3D-FLOW is a multi-dimensional (2D or 3D) hydrodynamic (and transport) simulation program which calculates non-steady flow and transport phenomena that result from tidal and meteorological forcing on a rectilinear or a curvilinear, boundary fitted grid.”* (Delft3D-FLOW, 2011)

As to the question of why to use an advanced modelling suite like FLOW, the answer is twofold. The main reason is that never before a detailed study about the flow patterns of the Havana Bay has been done. No study is available that quantifies flow patterns and velocities in the entrance channel and the bay as a result of tidal and meteorological forcing. Of course, there are general ‘thoughts’ about the hydrodynamic behaviour of the bay, but a translation of these opinions into quantified numbers is lacking.

The second part of the answer follows from the first part and the general goal of this report; what are the conditions in the parts of the bay designated for the marina and ferry terminal, depending on different scenarios.

The main goal of this appendix is to quantify and visualize flows, by simulating two different scenarios, i.e. a period of normal days and a hurricane situation as set out in the previous appendix.

To achieve this goal, first a description of the used model is given in chapter I.2. This will be followed by an explanation of the most important input parameters (I.3), with an extra focus on the boundary conditions. What follows is an analysis of the results of the simulations in chapter I.4, and this appendix ends with the conclusions and recommendations about the simulations and the modelling in general, I.5.

¹¹ From now on: FLOW

I.2 MODEL DESCRIPTION

I.2.1 COORDINATE SYSTEMS

Throughout all the modelling of the Bay of Havana, use has been made of an UTM-coordinate system. This is a Cartesian projection, with coordinates as northing and easting in metres. This decision has been made in the early stages of the project because of supposed simplicity and transparency. By simplicity and transparency is meant that a Cartesian projection in metres, instead of a projection using decimal degrees, gives an easier overview of distances in the model.

This decision implies that all other input data needs converting to the UTM-coordinate system. Most of Cuba, including Havana, is located in UTM-zone 17Q, this is the reference to which all other coordinates using different systems need to be converted¹².

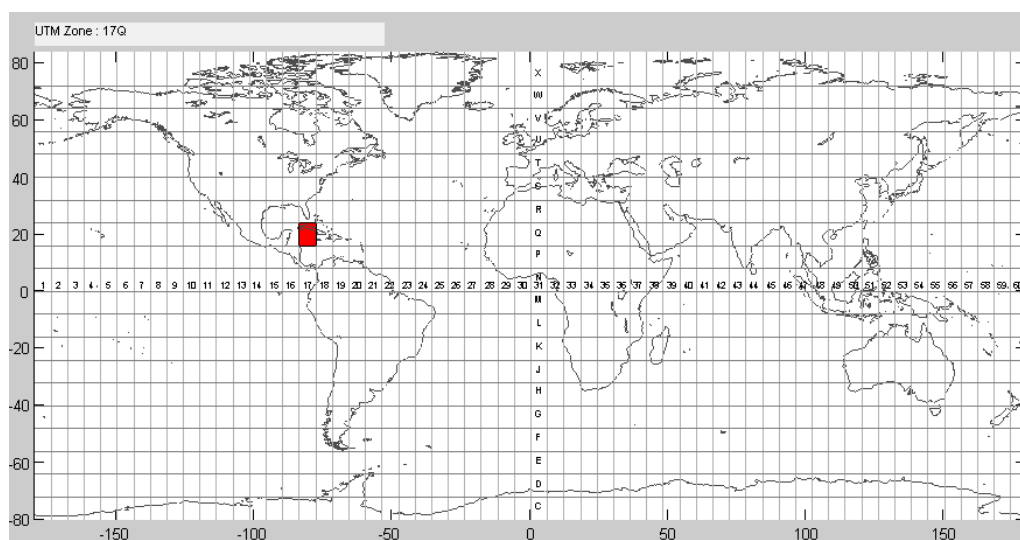


figure I.1 – UTM-coordinate system, zone 17Q of Cuba shown in red (Deltares)

I.2.2 COMPUTATIONAL GRID

As a reference for constructing the model grid a land boundary is used, derived from Google Earth. The computational grid itself can be seen in figure I.2. Important considerations in designing the grid are:

- **Grid density (resolution)**
To achieve the best and most detailed flow patterns, a higher resolution is desired. The drawback of a higher resolution is a longer computation time, a balance should be found between an acceptable accuracy and computation time. Therefore, a choice is made to give areas of low interest, low resolution and vice versa. Areas of high interest are the inlet channel, the areas around the existing piers on the west part of the harbour and the supposed locations of the marina and ferry terminal.
From the figure it can also be seen that there are other areas with a higher density, this is due to the curvature of the grid and restrictions in the modification of specific grid regions and therefore the increased resolution is unintended.

¹² Programs used to convert coordinates are: Google Earth, GEPATH 1.4.6, The Geographic Calculator and a batch convert spread sheet by Steve Dutch of the University of Wisconsin-Green Bay.

- Grid shape
To model the bay in greater detail, a curvilinear grid is used (instead of a rectilinear grid). A curvilinear grid makes it possible to better model the irregular shapes of the bay and its harbour basins. This is especially of interest to visualize the flow patterns at the entrance of the inlet channel.
- Boundary location
The model has three open boundaries, two are perpendicular to the coast and one is parallel. In the placement of the boundaries it is important to consider the distance they are removed from the closed boundaries and the areas of interest. This is because reflected waves propagating towards the open boundaries should be damped out before they are at the open boundary. This means that the boundaries should be located as far away from the areas of interest as possible.
- Water volume
To approach reality as much as possible, it is desired that the volume of water stored in the model is close to the volume in the actual bay. Therefore it is important to let the grid cells cover most of the area enclosed by the land boundary, and to fit them where possible to the land boundary.

More detailed structures of the harbour, such as piers, will be modelled using other means (this will be discussed in following paragraphs).

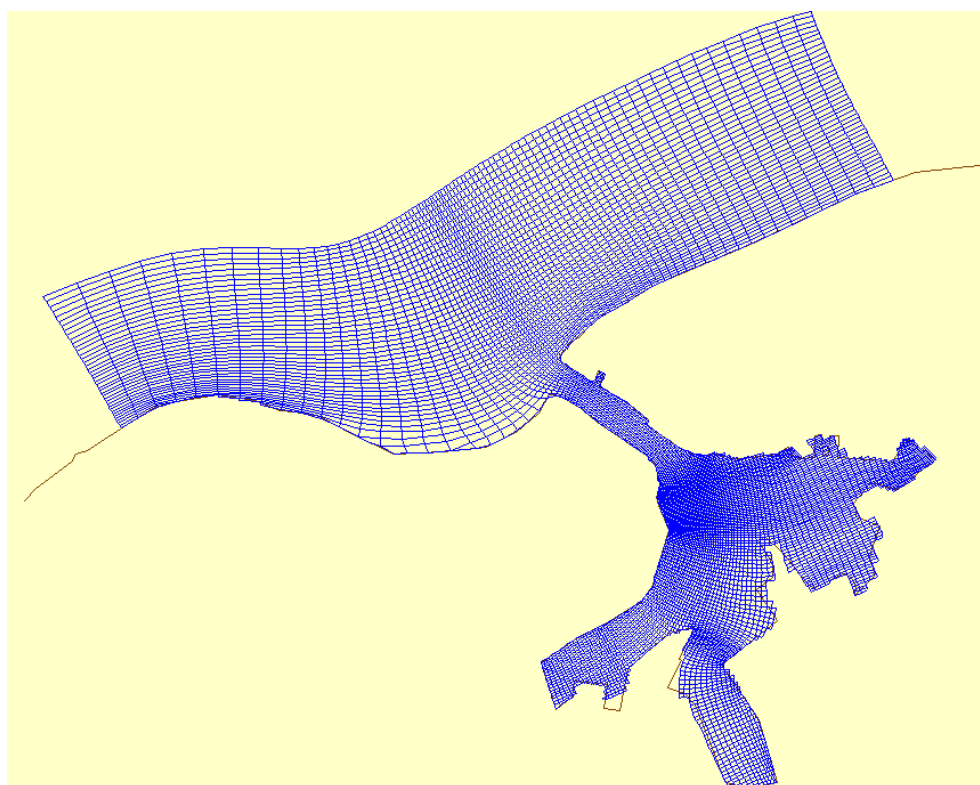


figure I.2 – land boundary with computational grid

I.2.3 BATHYMETRY

In order to make an accurate depth file, data provided by researchers from CUJAE University have been used. Two datasets of depth samples have been provided, one for the bay and entrance channel, and one consisting of depth contours for the area outside of the entrance channel. Converting these samples to UTM coordinates, combining and fine-tuning them, has resulted in the bathymetry shown in figure I.3.

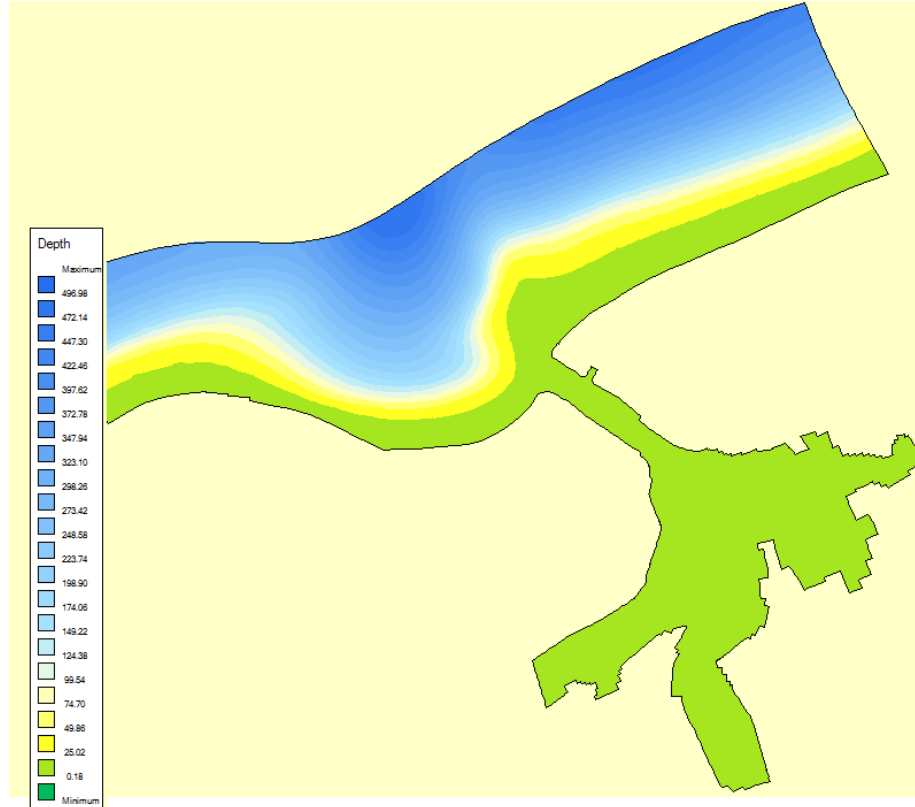


figure I.3 – bathymetry of the Bay of Havana and surrounding ocean

The figure above gives a slightly distorted look, because of the great depth of the Straits of Florida. A close-up of the entrance channel (figure I.4) shows the level of detail that is available.

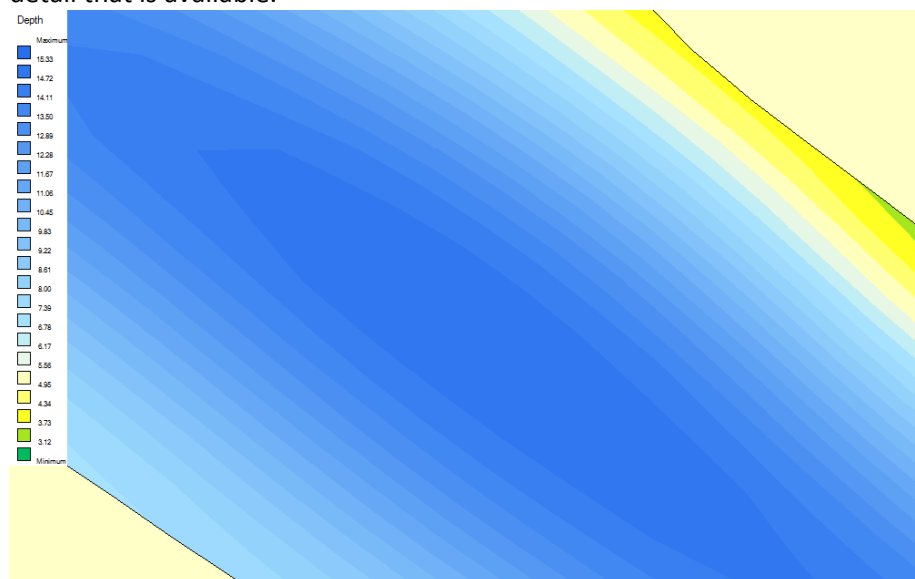


figure I.4 – close-up of the entrance channel

I.2.4 BOUNDARIES

The boundary conditions are the most critical input. There are three boundary conditions imposed, the location of the boundaries can be seen in figure I.5. The assumption is made that because of the deep water and the relatively short stretch of coastline, a tidal wave propagates swiftly along the coast without creating a phase difference. This assumption enables the use of an offshore boundary with a water elevation forcing type, in combination with two Neumann-type boundaries for the cross-shore boundaries. Because of an assumed lack of phase difference, the alongshore water level gradient the Neumann-type boundaries describe, can be taken as zero.

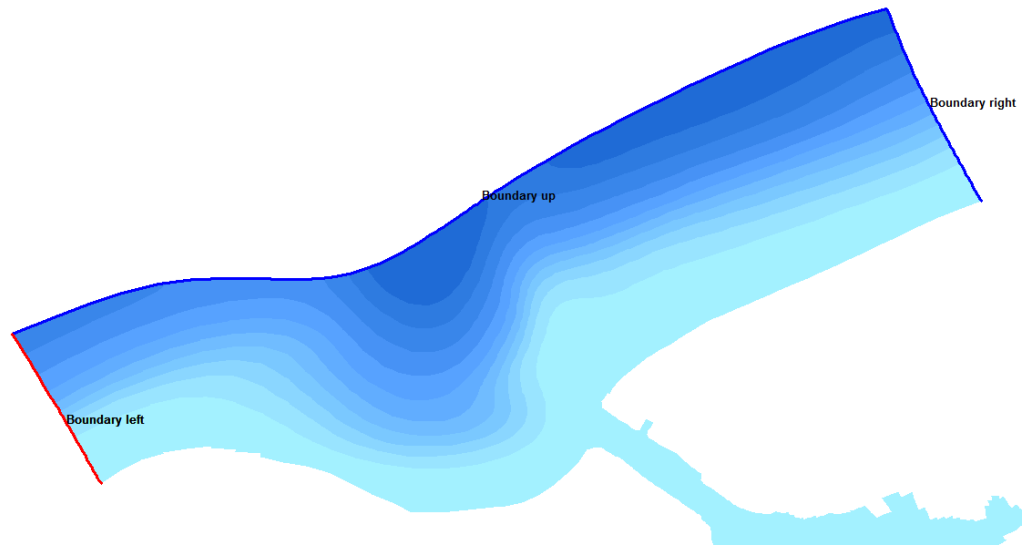


figure I.5 – boundary locations visualized

I.2.5 PIERS – DRY POINTS AND THIN DAMS

The existing terminals along the west of the bay are modelled using the dry points and thin dams features of Delft3D. Although it is known that some of the piers have been constructed using an open pile foundation instead of closed quay walls, it is assumed that they can be modelled using these methods. The piers and jetties in the eastern part of the harbour have not been modelled, since they are outside of the scope of this study.

Please note that the Margerito Iglesias 1, 2 and 3 piers have been removed in this model, according with the master plan of Tourist Port Havana.



figure I.6 – location of piers

I.2.6 DISCHARGES

The two rivers that discharge into the bay can be modelled as discharge points. For a regular situation the discharge is of such a level that it can be neglected. However, in section H.5.2 Hurricane Wilma, a discharge of $28 \text{ m}^3/\text{s}$ per river was determined, which was the result of a rainfall of 120 mm in 24 hours and a catchment area of 40 km^2 in total for both rivers. The total discharge into the bay will therefore be $28 * 2 = 56 \text{ m}^3/\text{s}$ during hurricane Wilma.

I.2.7 OBSERVATION POINTS

Within the model, observation points can be specified. This is useful because in these stationary points, one can easily see variations in time, e.g. water levels or depth averaged velocities.

In the model, four observation points are specified; one boundary observation point, two points in the channel and one point near the location of the marina. This can be seen in figure I.7.

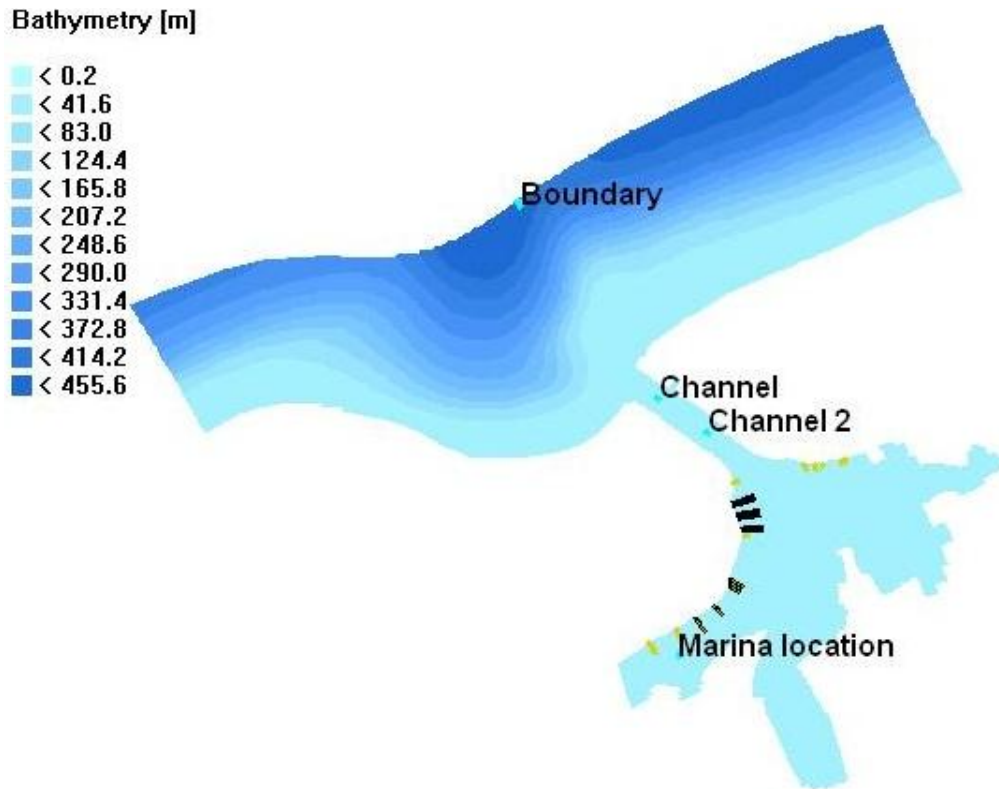


figure I.7 – locations of observation points

I.3 INPUT PER SCENARIO

I.3.1 NORMAL TIDE SITUATION

Time frame:

The simulation will run for 144 hours, with a reference date of Oct. 10 2013, finishing Oct. 16 2013. The computational time step, Δt , is taken as 0.2 minutes, i.e. 12 seconds. This should provide sufficient stability with a limited computational time. The reason for the simulated period of 144 hours is accuracy, because initial perturbations will have damped out after a few tidal cycles (Delft3D-FLOW, 2011 p. 46).

Initial conditions:

A uniform initial condition is used, that matches the first value of the boundary condition to prevent initial shockwaves propagating through the model. This should also limit the smoothing period to the default 60 minutes.

Boundaries:

The forcing type for the offshore boundary is a time-series of water elevations. For the time records, 6 days of predicted astronomical tides are used, with increments of 3 minutes. By ensuring that there are enough input values, a sufficiently smooth input signal is generated (figure I.8).

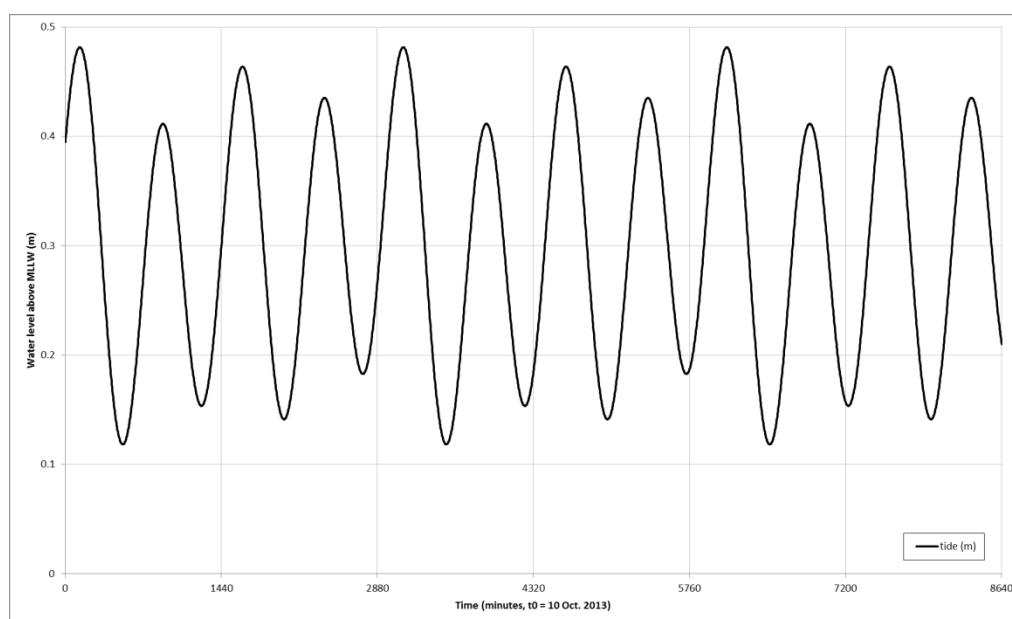


figure I.8 – tidal signal from Oct. 10 to Oct. 16

Physical parameters:

In considering the physical parameters, only non-default values will be named. For water density a value of 1025 kg/m^3 is used, and for wind a velocity of 3.1 m/s and a direction of 45° are used. This is wind blowing from the northeast, which is the dominant direction throughout the year.

Numerical parameters:

All numerical parameters are set to default values. Since the initial condition matches the boundary condition, the smoothing period does not require changing.

I.3.2 HURRICANE WILMA

Time frame:

The simulation will start four days in advance of the hurricane, starting Oct. 19th of 2005 and finishing Oct. 25 at 00:00h.

Initial conditions:

For the initial condition a uniform value is chosen for the reasons set out in the previous paragraph. The value is 0.46 m, as it is the value of the tidal elevation at the first time step.

Boundaries:

The offshore boundary is a water elevation time series, in three minute increments, derived from the signal in figure I.9. The other two boundaries (west and east) are Neumann type boundaries that describe an alongshore water level gradient of zero.

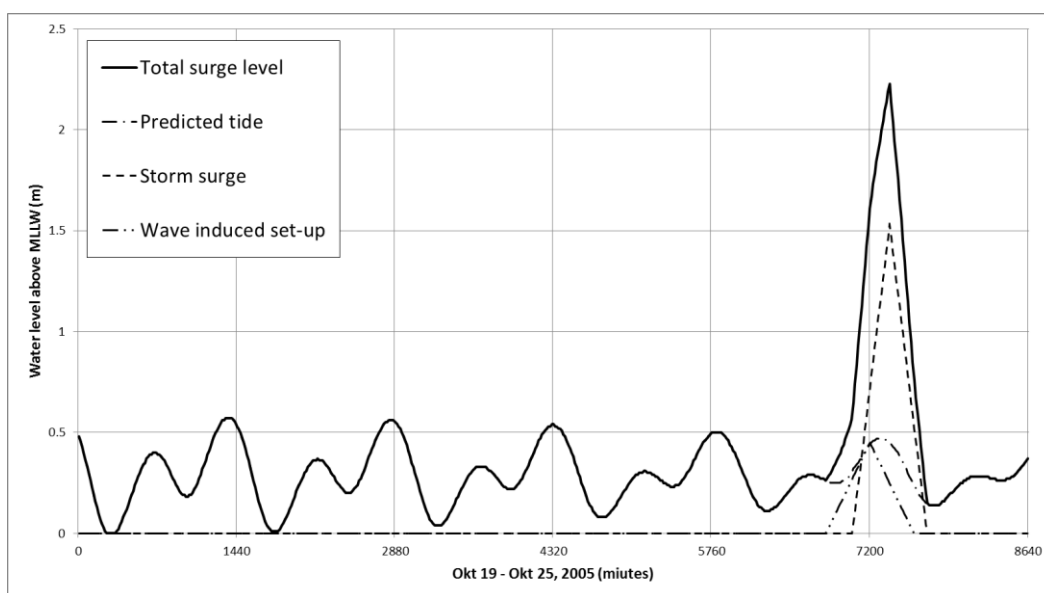


figure I.9 – reconstructed total water level due to Hurricane Wilma for six days

Physical parameters:

The wind is added as a uniform value of 32 m/s, blowing from the northeast, i.e. 315° from the north.

Also, a constant discharge of 28 m³/s per river will enter the bay as was determined in the previous section. This will also be added to the model by discharge points.

As the depth greatly varies across the model, initial perturbations take long to damp out. This is because the water depth at the boundaries is too large for friction to have an effect. To compensate for this, the horizontal eddy viscosity is varied across the model. In the areas of interest it has a normal value of 1 m²/s, whereas a value of 10 m²/s is used in the deeper areas, with a smooth transitional area.

Numerical parameters:

All numerical parameters are set to default values. Since the initial condition matches the boundary condition, the smoothing period does not require changing.

I.4 OUTPUT PER SCENARIO

In this chapter the model results will be presented. In the beginning the focus will be on larger scales, by looking at the bay as a whole. After that, the focus will shift towards the details, looking at portions of the system.

I.4.1 NORMAL TIDE SITUATION

Whole system:

- Water levels:

Water levels are what determine flow velocities. The main idea behind flow from ocean to bay, through the inlet channel, is a (small) difference in water levels.

These differences in water levels are visualized in figure I.10. The two images show water levels with a period of 6 hours in between. It can be seen in the image on the left, that at this point in time the ocean water level is higher than the level in the bay. 6 Hours later, on the right, the reverse can be seen. It is this phenomenon that causes currents in the channel.

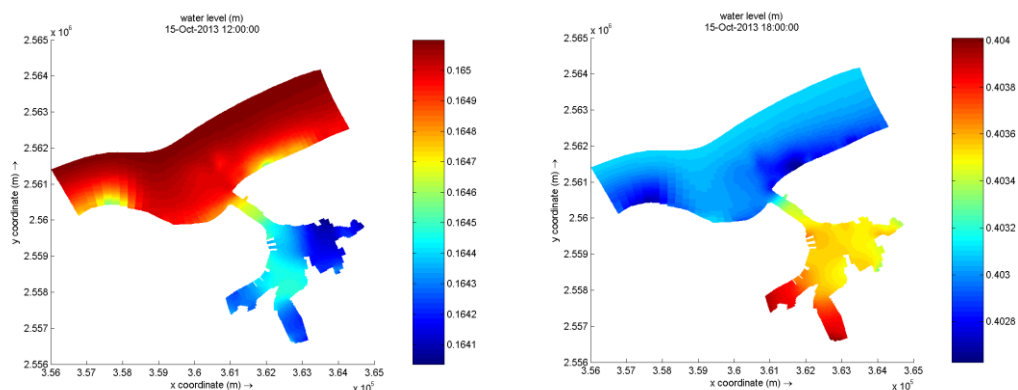


figure I.10 – water levels Oct. 15 (12:00 left, 18:00 right), dynamic legends

As can be seen from the images above, the legends of the two are not similar. This is caused by the fact that the legend scales according with the data it represents. If a fixed legend is used, scaled with a maximum of 0.5 m and a minimum of 0.1 m, the pictures do not show any water level difference (figure I.11).

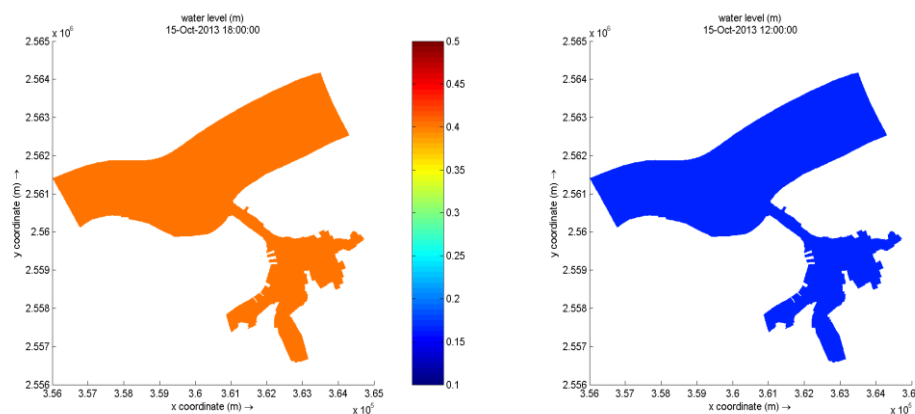


figure I.11 – water levels Oct. 15 (12:00 left, 18:00 right), fixed legends

These two apparent contradictions can be explained by considering the tidal propagation into the bay. As has been stated before, in the previous appendix, the characteristics of the combined channel and bay determine the type of response of the system towards the tidal forcing.

In this case, it appears that the bay responds nearly instantaneous towards the tidal forcing. That means that as the tidal wave propagates into the bay, it is only hindered minimally by the entrance channel. The amount of hindrance the channel provides, determines the amount of the phase difference between ocean and bay water levels. In the case of the Bay of Havana, the bay appears relatively small compared to the inlet channel.

The image on the left in figure I.12 shows what theoretically is happening in the bay. The ocean tide propagates into the bay, and transforms into a bay tide. The bay tide has a similar shape, but has a certain phase lag, which causes water level variations. The image on the right shows the situation for the Bay of Havana, and visually explains the lack of high flow velocities, as there is no discernible phase lag.

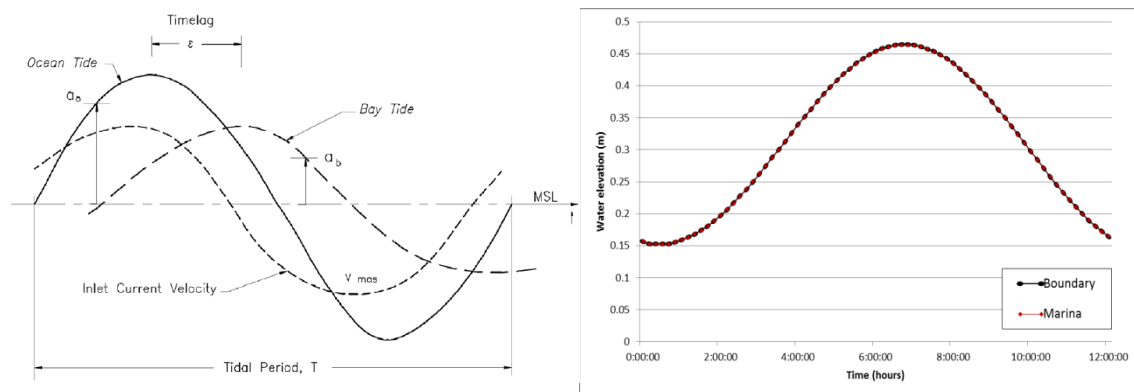


figure I.12 – theory (Coastal Engineering Manual, 2006) (image left) and reality (image right)

- Depth averaged velocities¹³:
Depth averaged velocities occur due to the small variations in water levels, as explained in the previous section. It is assumed that the highest velocities occur in the entrance channel due to the relative narrow width. This can be seen in figure I.13. Farther Bay inward, the velocities decrease rapidly. In this figure, only the magnitude is given, so there is no information about the direction of the flow. This will be evaluated in the next chapter, ‘entrance channel’.

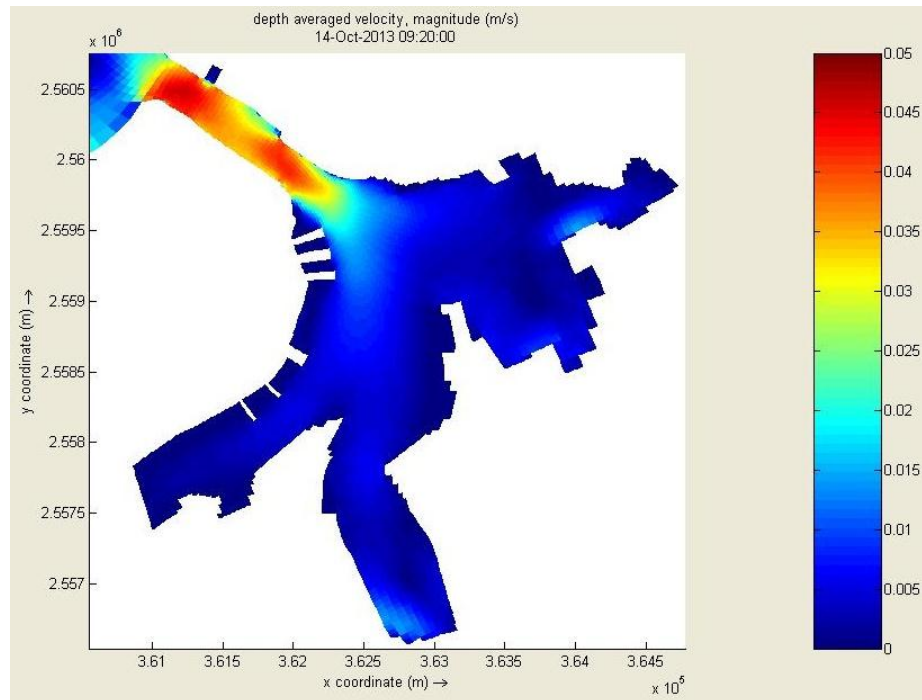


figure I.13 – depth averaged velocity (magnitude); Havana Bay area

Entrance channel:

- Water levels:
The water levels in the entrance channel are changing at almost the same time as the water levels near the boundary. However, there is a delay, but this is very small due to the co-oscillating character of the bay. Consequently, the water levels in the entrance channel are the same as in figure I.12. When the water levels are rising, it is assumed that there is inflow towards the bay and vice versa. Also, when the slope of the water level is maximal upward, the depth averaged velocity is assumed to reach its maximum absolute value.
- Depth averaged velocities:
In figure I.14, it can be seen that it takes almost two days for the initial perturbations to damp out. From the 12th of October until the 16th of October the signal is clean, i.e. without wiggles. Only this data will be taken into account.

¹³ Since the model is set up as a 2DH model, there is only one layer in the vertical direction. This has the consequence that velocities in a water column are computed as depth averages.

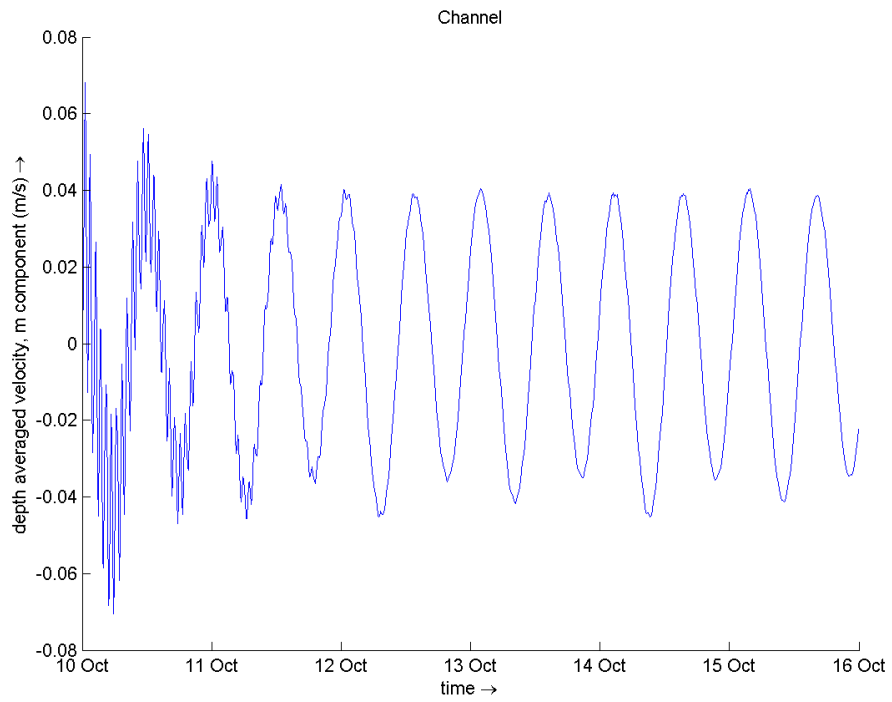


figure I.14 – depth averaged velocity (observation point); entrance channel

In figure I.15, a close-up of the entrance channel is given during a time when maximum flow velocities occur. A typical maximum value is 4.0 cm/s, which is very similar to the flow velocity obtained at the ‘basin storage’ approach (4.3 cm/s).

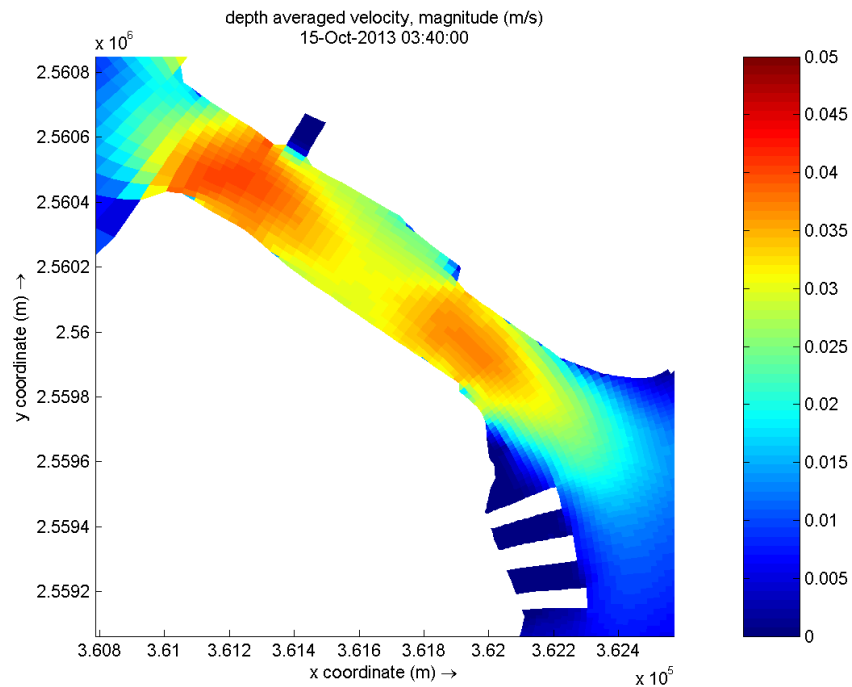


figure I.15 – depth averaged velocity (magnitude); entrance channel

In figure I.16 and figure I.17, two moments in time are shown, when maximal inflow and maximum outflow occur. There is approximately six hours in between those moments, which corresponds to the water level graph.

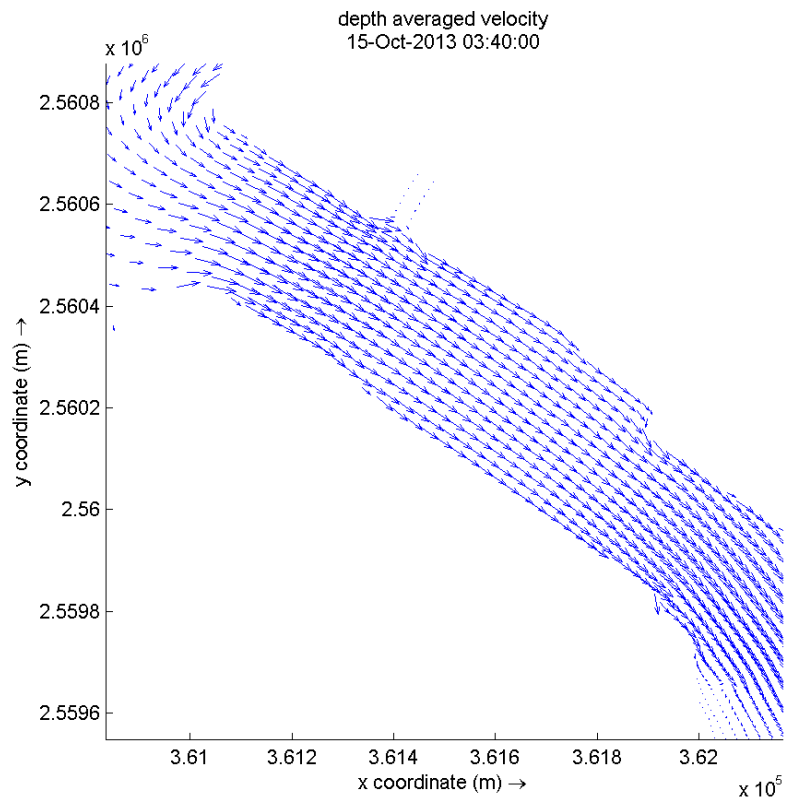


figure I.16 – depth averaged velocity (vector); inflow

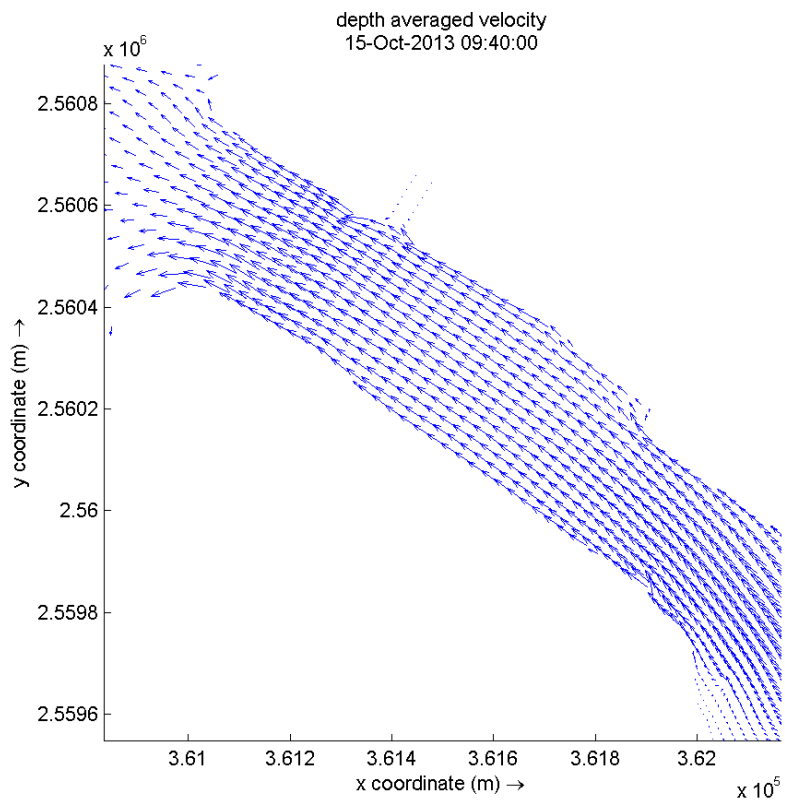


figure I.17 – depth averaged velocity (vector); outflow

Ensenada de Atarés:

- Water levels:
For the entrance channel it appeared that the water levels are changing at (almost) the same time as the water levels near the boundary. This proves to be the case for the Ensenada de Atarés as well, in which the marina will be located. In fact, this was already expected due to the high propagation speed of the tidal wave. In chapter H.2 was calculated that a tidal wave will propagate through the entire system in about 8 minutes. This is very short compared to the tidal period of 12 hours, so the water level is almost instantaneous responding to the tide.
- Depth averaged velocities:
From observation point 'Marina location', it appears that the flow velocities are very low due to the external tide. In the entrance channel, the flow velocity was about 4.0 cm/s. It is expected that the flow velocities near the marina are substantially smaller due to a greater width and due to the closed side at the south of the basin. It appears that maximum flow velocities occur of 0.25 cm/s (figure I.18).

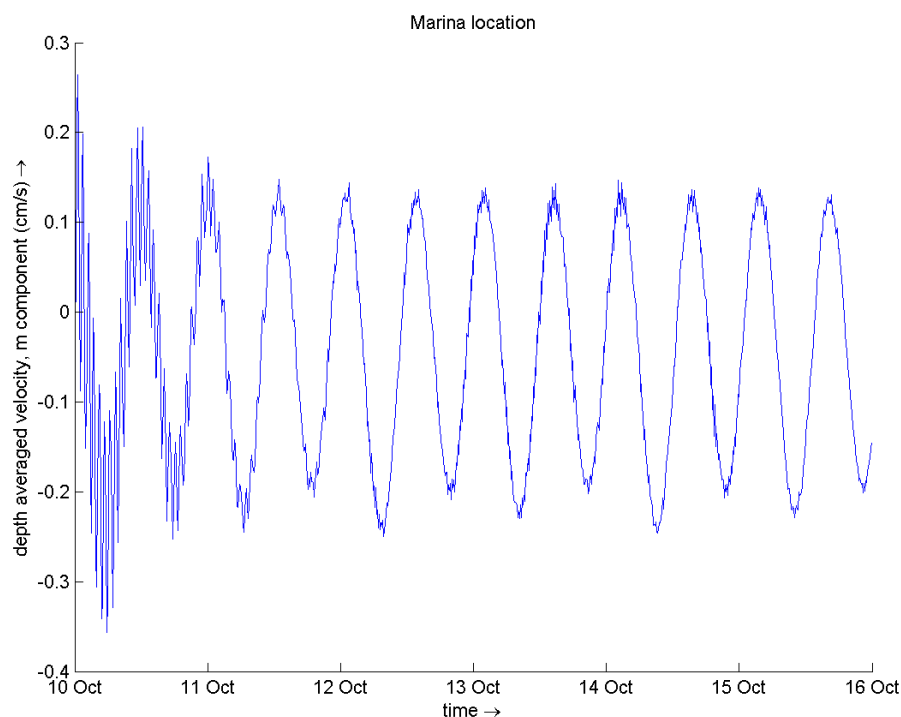


figure I.18 – depth averaged velocity (observation point); marina location

I.4.2 HURRICANE WILMA

Whole system:

Hurricane Wilma can be considered to be similar to a normal tidal situation. The main difference between the two is that for Wilma there is a much higher water elevation, although it is only for a relatively short time. In this section it will be investigated whether the bay-inlet system is still able to swiftly adapt to the higher water elevation

- Water levels:

The difference in water level between bay and ocean is most telling of the occurring flow velocities. This difference over time is visualized in figure I.19, it can be see that the blue line (the water level in the Bay of Atarés) is nearly all the time above the red line (ocean water level) but there is a not a clear phase difference. From this it can already be concluded that there will not be high flow velocities, i.e. the bay is able to swiftly adapt to the storm surge.

The fact that the water level in the marina is higher can be contributed to the addition of fresh water discharge from the two rivers. This discharge is added to the tide and storm surge and leaves the bay through the entrance channel (for details see the paragraph 'Entrance channel').

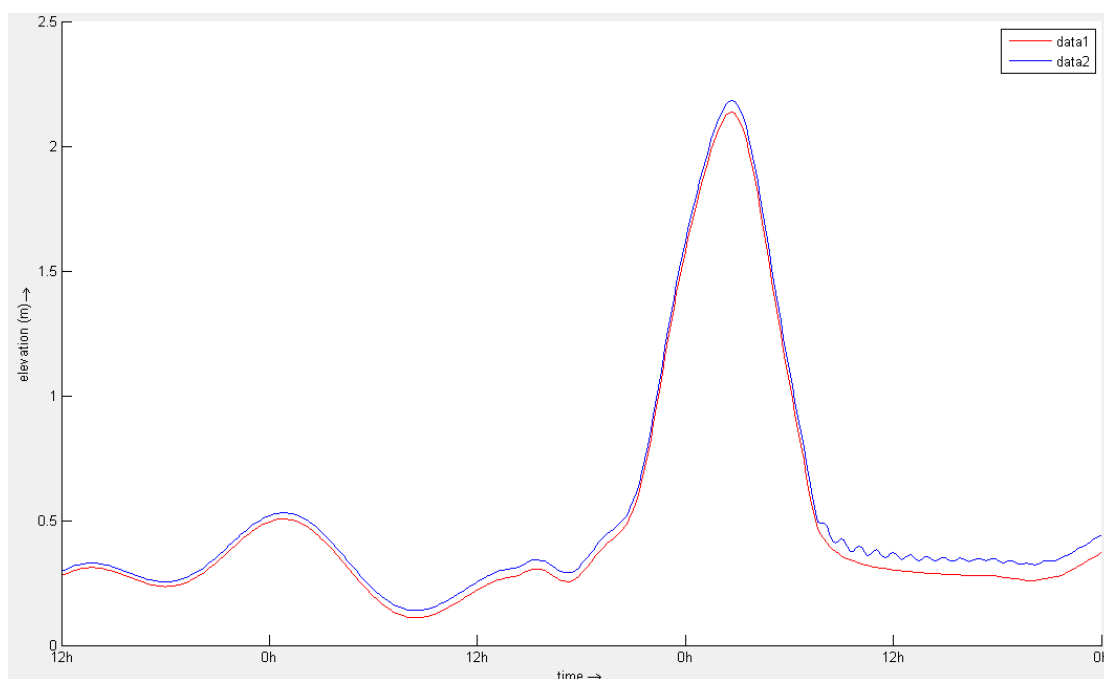


figure I.19 – water levels from Oct. 22 12:00h until Oct. 25 00:00h, boundary (red) and Atares (blue)

- Depth averaged velocities:

As with a normal tidal situation the highest flow velocities occur in the channel. The rest of the bay has much lower current velocities, as can be seen in figure I.20. What else is noticeable in the figure is the formation of eddies in parts of the bay. An especially strong one is formed southeast of the entrance channel, when the storm surge is receding.

Other parts of the bay with noticeable patches of yellow/red (higher flow velocities) are located in the south and some in the west. These flows are likely the result of instabilities in the model.

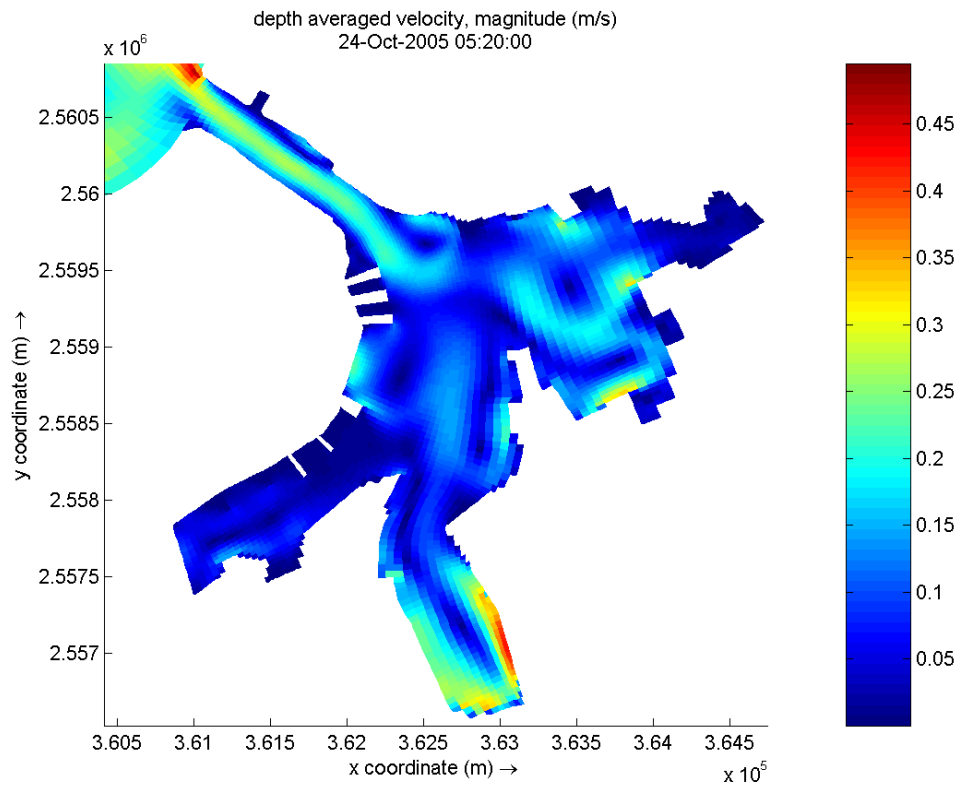


figure I.20 – flow velocities for the Bay of Havana during Hurricane Wilma

Entrance channel:

The flow velocities over time in the entrance channel are presented in figure I.21. The peak of the storm surge is clearly represented in the flow velocity. There is a peak of inflow, which yields a maximum inflow velocity of 23 cm/s, followed by a maximum outflow velocity of 18 cm/s.

The wiggles in the signal that follow the hurricane are attributed to a lack of robustness of the model.

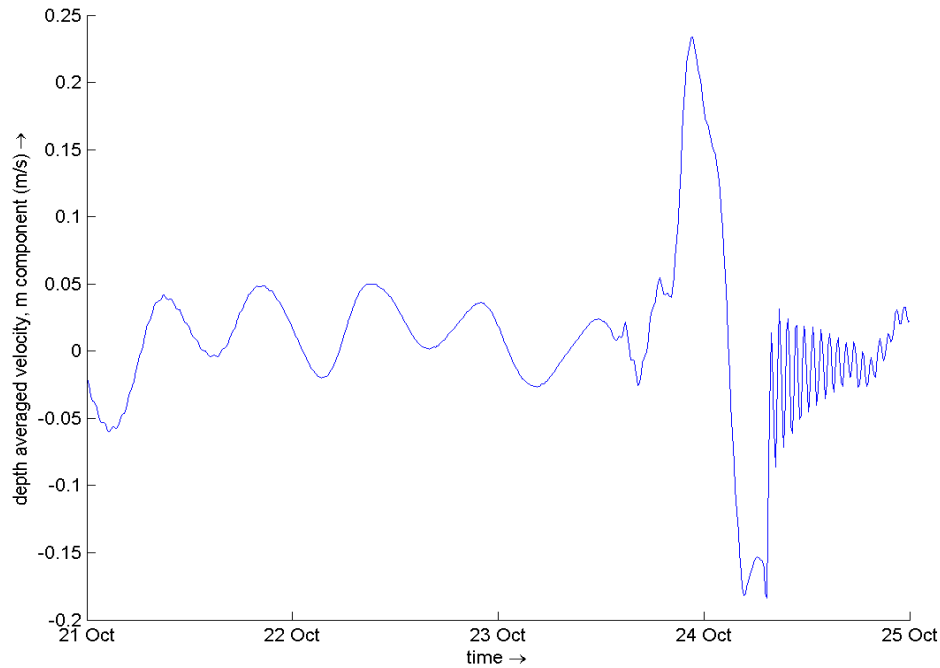


figure I.21 – depth averaged flow velocities in the entrance channel

There is also a concentration of in- and outflow in the channel. This is especially noticeable in an outflow situation. It appears that the shape of the channel enhances the formation of a flow channel, as the flow is too fast to make use of the full channel width. This can be attributed to the recess on the north side of the channel, where dark blue colours (lower flow velocities) can clearly be seen (figure I.22).

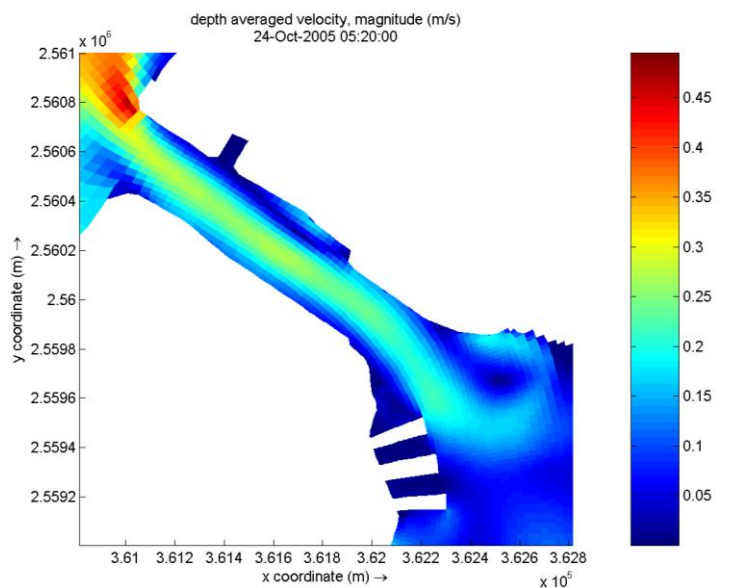


figure I.22 – flow concentration in the channel

I.5 CONCLUSIONS AND RECOMMENDATIONS

I.5.1 NORMAL TIDE SITUATION

The output of the Delft3D-flow simulation shows an average current in the entrance channel of 4 cm/s, both during low tide as during high tide. This is close to the value obtained from the basin storage approach.

However, in reality the case is much more complex. A report about the characterization of the Havana Bay (Lázaro, 2006) shows that the flow patterns differ in the vertical water column. A distinction can be made between two layers. In the upper layer, less dense water is **constantly** flowing towards the sea, even in the case of tidal inflow. According to the report, this is the result of fresh water discharge ($17 \text{ m}^3/\text{s}$) into the bay from natural streams, industrial activity et cetera. In the lower layer there is mainly in- and outflow of salt water caused by the tide. Therefore, *it can be reasoned that the tidal flow is concentrating in the lower part of the basin and that the fresh water discharge is concentrated in the upper part.*

Circulation of water with a rising tide

The global trend is outflow of water in the upper layer and inflow of water in the lower layer.

Measurements carried out in the *upper* layer give the following result:

- In the centre of the entrance channel: outflow of 7.8 cm/s.
- Left side of entrance channel: outflow of 4.0 cm/s.
- Right side of entrance channel (near Casablanca): tidal inflow in SE direction of 4.7 cm/s

Measurements carried out in the *lower* layer give the following result:

- In the centre of the entrance channel: inflow of 12.5 cm/s.
- Left side of entrance channel: inflow of 4.0 cm/s.
- Right side of entrance channel (near Casablanca): inflow of 7.0 cm/s.

Inside the Bay, the general trend of flow is movement towards the water outlet. Average speeds of 15 cm/s occur near the main piers and jetties.

Circulation of water with a falling tide

The global trend is more intense outflow of water in the upper layer and less intense inflow of water in the lower layer.

Measurements carried out in the *upper* layer give the following result:

- In the centre of the entrance channel: outflow of 12.9 cm/s.
- Left side of entrance channel: outflow of 4.0 cm/s.
- Right side of entrance channel (near Casablanca): outflow of 6.0 cm/s.

Measurements carried out in the *lower* layer give the following result:

- In the centre of the entrance channel: inflow of 8.9 cm/s.
- Left side of entrance channel: inflow of 4.0 cm/s.
- Right side of entrance channel (near Casablanca): inflow of 5.3 cm/s.

Inside the bay, also here the general trend is movement towards the water outlet with the same magnitude of 15 cm/s near piers and jetties.

It must be stated that regardless of the above, winds determine the magnitude and direction of the current in the upper layer of about 20 cm thickness.

If one wants to obtain the same results in Delft3D-Flow, the model needs to be adapted from a depth averaged model to a 2DH model with several layers or even a fully three dimensional model. However, for a rough estimation of the occurring currents in the entrance channel, both the results of the basin storage approach and the Delft3D-flow simulation show a good resemblance with reality.

The final conclusion of this scenario is that in this normal situation, which is of major importance for the usability of a marina and ferry terminal, no currents will occur with a negative impact on the navigability for ships. This holds for both the entrance channel as the marina itself.

I.5.2 HURRICANE WILMA

From an engineering point of view the modelling of a hurricane seems interesting. Even though hurricanes can occur rather frequently, they are considered to be extreme cases. To know the behaviour of the Bay of Havana during an extreme event is useful.

In the case of the Bay of Havana however, it seems that knowing the flow characteristics during a hurricane with a high storm surge is less relevant. During such a hurricane there are other processes taking place which, after the modelling, can be rated as 'more important'.

An important aspect to realize is that due to the rock foundation, there is no change in coastal morphology. The water flows in and out and the system stays in the same shape, the flows have no permanent impact on the system in the timescales considered. Whereas for design reasons, the other processes such as wind and waves are of more importance.

The most important conclusion is that the flow velocities are more dependent on the inlet-bay dimensions than on the external forcing, which is proven by the simulations. This is due to the relatively great depth and width of the entrance channel. In a hypothetical situation, in which the dimensions of the entrance channel are reduced, significantly higher flow velocities will occur. But since there is almost no morphological change in the system, this is very unlikely to happen.

I.5.3 FINAL RECOMMENDATIONS

The final recommendations about modelling the Havana Bay are stated below:

Multiple layers

To obtain detailed results of complex flow patterns, including flow distribution over the vertical water column, the Delft3D model needs to be adapted to a 2DH model with multiple layers or to a fully 3D model. In this case, more complex flow patterns can be calculated, in contrary to the depth averaged model.

Fresh water discharges

It is of importance to quantify the fresh water discharge in detail, both in magnitude and location, and to implement this in the model. Both the distribution of salinity over the horizontal plane of the bay, as the salinity distribution over the vertical is required to assess its influence.

Grid size

When modelling a coastal region with the setup of boundary conditions in a way as is done in this analysis, the boundaries should be placed as far away from the areas of interest as possible. In some model runs the effects of boundary errors might have influenced the results, but due to time and computational power restrictions the decision was made not to alter the grid. For future investigations the boundary effects should be analysed more thoroughly.

Grid resolution

To analyse the flow patterns in a more detailed manner (both for the channel and the bay area), it is necessary to refine the computational grid by some factor. This will however increase the computation time considerably.

Another point of interest is the resolution of the grid on the ocean side of the entrance channel. It is recommended that the resolution difference in the alongshore direction of this portion of the coast is more evenly distributed in order to do further analysis of the flow patterns in this area.

Model calibration and validation

If for future analysis the model is adapted to include more details, special attention should be paid to the calibration and validation of the model. In the present situation there is very little data available to compare the model results against; in fact, there is only one report that describes the flow patterns in some detail.

The current model is calibrated without actual data, but only in such a way that the model gives results which are 'to be expected'. For validation, the data in the mentioned report have been used (Lázaro, 2006). This data is not ideally suited for this purpose, as the report itself states that more measurements are needed.

In an ideal situation multiple datasets are available; for instance, one can be used for calibration and another for validation.

General usefulness

If further research on flow patterns in the Bay of Havana is done, the usefulness of such research should be considered in advance. As the simulations in this study have shown, the flow patterns during a normal and an extreme situation are of little consequence. During a normal situation, the dominating processes are wind and (the resulting) waves (see 'Appendix K: Hydrodynamic analysis – SWAN'). During an extreme scenario, the biggest consequence of a storm surge is flooding, especially combined with wind and waves.

Appendix J: HYDRODYNAMIC ANALYSIS – PRELIMINARY INVESTIGATION - WAVES

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J.1 INTRODUCTION

This appendix will focus on the analysis of wave propagation into the Bay of Havana. For the design of a marina and a ferry terminal it is useful to know in what way the waves will have effect on the system. It will also provide a general understanding of the waves in the bay, which is useful for shipping and other general purposes.

The goal in this appendix is to make a preliminary investigation of the waves that can occur in the Havana Bay. The appendix will be divided into two sections:

- The first section will focus on the *internal waves*, i.e. waves generated *in* the bay by local wind conditions.
- The second section will be on *external waves*. These waves will originate offshore at deep water and will travel to the location of the bay. It is likely that these waves will penetrate the bay through the entrance channel. In this section these external waves will be quantified.

In chapter J.2, the focus will be on the determination of internal waves. Two empiric methods will be given; ‘the Bretschneider method’ and ‘the method of Dorrestein and Groen’. In chapter J.3, the determination of external waves will be presented; an analysis of ARGOSS data (J.3.1), wave data from ‘Instituto de Meteorologia’ (J.3.2), an analysis of harbour resonance (J.3.3) and an elaboration on average wave conditions (J.3.4).

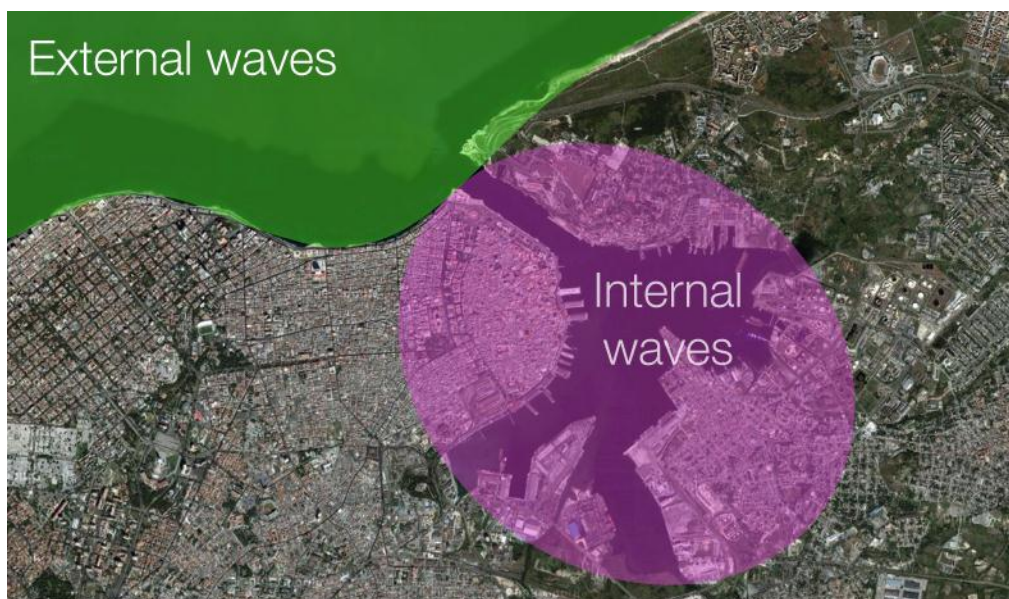


figure J.1 – area of interest for internal- and external waves

J.2 DETERMINATION OF INTERNAL WAVES

The most important waves are generated by wind. In case no local measurements are available or to get a first impression of these locally generated wind waves, empirical methods can be used. With these methods, significant wave heights and wave periods can be estimated. In this chapter, two empirical methods will be used, i.e. the ‘Bretschneider method’ and the ‘method of Dorrestein and Groen’. These methods are based on the concept that wave growth is dependent on *wind speed*, *water depth*, *fetch* and *wind duration* (Vrijling, et al., 2011), (Bezuyen, et al., 2011). These methods yield different results as both methods are based on different datasets. The wind supplies a friction force to the water mass, which creates a wave pattern. The fetch determines the distance that is subjected to this friction force. In general, a high wind speed and a long fetch both increase the energy for creating waves and therefore higher waves will occur. Furthermore, storm duration has its influence on wave growth, as it determines the duration of energy transfer from wind to waves. However, wave growth is limited by depth induced breaking due to the depth of the basin. The depth, corresponding with the directional fetch, is taken as the average depth over the entire fetch.

J.2.1 METHOD OF DORRESTEIN AND GROEN

The first method is to use graphs, so called ‘nomographs’ (Dorrestein, et al., 1973). These graphs are based on observations and have been developed to determine wave heights and wave periods. Firstly, one assumes ‘deep water’, which has to be verified later. To use the graphs, one starts with a direction and a wind speed. The direction determines the length of the fetch, which follows from local geometry. Using figure J.2, one obtains the wave heights and wave periods for a minimal storm duration that has to occur.

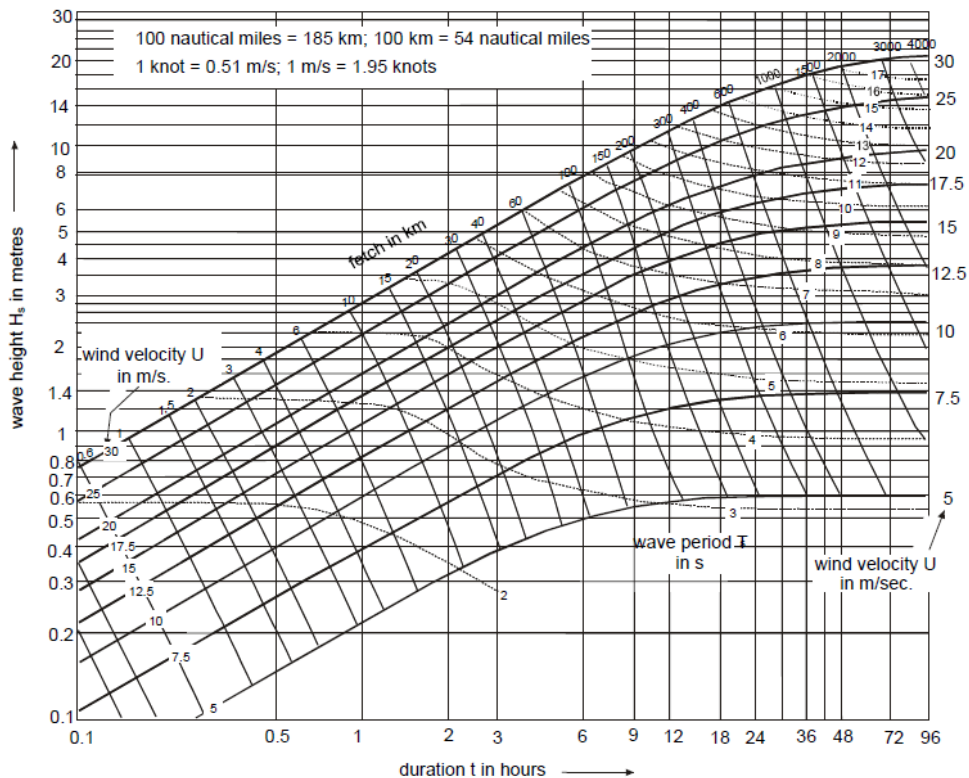


figure J.2 – nomograph for deep water

In this analysis a variety of wind directions and wind speeds are used as input to give a complete view of all possible wind waves that can occur. The input is classified in wind directions with corresponding fetch, which follows from satellite images. Three different wind speeds are used to account for different situations:

- The first row shows a wind speed of 10.7 m/s in all directions. This matches a wind speed of 5 on the Beaufort scale, which is the maximum wind speed for entrance to the bay.
- The wind speeds in the second row correspond to the maximum annual wind speed, measured in Casablanca, Havana (Lázaro, 2006).
- The third and fourth rows correspond to wind speeds in extreme events. This has been done to gain insight in wave growth in the case of tropical cyclones and hurricanes. For the nomograph method, the fourth row (50 m/s winds) cannot be read from the graphs.

From the nomographs, one acquires the values for the significant wave period T_s . However, T_p is more often used as a design parameter. T_s is converted to T_p by the relation $T_p = 1.1 * T_s$.

Note: storm duration is not a restricting criterion in all cases, since the combination of wind speeds and fetches require wind fields only lasting half an hour or shorter. Storms always have a larger duration.

In table J.1 to table J.5, the results of five directions are given, all in the range from north to east. Only these directions are taken into account, because it is expected that winds from these directions cause the most unfavourable wave heights at the location of the marina.

table J.1 – N-Direction using nomographs

Fetch: ≈ 1 640 m	Depth 11.0 m	
Wind speed (m/s)	Wave height H_s (m)	Wave period T_p (s)
10.7	0.35	≈ 2
26.2	0.97	2.9
30	1.15	3.2
50	Not in nomograph	Not in nomograph

table J.2 – NNE-Direction using nomographs

Fetch: ≈ 2 120 m	Depth ≈ 10.0 m	
Wind speed (m/s)	Wave height H_s (m)	Wave period T_p (s)
10.7	0.39	≈ 2
27.4	1.2	3.2
30	1.3	3.3
50	Not in nomograph	Not in nomograph

table J.3 – NE-Direction using nomographs

Fetch ≈ 3 730 m	Depth ≈ 10.0 m	
Wind speed (m/s)	Wave height H_s (m)	Wave period T_p (s)
10.7	0.51	2.2
26.8	1.48	3.4
30	1.7	3.6
50	Not in nomograph	Not in nomograph

table J.4 – ENE-Direction using nomographs

Fetch \approx 3 540 m	Depth \approx 11.0 m	
Wind speed (m/s)	Wave height H_s (m)	Wave period T_p (s)
10.7	0.48	2.2
22.7	1.19	3.1
30	1.7	3.6
50	Not in nomograph	Not in nomograph

table J.5 – E-Direction using nomographs

Fetch \approx 2 070 m	Depth \approx 10.5 m	
Wind speed (m/s)	Wave height H_s (m)	Wave period T_p (s)
10.7	0.38	\approx 2
22.7	0.95	2.8
30	1.3	3.3
50	Not in nomograph	Not in nomograph

Next step is checking if the deep water assumption is justified. In order to do so table J.6 is used. The wave length L is to be computed iteratively by:

$$L = \frac{gT_s^2}{2\pi} * \tanh\left(\frac{2\pi h}{L}\right)$$

in which h is the local water depth.

To serve as an example one calculation is shown; a 30 m/s wind from the east yields a wavelength L of 14.0 m. Checking the ratio h/L from table J.6 yields that the deep water assumption is justified. This appears to be the case for all values in table J.1 to table J.5.

table J.6 – criteria for deep, intermediate and shallow water

	h/L	$\tanh\left(\frac{2\pi h}{L}\right)$	c
Deep water	$> 1/2$	≈ 1	$\frac{gT}{2\pi} \approx 1,56T$
Intermediate depth			$\frac{gT}{2\pi} \tanh\left(\frac{2\pi h}{L}\right)$
Shallow water	$< 1/20$	$\approx 2\pi h/L$	\sqrt{gh}

J.2.2 METHOD OF BRETSCHNEIDER

The second method used in this analysis is the ‘Bretschneider method’ (Bretschneider, 1958). These formulas are derived by curve-fitting through a cloud of measured data of wind waves. These empirical formulas are given below:

$$\tilde{H} = 0.283 * \tanh(0.53 * \tilde{d}^{0.75}) * \tanh\left(\frac{0.0125 * \tilde{F}^{0.42}}{\tanh(0.53 * \tilde{d}^{0.75})}\right)$$

and,

$$\tilde{T} = 7.54 * \tanh(0.833 * \tilde{d}^{0.375}) * \tanh\left(\frac{0.077 * \tilde{F}^{0.42}}{\tanh(0.833 * \tilde{d}^{0.375})}\right)$$

The parameters denoted with a tilde represent dimensionless parameters, needed to be able to use the tangent hyperbolic function. The definitions of these parameters are shown below:

$$\tilde{H} = \frac{gH_s}{U^2}$$

$$\tilde{T} = \frac{gT_p}{U}$$

$$\tilde{F} = \frac{gF}{U^2}$$

$$\tilde{d} = \frac{gd}{U^2}$$

From these relations, one can derive values for H_s and T_p . The input for this method is the same as for the nomograph method, which has been used in chapter J.2.1. The results can be seen in table J.7 to table J.11.

table J.7 – N-Direction using Bretschneider formulas

Fetch: ≈ 1 640 m		Depth ≈ 11.0 m
Wind speed (m/s)	Wave height H_s (m)	Wave period T_p (s)
10.7	0.32	2.07
26.2	0.89	3.22
40	1.42	3.93
50	1.79	4.37

table J.8 – NNE-Direction using Bretschneider formulas

Fetch: ≈ 2 120 m		Depth ≈ 10.0 m
Wind speed (m/s)	Wave height H_s (m)	Wave period T_p (s)
10.7	0.36	2.19
27.4	1.03	3.46
40	1.53	4.14
50	1.92	4.58

table J.9 – NE-Direction using Bretschneider formulas

Fetch \approx 3 730 m	Depth \approx 10.0 m	
Wind speed (m/s)	Wave height H_s (m)	Wave period T_p (s)
10.7	0.45	2.47
26.8	1.22	3.85
40	1.84	4.65
50	2.28	5.14

table J.10 – ENE-Direction using Bretschneider formulas

Fetch \approx 3 540 m	Depth \approx 11.0 m	
Wind speed (m/s)	Wave height H_s (m)	Wave period T_p (s)
10.7	0.45	2.46
22.7	1.02	3.55
40	1.85	4.63
50	2.30	5.13

table J.11 – E-Direction using Bretschneider formulas

Fetch \approx 2 070 m	Depth \approx 10.5 m	
Wind speed (m/s)	Wave height H_s (m)	Wave period T_p (s)
10.7	0.36	2.18
22.7	0.83	3.15
40	1.53	4.13
50	1.93	4.58

The above calculations do not take into account depth induced breaking. Depth induced breaking starts at wave heights of $H_b = 0.88 * h$. For all cases it proves that depth induced breaking never occurs in the bay.

J.2.3 CONCLUSIONS

To provide some insight in the upper boundary of locally generated wind waves, the nomograph method is used for the normal situation as well as the maximum annual wind speed situation, as this method gives the highest wave heights. At wind speeds up to 10.7 m/s (Beaufort 5), wave heights of at most **0.51 m** will occur. With annual maximum wind speeds, maximum wave heights of **1.48 m** will occur. In the case of hurricanes, wind generated waves up to **2.3 m** can occur according to the Bretschneider formulas.

Furthermore:

- Shielding of the wind in the lee-side areas of El Morro and Casablanca are not taken into account. Taking this into account will decrease the wave growth.
- Small structures like piers have been neglected in determining the fetch.
- In general the values for H_s are around 15 % higher for the nomograph method compared to the Bretschneider method.
- In general the values for T_p are around 15 % lower for the nomograph method compared to the Bretschneider method.
- Diffraction is not taken into account. Also, the interaction between waves may result in different wave heights.
- Refraction is not taken into account; this can be justified because few variations occur in the bathymetry of the Havana Bay.

J.3 DETERMINATION OF EXTERNAL WAVES

In this chapter, the external waves will be quantified. These waves are generated outside of the Havana Bay, for instance waves generated by a local storm near the coast of Havana. But also waves that have been generated in a distant storm (swell waves) are considered external waves. In section J.3.1, an analysis of ARGOSS data will be given. In here, the peak over threshold method will be used to quantify storms and to obtain wave parameters with a certain return period. Section J.3.2 is also about the determination of wave parameters with extreme conditions, but here an analysis of 'Instituto de Meteorologica' is summarised. Then, some information is given on seiches that might be of importance to the Havana Bay (J.3.3). This chapter concludes with some information about average wave conditions (J.3.4).

J.3.1 ANALYSIS OF ARGOSS DATA

In this chapter, the significant wave height and peak period will be calculated from a dataset of twenty years of sequential data¹⁴. This dataset contains measurements obtained by buoys. Missing values in this dataset are obtained from a WAVEWATCH model.

From this data, design values will be obtained for a storm with an exceedance frequency of 1/225 per year. This value has previously been determined and is the result of a 20% probability of failure in a lifetime of 50 years. For a more detailed explanation of these values, see paragraph 'H.4.1 Determination design storm'.

With the use of this data, one can easily find the probability of an individual wave that exceeds a certain threshold value. However, for the design of a structure (in this case the marina and ferry terminal), the exceedance of a design storm is needed, not the exceedance of an individual wave (Verhagen, et al., 2009).

The Peak over Threshold method (PoT-analysis)

In order to transform these individual observations into storms, one can use the fact that sequential wave height observations are not random. This is true because every three hours measurements are done and that it is very likely that these measurements belong to the same storm. A storm can then be defined by applying a certain, arbitrarily selected, threshold value, for instance 2.0 m. Sequential measurements above this threshold are then considered to belong to the same storm. The reason for introducing a threshold is to avoid the significant influence of small wave heights during calm periods on the final result. One should assume the threshold as high as possible, while keeping in mind that sufficient data is needed to carry out a reliable analysis. It is obvious that if the threshold is higher, fewer storms occur in the same amount of time and that less data is available for analysis.

Wave directions

The offshore location of the ARGOSS data is at 24° latitude and -82.5° longitude, which is approximately 90 km from the Havana Bay. The local depth of that point is 962 m. From this location, waves can propagate to the shore from three main directions:

- Waves propagating directly to the area of interest, i.e. waves are coming from the north. When dividing the full range (360°) into eight segments, this results in a range of **337.5° – 22.5°** (north is 0°).

¹⁴ Data has been provided by BMT ARGOSS

- Waves propagating from a northeast direction, i.e. waves from **22.5° – 67.5°**. These waves can be of interest because of refraction¹⁵. In that case the waves will turn toward the coast and will propagate into the area of interest.
- Waves propagating from a northwest direction, i.e. waves from **292.5° – 337.5°**. Also in this case, refraction can lead to a change in wave direction and consequently propagation of waves into the Havana Bay.

Considering the location of the bay inlet, waves propagating from the west can also be of importance. However, there is no possibility that a wave from the west, which enters the location of the ARGOSS data, can reach the area of interest. Because in this case only one offshore data point is available for analysis, it is assumed that the same wave conditions can and will occur in the region more west of the current ARGOSS location. Consequently, waves propagating from the west can be taken into account; this direction corresponds to a range **247.5° – 292.5°**.

Summarizing, offshore generated waves, which will propagate into the area of interest (Havana Bay), are coming from a directional range of **247.5° – 67.5°**.



figure J.3 – location of ARGOSS data relative to the area of interest.

¹⁵ Refraction is the phenomenon of the wave direction changing due to depth-induced variations in the phase speed in the lateral direction (i.e. along the wave crest). (Holthuijsen, 2007)

If, for instance, one wants to obtain the significant wave height with a certain return period for the northern direction, the dataset must be filtered according to this direction. This method results in a wave height for every direction and one can easily see what the direction is where most severe waves occur.

However, the location of the data is a limiting factor to this approach. At a distance of 40 kilometres northeast from the location of the ARGOS data, Key West is located and these series of islands will block incoming waves from the northeast and north. This is especially true for the higher wave heights and therefore, the resulting extrapolation will be distorted. For that reason, the entire dataset is analysed and it is assumed that the resulting waves can come from any direction. The results will still be distorted because of the lower wave heights from the northern directions, but this will partly be compensated by the other directions. The final value will therefore be less distorted if one processes the entire dataset instead of separate directions.

Data analysis

The dataset of twenty years contains 58 432 wave records. When applying a threshold of $H_s > 1.50$ m, 5 967 records (storms) remain for analysis. This value is high enough for a reliable analysis. These storms are classified in wave height bins of 0.25 m each and the result can be seen in table J.12.

The probability of a wave height H'_s being equal or less than a specific wave height H_s is defined as:

$$P = P(H'_s \leq H_s)$$

A probability of exceedance that H'_s is greater than a specific wave height H_s is defined as:

$$Q = Q(H'_s > H_s) = 1 - P$$

These are individual exceedance probabilities and to transform these into exceedance probabilities for storms, the average number of storms per year (N_s) is required:

$$N_s = \frac{\text{total number of storms}}{\text{number of years}} = \frac{5\,967}{20} = 298.35 \text{ storms per year}$$

For transformation of the general probability of exceedance (Q) to the probability of exceedance of a storm in a year (Q_s), Q needs to be multiplied with the average number of storms in a year:

$$Q_s = N_s Q$$

The values of Q_s are also given in table J.12. They represent the expected number of storms in a year.

table J.12 – PoT analysis of ARGOSS data using a threshold of 1.50 m

Wave height class H_{ss} (m)		Number of storms		P	Q	Q_s	$\ln(Q_s)$	$\alpha = 0.5$
Lower	Upper	per bin	cum.					Reduced Weibull W
1.50	1.75	2805	2805	0.47009	0.52991	158.10	5.06	0.403
1.75	2.00	1474	4279	0.71711	0.28289	84.40	4.44	1.594
2.00	2.25	785	5064	0.84867	0.15133	45.15	3.81	3.566
2.25	2.50	427	5491	0.92023	0.07977	23.80	3.17	6.394
2.50	2.75	193	5684	0.95257	0.04743	14.15	2.65	9.294
2.75	3.00	108	5792	0.97067	0.02933	8.75	2.17	12.455
3.00	3.25	62	5854	0.98106	0.01894	5.65	1.73	15.734
3.25	3.50	43	5897	0.98827	0.01173	3.50	1.25	19.763
3.50	3.75	22	5919	0.99196	0.00804	2.40	0.88	23.259
3.75	4.00	16	5935	0.99464	0.00536	1.60	0.47	27.335
4.00	4.25	7	5942	0.99581	0.00419	1.25	0.22	29.977
4.25	4.50	4	5946	0.99648	0.00352	1.05	0.05	31.917
4.50	4.75	5	5951	0.99732	0.00268	0.80	-0.22	35.063
4.75	5.00	1	5952	0.99749	0.00251	0.75	-0.29	35.832
5.00	5.25	2	5954	0.99782	0.00218	0.65	-0.43	37.565
5.25	5.50	2	5956	0.99816	0.00184	0.55	-0.60	39.641
5.50	5.75	2	5958	0.99849	0.00151	0.45	-0.80	42.208
5.75	6.00	1	5959	0.99866	0.00134	0.40	-0.92	43.752
6.00	6.25	0	5959	0.99866	0.00134	0.40	-0.92	43.752
6.25	6.50	0	5959	0.99866	0.00134	0.40	-0.92	43.752
6.50	6.75	0	5959	0.99866	0.00134	0.40	-0.92	43.752
6.75	7.00	3	5962	0.99916	0.00084	0.25	-1.39	50.191
7.00	7.25	0	5962	0.99916	0.00084	0.25	-1.39	50.191
7.25	7.50	0	5962	0.99916	0.00084	0.25	-1.39	50.191
7.50	7.75	1	5963	0.99933	0.00067	0.20	-1.61	53.403
7.75	8.00	0	5963	0.99933	0.00067	0.20	-1.61	53.403
8.00	8.25	1	5964	0.99950	0.00050	0.15	-1.90	57.690
8.25	8.50	1	5965	0.99966	0.00034	0.10	-2.30	64.014
8.50	8.75	0	5965	0.99966	0.00034	0.10	-2.30	64.014
8.75	9.00	0	5965	0.99966	0.00034	0.10	-2.30	64.014
9.00	9.25	0	5965	0.99966	0.00034	0.10	-2.30	64.014
9.25	9.50	0	5965	0.99966	0.00034	0.10	-2.30	64.014
9.50	9.75	1	5966	0.99983	0.00017	0.05	-3.00	75.586
9.75	10.00	1	5967	1	0	0		
SUM		5967						

Extrapolation

For data extrapolation a Weibull distribution will be used:

$$P(H_{ss}) = Q = \exp \left[- \left\{ \frac{H_{ss} - \gamma}{\beta} \right\}^\alpha \right]$$

The Weibull distribution has three variables (α , β and γ) and linear regression will provide two constants, A and B, from which β and γ can be obtained. In order to find these constants, the equation above can be reduced to:

$$(-\ln Q)^{1/\alpha} = \frac{1}{\beta} H_{ss} - \frac{\gamma}{\beta}$$

This can be reduced to $W = AH_{ss} - B$, in which $W = -(\ln Q)^{1/\alpha}$, $A = 1/\beta$ and $B = \gamma / \beta$ (Verhagen, et al., 2009).

If one plots W on the vertical axes and H_{ss} on the horizontal axes, it is easy to obtain a linear equation by adding a trendline. Then, β and γ can easily be obtained from the coefficients of this trendline, but α requires another approach. Changing α results in new values for W and a corresponding new graph. The value of α that provides the straightest line and the highest correlation coefficient R^2 is the best value for α . In this case $\alpha = 0.5$ with a correlation coefficient of 0.9781.

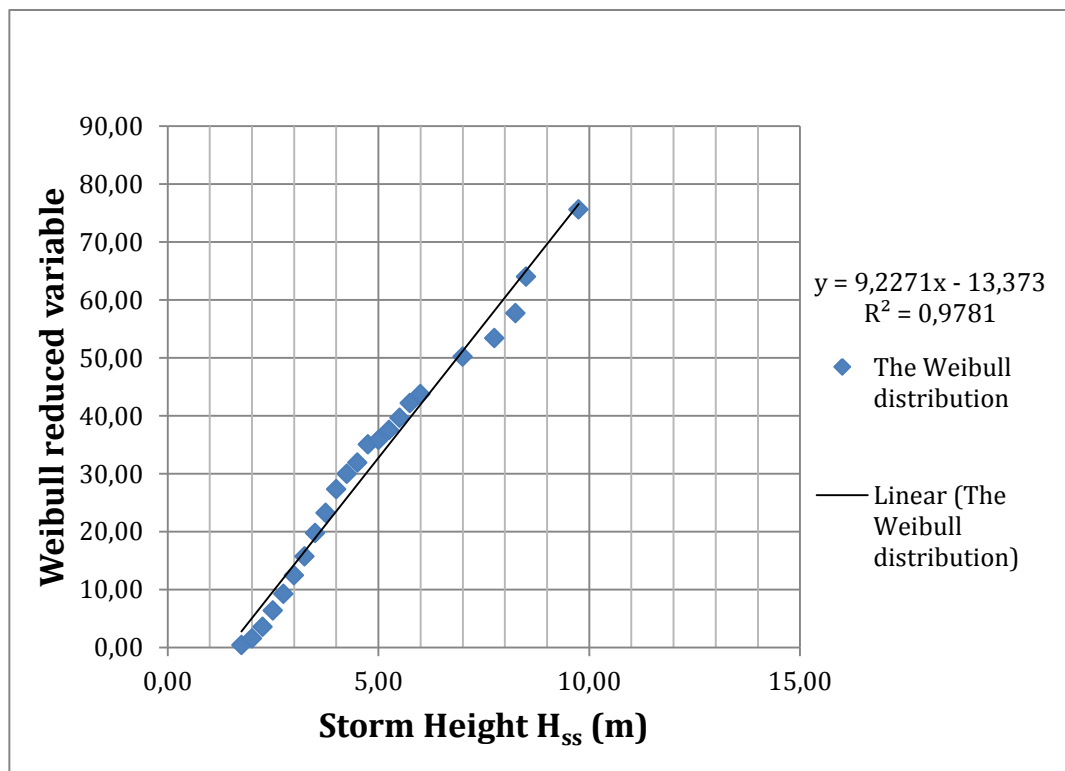


figure J.4 – reduced Weibull variable W plotted against storm height H_{ss}

If all three variables of the Weibull distribution are known, one can obtain a wave height with a certain return period using the formula given below:

$$H_{ss} = \gamma + \beta \left\{ -\ln \left(\frac{Q_s}{N_s} \right) \right\}^{1/\alpha}$$

in which Q_s is the return period of the event. In this case $\alpha=0.5$, $\beta=0.1084$, $\gamma=1.4493$ and with $N_s=298.35$ the formula can be applied for different return periods. In table J.13 the results are shown for different return periods.

$$H_{ss} = 1.4493 + 0.1084 \left\{ -\ln \left(\frac{Q_s}{298.35} \right) \right\}^{1/0.5}$$

table J.13 – significant wave height and peak period for different return periods

Return period (years)	Significant wave height H_s (m)	Assumed wave steepness (-)	Deep water wavelength L_0 (m)	Peak period T_p (s)
10	8.39	0.04	210	11.6
20	9.64	0.04	241	12.4
50	11.46	0.045	255	12.8
100	12.95	0.05	259	12.9
225	14.84	0.05	297	13.8

Wave period

For determination of the peak period T_p , one assumes a wave steepness in deep water. The average steepness is about 1:30 (=0.0333) and the maximum steepness is limited to 1:15 (=0.0667). The latter is a universal, physical limitation in deep water, imposed by wave breaking, (Holthuijsen, 2007). It is assumed that these extreme waves have a higher steepness than average waves. To make a rough estimation of the peak period T_p , a steepness of 0.04 will be used for the waves with a return period of 10 and 20 years. For the 1/50 year wave, a steepness of 0.045 will be assumed and for the remaining extreme waves with a return period of 100 and 225 years, the steepness is assumed even higher (0.05).

With a known H_0 and steepness, L_0 can be calculated. If L_0 is known, the peak period T_p can be calculated with the formula given below. This has been done for every significant wave height in table J.13.

$$T_p = \sqrt{\frac{L_0 * 2\pi}{g}}$$

J.3.2 WAVE DATA FROM ‘INSTITUTO DE METEOROLOGIA’

In a report about meteorological characteristics for the Havana coast, extreme wave regimes have been analysed for dominating winds from the north and northwest (Instituto de Meteorologia , 1994). Waves are generated using the methods recommended by the GOSTROI manuals (1975, 1983), which are based on the formulations of Krylov (1966) and Rsheplinsky (1972). With these methods average wave heights are calculated. Significant wave heights are obtained by multiplying these average wave heights by a factor 1.59. The resulting waves have been sorted in descending order and from this acquired dataset, return periods have been calculated. The results are shown in table J.14.

table J.14 – return periods and corresponding parameters for deep water waves produced by north and north-western winds

Return period (years)	Wind speeds used for wave generation (m/s)	Significant wave height H_s (m)	Wave period (s)
10	21	7.95	10.57
20	25	9.06	10.98
50	34	10.34	11.04
75	38	11.61	11.45
100	42	11.93	11.55
200	55	13.83	11.75
500	68	15.90	12.15
1000	80	18.28	12.73

In this analysis, a return period of 225 years is wanted and according to table J.14 this value will be close to **13.83 m**. It must be noted that the results in this analysis are much more unreliable than the results obtained from the ARGOSS data. The latter uses a reliable dataset with 20 years of wave measurements. Extrapolation of this data yields a wave height with a corresponding return period.

The method in this paragraph is based on wave generation by a constant wind and is not coupled to real observations. For that reason, the analysis of ARGOSS data is assigned to be more solid and reliable and will therefore be used in future evaluations.

J.3.3 HARBOUR BASIN RESONANCE

The harbour basin has its own natural period of oscillation, in case the incident wave period is close to the natural period this can lead to resonance. Resonance can lead to high wave heights, which is unwanted for berthed ships. Seiches are those waves with periods matching the natural frequency of the harbour; they are standing waves and can have amplitudes in the order of 1 m. Seiches are generated by waves from the open ocean, which are likely caused by storms and areas of low pressure.

The natural period (T_n) for an open-ended basin, with a more or less uniform depth and rectangular shape, can be estimated using the following formula:

$$T_n = \frac{4 * l_B}{(1 + 2n)\sqrt{gh}}$$

In which l_B is the length of the basin, h is water depth and n is the mode of oscillation. If this formula is used for the Bay of Havana, with a length of roughly 3 km and a depth of 12 m, this leads to $T_1 = 1477$ s, $T_2 = 492$ s and $T_3 = 293$ s.

Seiches could be a cause of concern for the Havana Bay, as the bay is directly connected with the Gulf of Mexico, where storm fronts with low pressure areas regularly occur. For the Bay of Havana however, it appears seiches are of no concern, as according to local authorities they never appear in Havana. This can be explained by the irregular shape of the bay, which minimises resonance.

J.3.4 AVERAGE WAVE CONDITIONS

Using the ARGOS dataset with 20 years of sequential wave data, one can easily obtain the average wave height and wave period. These values are useful from nautical point of view, because they are most likely to occur on average days when shipping is most active. For instance, these wave parameters can be determining for the navigability of ships near the entrance channel. The average significant wave height (H_s) is **0.84 m** and the average peak period (T_p) is **4.97 s**. It is assumed that these offshore wave conditions also occur in the near shore region of the Havana Bay. This is a valid assumption, because of the large water depth at that location and the relatively low wave height. These waves are therefore still considered to be in deep water.

With the present rules, shipping is not allowed in the harbour from wind speeds ≥ 6 Beaufort (10.8 m/s). Therefore, this wind speed can be considered as a maximum value when shipping is operational. It is interesting to know, what kind of offshore wave parameters are associated with this wind speed.

In the entire record of wave and wind data, a filter has been applied from wind speeds \geq Beaufort 5 and wind speeds \leq Beaufort 6. This corresponds to a range of **8 m/s – 10.8 m/s**. The wave heights associated with these wind speeds are then averaged. In total, 11 656 records remain after applying the filter. The resulting average significant wave height (H_s) is **1.3 m** and the average peak period (T_p) is **5.2 s**. It must be noted that this is a very rough assumption, because the occurring offshore wave heights are not completely wind induced. There can also be a swell component, which is neglected in this brief analysis.

Appendix K: HYDRODYNAMIC ANALYSIS – SWAN

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K.1 INTRODUCTION

In ‘Appendix J: Hydrodynamic analysis – Preliminary investigation - Waves’ empiric methods have been used to get first estimations of locally generated wind waves. Also, external waves have been quantified that may cause wave penetration into the Havana Bay.

Because the empiric methods have several shortcomings (uniform depth, not based on physical processes), a more detailed analysis is wanted. For external waves, the use of an advanced wave model is the only possibility because of the complex two dimensional processes involved, such as refraction, reflection, wave breaking and energy dissipation. These processes are highly dependent on the local geometry and bathymetry of the bay. For that reason, in order to obtain wave heights and wave periods in detail, use will be made of a two dimensional wave model called SWAN.

“Swan¹⁶ is a third-generation wave model for obtaining realistic estimates of wave parameters in coastal areas, lakes and estuaries from given wind, bottom and current conditions. However, SWAN can be used on any scale relevant for wind-generated surface gravity waves. The model is based on the action balance equation with sources and sinks”. (Obtained from page 3 of the SWAN user manual).

The SWAN model can take the following physical aspects into account:

- Wave refraction in variable depth and/or spatially varying current
- Depth and current-induced shoaling
- Wave generation by wind.
- Dissipation by white capping, depth-induced breaking and bottom friction
- Nonlinear wave-wave interactions (both quadruplets and triads)
- Transmission and reflection
- Diffraction

The goal of this appendix is to obtain detailed results of different wave parameters near the location of the marina and the entrance channel; both for internal and external waves.

In chapter K.2, a sensitivity analysis for internal waves will be given. Different wind speeds and directions will be analysed to acquire the most unfavourable situation. The same will be done in chapter K.3, but for external waves. Variations will be made in wave height, wave period and direction in order to quantify the wave penetration into the Havana Bay. In chapter K.4, extreme case scenarios will be simulated using unfavourable wind directions, but also the wave direction with maximum wave penetration will be taken into account. In chapter K.5, some recommendations will be given about the modelling.

¹⁶ SWAN stands for **S**imulating **W**aves **N**earshore

K.2 SENSITIVITY ANALYSIS – INTERNAL WAVES

Using the modelling program SWAN¹⁷ it is possible to compute waves generated by local wind. For the design of the marina it is important to know the significant wave height and peak period of these waves. As this sensitivity analysis is a rough study, a computational grid with a lower level of detail is used, to limit computation time.

From figure K.1 it can be expected that waves from the directions north-northeast, northeast and east-northeast are the most severe, because from these directions the wind fetch is longest.



figure K.1 – Bay of Havana and its surroundings (north is up)

K.2.1 MODEL RESULTS

Different simulation runs have been carried out, with different wind speeds and directions. The variables correspond to the values used in the empirical wave analysis. The results can be seen in table K.1. Because there is detailed bathymetry available, the model also takes refraction into account.

In addition to the values for wind speed used for the empirical analysis, also values of 5.5 and 21.7 m/s are analysed, as these respectively represent an average day and a once per year returning wind speed.

table K.1 – significant wave height and peak period for the location of marina

Wind speed [m/s]	East		ENE		N-East		NNE		North	
	H _s [m]	T _p [s]	H _s [m]	T _p [s]	H _s [m]	T _p [s]	H _s [m]	T _p [s]	H _s [m]	T _p [s]
5.5	0.13	1.52	0.15	1.58	0.15	1.59	0.13	1.53	0.09	1.34
10.7 ¹⁸	0.28	2.05	0.31	2.12	0.32	2.96	0.28	2.07	0.21	1.91
21.7	0.64	2.82	0.71	2.96	0.71	2.96	0.65	2.85	0.51	2.61
27.0	0.82	3.11	0.90	3.29	0.89	3.31	0.80	3.22	0.66	2.99
40.0	1.23	3.57	1.34	3.84	1.33	3.93	1.18	3.96	0.96	3.31

¹⁷ For the input file see K.2

¹⁸ A wind speed of 10.7 m/s corresponds to 5 Bft, which is the current limit for shipping inside the Bay of Havana (no shipping at 6 Bft).

K.2.2 CONCLUSIONS

Directions:

From the model results it can be concluded that the most important wind directions are east-northeast, northeast and north-northeast. Based on fetch length this seems a logical conclusion, but the results show that the east direction produces similar waves with shorter fetch lengths, indicating that refraction also has influence.

As the prevailing wind direction over the year is northeast, internal waves can become problematic.

Wind speed:

For general shipping purposes winds of 10.7 m/s or 5 Bft are of importance, the results show that during these wind speeds from no direction waves higher than 0.40 m occur (figure K.2). This shows that for shipping the internal waves are of no consequence. For berthed ships, winds higher than 5 Bft also have to be taken into account. The average annual maximum of 27 m/s causes significant wave heights of nearly 1 m (figure K.2).

The criterion for a 'good' wave climate, for a marina, is that a significant wave height of 0.3 m may occur once a year (Department of Fisheries and Oceans, 1981). The model and the empirical results show that these wave heights occur with wind speeds of 10.7 m/s. The wind analysis done in paragraph 'H.4.4 ARGOS data' shows that these winds can have a yearly occurrence probability of 5%, which, without any countermeasures, does not result in a 'good' wave climate.

Comparison with empirical methods:

In general the results match those of the empirical methods used in the preliminary investigation into waves. For wind speeds in the order of 10.7 m/s and 27 m/s, both methods show similar results. The results of wind speeds of 40 m/s differ more, the method of Bretschneider results in considerable higher waves¹⁹. This difference can be the result of the limiting factors that the mathematical model, opposed to the empirical method, takes into account. Limits such as depth induced breaking due to changing bathymetry, and possibly even white-capping in deeper portions of the bay can be the causes of lower maximum values.

A limit of the model is the lack of piers and jetties, it can be stated that the piers on the western part of the bay can reduce the wind waves even further.

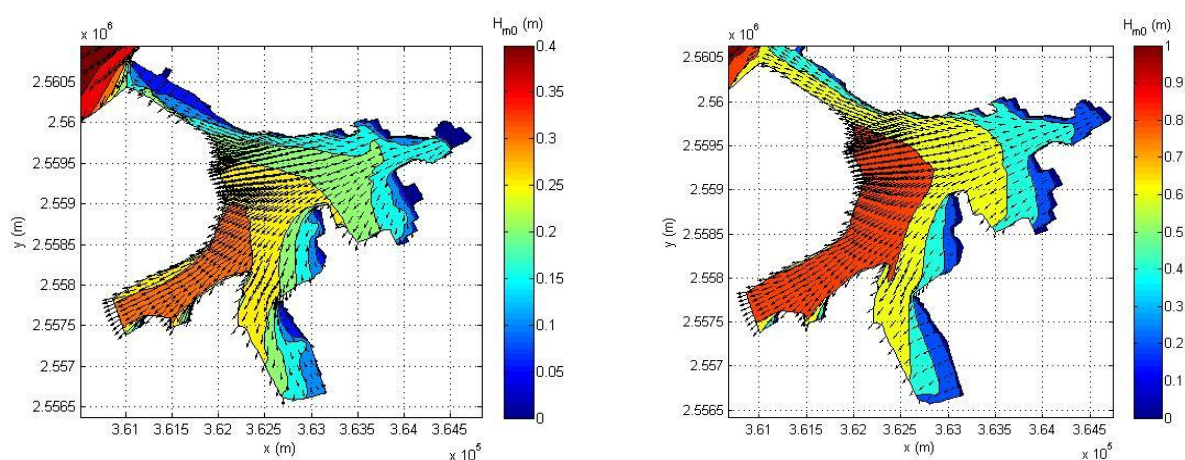


figure K.2 – resulting significant wave height from wind speeds of 10.7 m/s NE (left) and 27 m/s ENE (right)

¹⁹ The nomograph-method does not allow for these high wind speeds.

K.2.3 GENERAL INPUT FILE

```

$*****HEADING*****
PROJECT 'Havana' 'TUD'
$*****MODELINPUT*****
SET LEVEL = 0
SET MAXERR = 30 CART
$ Definitieve rooster en bodem - from Delft3D
CGRID CURV 227 90 EXCEPT 0.0 0.0 CIR 36 0.03 1.00
READ COOR 1. 'Cuba2.grd' IDLA=3 NHEDF=3 FORMAT '(10X,5F12.3)'
INPUT GRID BOT CURVI 0. 0. 227 90 EXC 999.0
READ BOTTOM 1. 'Cuba.bot' IDLA=4 NHEDF=0 FREE
$*****WINDINPUT*****
WIND 10.7 180
$*****WAVEINPUT*****
$*****PHYSICS *****
GEN3 KOM
WCAP KOM DELTA 1
QUAD
TRIAD trfac=0.1 cutfr=2.5
BREAKING 1 0.73
FRICTION JONSWAP CFJON=0.038
$*****NUMERICS*****
NUM STOPC 0.00 0.01 0.001 98 STAT mxitst=50 alfa=0.002
$*****OUTPUT*****
OUTPUT OPTIONS '%!' TABLE 16 BLOCK 9 1000 SPEC 8
BLOCK 'COMPGRID' NOHEAD 'Cuba.mat' XP YP DEP HSIG TMM10 TPS DIR DSPR
POINT 'Channel' 361261.792 2560488.303
TABLE 'Channel' HEADER 'CHANNEL.txt' XP YP DEP HSIG TMM10 TPS DIR DSPR
POINT 'Marina' 361290.631 2557875.803
TABLE 'Marina' HEADER 'MARINA.txt' XP YP DEP HSIG TMM10 TPS DIR DSPR
$*****CALCULATION *****
COMPUTE
STOP

```

In this case, SWAN uses only input from winds. The following physical aspects are taken into account, (SWAN development team, 2013):

- ‘GEN3’ refers to the third generation mode for wind input, quadruplet interactions and whitecapping. ‘KOM’ refers to exponential wave growth: Komen et al. (1984). The default values are used.
- ‘WCAP’ refers to white capping and with this command the user can influence the computations about white capping. Also here, ‘KOM’ refers to the method of Komen et al. (1984) for whitecapping. ‘DELTA 1’ refers to a coefficient which determines the dependency of the whitecapping on wave number. The default values are used.
- With the option ‘QUAD’, the user can influence the computation of nonlinear quadruplet wave-wave interactions. This is activated by default. Quadruplet wave-wave interactions are responsible for the energy distribution between four wind generated waves. The total energy remains constant, but the individual waves can gain or lose energy, (Holthuijsen, 2007).
- In shallow water, also triad wave-wave interactions can occur. Three freely propagating waves can transfer energy to one another by resonance. This can only occur in shallow water. Since the bay can be regarded as shallow water, the command ‘TRIAD’ will be used. ‘trfac’ is the value of the proportionality coefficient α_{EB} . ‘cutfr’ refers to the maximum frequency that will be considered in the triad computations. The value 2.5 is the ratio of this maximum frequency over the mean frequency.
- Obviously, SWAN will take wave breaking into account, but with the command ‘BREAKING’, one can adapt certain values. ‘1’ refers here to parameter α (proportionality coefficient of the rate of dissipation). ‘0.73’ refers to parameter γ , which is the ratio of maximum individual wave height over depth. For both parameters, default values have been used.
- With the option ‘FRICTION’, SWAN can take bottom friction into account. The default option is ‘JONSWAP’. This indicates that the semi-empirical expressions, derived from the JONSWAP results for bottom friction dissipation (Hasselmann et al., 1973, JONSWAP), are activated.

K.3 SENSITIVITY ANALYSIS – EXTERNAL WAVES

In this analysis the goal is to gain insight into what wave directions produce the most wave penetration. Second to this investigation is to analyse what wave parameters produce the most penetration, i.e. what wave height and wave period. To achieve this, several SWAN model runs will be done, based on four main wave directions: northeast, north, northwest and west (figure K.3). To determine what the effects of wave height and period are, the model runs will also be done with nine different wave parameters. The wave conditions have been chosen in such a way that it is most clear what factors determine penetration. To isolate solely the effects of waves, the simulations will be done without wind.

Virtual measuring points have been set for the entrance channel and the future location of the marina. The virtual buoy in the entrance channel is located roughly 100 m from the entrance mouth (on the ocean side).

It must be noted that this analysis of wave penetration is not conclusive, that is to say, it is not definitive what amount of wave penetration there is into the Bay of Havana. This analysis is only to make clear what the effect of waves is on penetration, in a following paragraph the combined effect of waves and wind is analysed.



figure K.3 – incoming wave directions

K.3.1 WAVES FROM THE NORTHEAST

Beforehand it can be stated that waves originating from the northeast produce little wave penetration, since the entrance channel is nearly perpendicularly oriented relative to the northeast. Therefore, next to a situation with no incoming waves, this situation can be used as a zero-scenario, i.e. a scenario to compare the others with. Furthermore, for shipping reasons this scenario is worthwhile as it shows how much hindrance there is from waves on the approach direction of ships.

The results of all the simulations are presented in table K.2 and table K.3. A graphical representation of the distribution of wave height in the Bay of Havana is shown in figure K.4²⁰. This image shows that the bay is unaffected by waves from the northeast. In the channel however, there is some penetration due to the refracting waves. Dampening of the waves happens rapidly, as the significant wave height at the end of the channel is negligible.

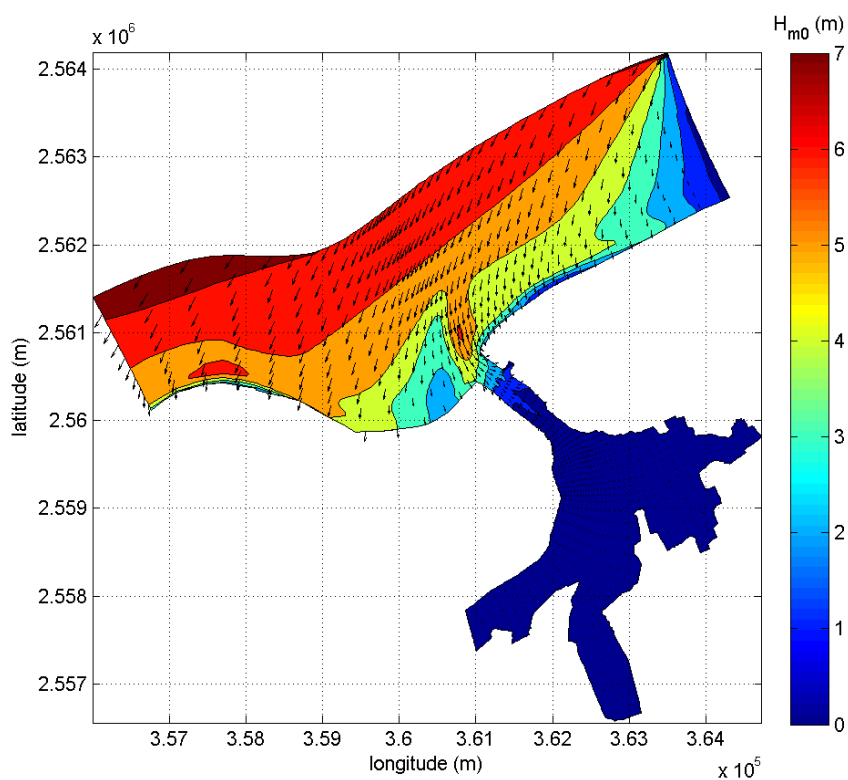


figure K.4 – significant wave heights from an incoming wave with $H_s = 8$ m and $T_p = 12$ s

²⁰ The focus is on the channel and the bay, the effects on the borders of the model should be neglected, as the results there are influenced by the boundaries

table K.2 – significant wave height and mean absolute wave period for waves from the northeast in the channel

H_s \ T_p	6 s		9 s		12 s	
	H_s channel	$T_{m-1,0}$ channel	H_s channel	$T_{m-1,0}$ channel	H_s channel	$T_{m-1,0}$ channel
2 m	0.29 m	5.97 s	0.45 m	8.91 s	0.59 m	11.58 s
5 m	0.86 m	6.07 s	1.14 m	8.63 s	1.51 m	10.87 s
8 m	0.92 m	6.21 s	1.67 m	8.66 s	2.19 m	10.53 s

table K.3 – significant wave height and mean absolute wave period for waves from the northeast in the marina

H_s \ T_p	6 s		9 s		12 s	
	H_s marina	$T_{m-1,0}$ marina	H_s marina	$T_{m-1,0}$ marina	H_s marina	$T_{m-1,0}$ marina
2 m	0.00 m	0.00 s	0.01 m	8.92 s	0.01 m	11.37 s
5 m	0.01 m	6.46 s	0.02 m	8.83 s	0.03 m	10.67 s
8 m	0.02 m	6.56s	0.03 m	8.88 s	0.04 m	9.83 s

K.3.2 WAVES FROM THE NORTH

The north seems a more probable direction from which wave penetration occurs. The refraction phenomenon can result in waves bending towards the coast and the entrance channel. However, figure K.5 shows that while there is refraction of waves towards the entrance channel, the same phenomenon also makes waves bend away from the channel. This refraction of waves away from the channel is most obvious directly west from the entrance, as the coast is more curved there.

Even though the contribution of refraction is less than expected, there is more wave penetration from the north than from the northeast, as table K.4 shows.

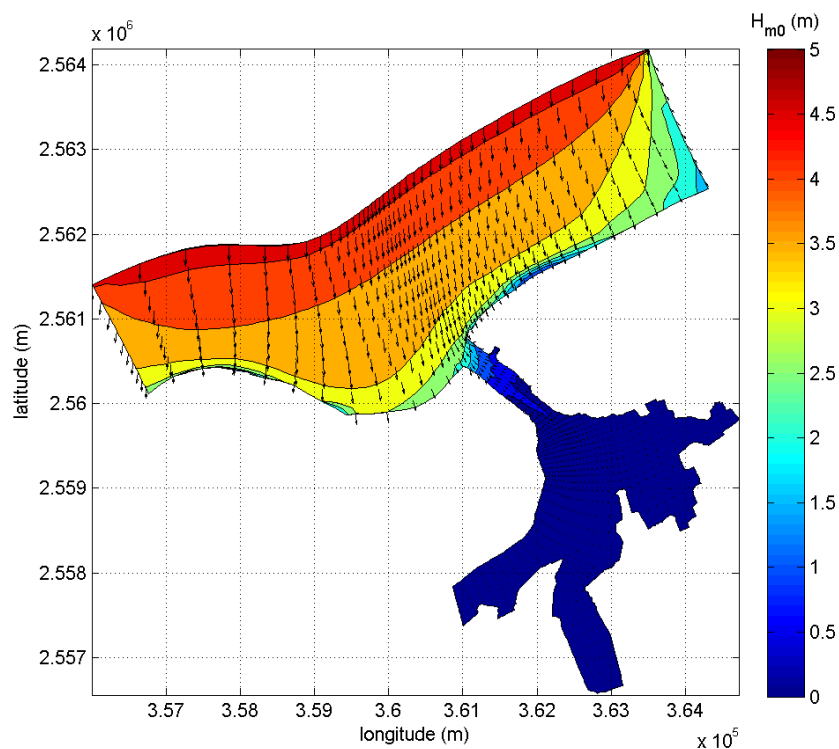
figure K.5 – significant wave heights from an incoming wave with $H_s = 5$ m and $T_p = 6$ s

table K.4 – significant wave height and mean absolute wave period for waves from the north in the channel

$H_s \backslash T_p$	6 s		9 s		12 s	
	H_s channel	$T_{m-1,0}$ channel	H_s channel	$T_{m-1,0}$ channel	H_s channel	$T_{m-1,0}$ channel
2 m	0.66 m	6.53 s	0.74 m	8.29 s	0.81 m	11.01 s
5 m	1.30 m	5.96 s	1.76 m	8.33 s	1.98 m	10.59 s
8 m	1.60 m	6.20 s	2.44 m	8.50 s	2.33 m	10.32 s

Wave penetration does not occur as far inward as the marina. The wave heights are slightly larger than when waves are coming in from the northeast, but the heights are still in the order of centimetres (table K.5).

table K.5 – significant wave height and mean absolute wave period for waves from the north in the marina

$H_s \backslash T_p$	6 s		9 s		12 s	
	H_s marina	$T_{m-1,0}$ marina	H_s marina	$T_{m-1,0}$ marina	H_s marina	$T_{m-1,0}$ marina
2 m	0.01 m	6.01 s	0.01 m	8.33 s	0.01 m	10.64 s
5 m	0.03 m	6.16 s	0.03 m	8.35 s	0.03 m	9.97 s
8 m	0.03 m	6.30 s	0.05 m	8.41 s	0.05 m	9.18 s

K.3.3 WAVES FROM THE NORTHWEST

As the entrance channel is orientated towards the northwest, it is expected this wave direction produces the most wave penetration. The results of the simulations confirm this suspicion, as is clearly visible in the third row of table K.6. Compared to the two previous scenarios, the wave penetration into the channel is fiercer. For example the simulation of $H_s = 2$ m and $T_p = 9$ s is used (figure K.6). A relatively low wave is propagated towards shore, then propagates through the channel and dampens out only towards the end (although it has a long period).

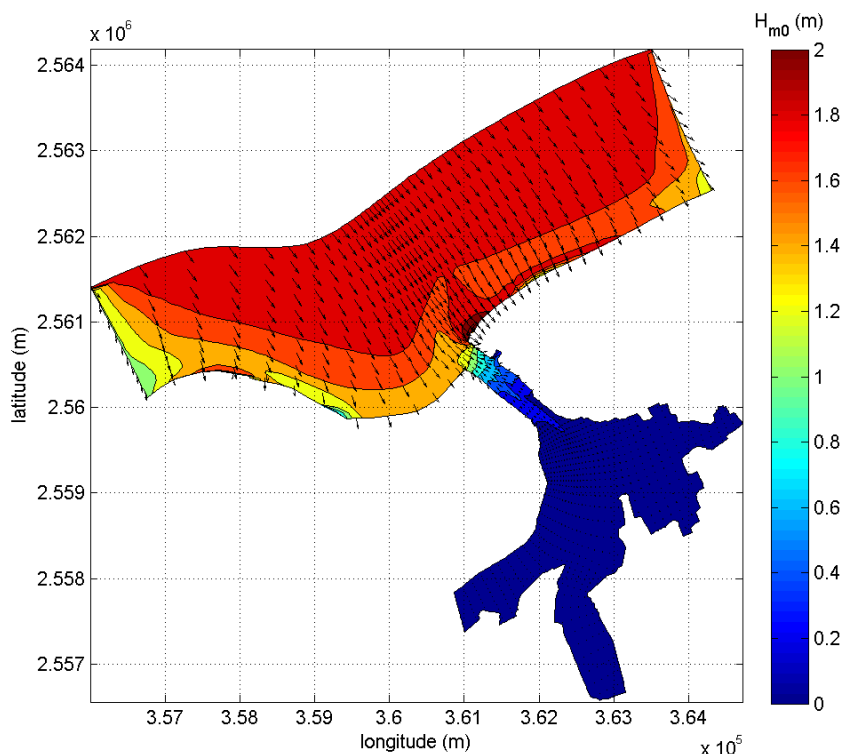


figure K.6 – significant wave heights from an incoming wave with $H_s = 2$ m and $T_p = 9$ s

table K.6 – significant wave height and mean absolute wave period for waves from the northwest in the channel

H_s \ T_p	6 s		9 s		12 s	
	H_s channel	$T_{m-1,0}$ channel	H_s channel	$T_{m-1,0}$ channel	H_s channel	$T_{m-1,0}$ channel
2 m	0.92 m	5.33 s	0.85 m	7.79 s	0.81 m	10.50 s
5 m	1.72 m	5.89 s	2.01 m	8.08 s	2.00 m	10.43 s
8 m	2.06 m	6.16 s	2.87 m	8.34 s	3.07 m	10.12 s

In the case of the marina there is less difference compared to the previous scenarios. Although wave heights are somewhat higher, they are still not of such nature to cause concern.

table K.7 – significant wave height and mean absolute wave period for waves from the northwest in the marina

H_s \ T_p	6 s		9 s		12 s	
	H_s marina	$T_{m-1,0}$ marina	H_s marina	$T_{m-1,0}$ marina	H_s marina	$T_{m-1,0}$ marina
2 m	0.02 m	5.86 s	0.01 m	7.83 s	0.01 m	9.90 s
5 m	0.03 m	6.02 s	0.03 m	7.90 s	0.03 m	9.76 s
8 m	0.04 m	6.17 s	0.05 m	7.99 s	0.05 m	9.05 s

K.3.4 WAVES FROM THE WEST

Waves from the west are harder to model correctly as the grid is set up in such a way that it is difficult for these waves to enter, as they can only enter on the northern boundary. The consequences of this problem can be seen in figure K.7, as the western boundary produces effects that penetrate into the area of interest. Nevertheless, the wave vectors show that western waves can divert towards the channel. But also in this scenario it is the case that penetration is limited to the first section of the entrance channel.

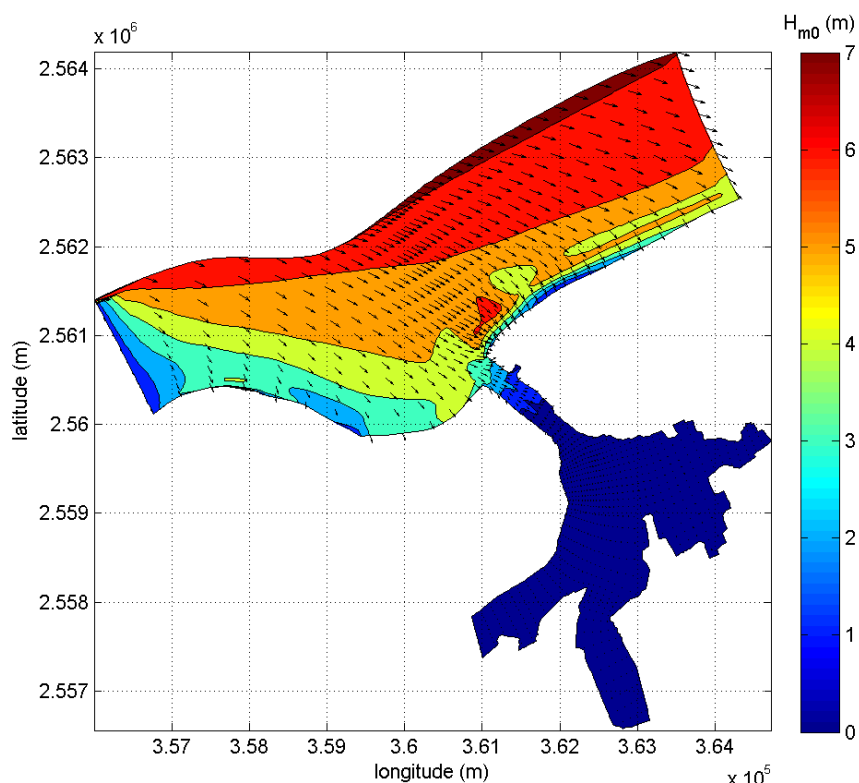


figure K.7 – significant wave heights from an incoming wave with $H_s = 8$ m and $T_p = 12$ s

table K.8 – significant wave height and mean absolute wave period for waves from the west in the channel

$H_s \backslash T_p$	6 s		9 s		12 s	
	H_s channel	$T_{m-1,0}$ channel	H_s channel	$T_{m-1,0}$ channel	H_s channel	$T_{m-1,0}$ channel
2 m	0.82 m	5.12 s	0.67 m	7.45 s	0.60 m	10.13 s
5 m	1.67 m	5.64 s	1.62 m	7.71 s	1.49 m	10.20 s
8 m	2.11 m	5.95 s	2.43 m	8.05 s	2.37 m	10.16 s

table K.9 – significant wave height and mean absolute wave period for waves from the west in the marina

$H_s \backslash T_p$	6 s		9 s		12 s	
	H_s marina	$T_{m-1,0}$ marina	H_s marina	$T_{m-1,0}$ marina	H_s marina	$T_{m-1,0}$ marina
2 m	0.01 m	5.76 s	0.01 m	7.48 s	0.01 m	9.55 s
5 m	0.03 m	5.85 s	0.02 m	7.53 s	0.02 m	9.53 s
8 m	0.04 m	5.98 s	0.04 m	7.64 s	0.03 m	9.24 s

K.3.5 CONCLUSIONS

In general it can be concluded that wave penetration solely due to waves (without wind) is limited to the entrance channel. The marina and the rest of the basin are without notable waves due to external forcing. The penetration, for imposed wave conditions from any direction, is limited to the entrance channel.

As expected, the northwest is the wave direction that produces the most penetration. But the difference with the scenarios north and west is not that great, as in all scenarios the waves have damped out at the end of the channel.

The variations in wave height show that as the initial imposed wave height increases, the penetrated wave height is also larger, but it appears it is also limited. This can be seen if the rows of the tables with the simulation results are compared, the difference in wave height between the second and first row is generally larger than between the third and second.

For the design of the marina it can be concluded that the contribution of external waves to the internal waves is negligible compared to the internal waves caused by wind forces. At most, the contribution can be quantified to be in the order of centimetres, which is of no consequence to the berthed ships.

K.3.6 GENERAL INPUT FILE

```

*****HEADING*****
PROJECT 'Havana' 'TUD'
$*****MODELINPUT*****

SET LEVEL = 0

SET MAXERR = 30 CART

CGRID CURV 227 90 EXCEPT 0.0 0.0 CIR 36 0.03 1.00

READ COOR 1. 'Cuba2.grd' IDLA=3 NHEDF=3 FORMAT '(10X,5F12.3)'

INPUT GRID BOT CURVI 0. 0. 227 90 EXC 999.0
READ BOTTOM 1. 'Cuba2.bot' IDLA=4 NHEDF=0 FREE

$*****WINDINPUT*****

$WIND 10 315

$*****WAVEINPUT*****

BOUNDARY SHAPESPECTRUM JONSWAP 3.3 PEAK DSPR DEGREES
BOUNDSPEC SEGMENT XY 356010.757 2561404.128 363493.819 2564182.709 CON PAR 8 9 315 30

$*****PHYSICS*****

GEN3 KOM
WCAP KOM DELTA 1
OFF QUAD
TRIAD trfac=0.1 cutfr=2.5
BREAKING 1 0.73
FRICTION JONSWAP CFJON=0.038

$*****NUMERICS*****

NUM STOPC 0.00 0.01 0.001 98 STAT mxitst=100 alfa=0.002

$*****OUTPUT*****

OUTPUT OPTIONS '%' TABLE 16 BLOCK 9 1000 SPEC 8

GROUP 'RESULTS' 0 227 0 90
TABLE 'RESULTS' HEADER 'RESULTS.txt' XP YP HS TPS

BLOCK 'RESULTS' NOHEADER 'Havana.mat' LAY 4 XP YP HSIG TMM10 DIR DSPR TPS

BLOCK 'COMPGRID' NOHEAD 'Cuba.mat' XP YP DEP HSIG TMM10 TPS DIR DSPR

POINT 'Offshore' 359864.961 2562248.999
TABLE 'Offshore' HEADER 'OFFSHORE.txt' XP YP DEP HSIG TMM10 TPS DIR DSPR

POINT 'Channel' 361261.792 2560488.303
TABLE 'Channel' HEADER 'CHANNEL.txt' XP YP DEP HSIG TMM10 TPS DIR DSPR

POINT 'Marina' 361923.195 2558208.627
TABLE 'Marina' HEADER 'MARINA.txt' XP YP DEP HSIG TMM10 TPS DIR DSPR

CURVE 'Curve' 359643.632 2562009.741 10 361018.483 2560603.439 5 362064.317 2559862.305 5 362369.515
2559418.196 5 362462.874 2559082.040 5 362141.161 2558350.074 5 361582.114 2557967.425

TABLE 'Curve' HEADER 'CURVE.txt' Xp Yp DEP HSIG TMM10 TPS DIR DSPR

$*****CALCULATION*****

COMPUTE
STOP

```


K.4 EXTREME CASE SCENARIOS

The results of both sensitivity analyses are used to investigate the wave conditions during extreme cases. As waves and wind are correlated, it is likely a scenario occurs where both forcing types act on the system in the same time.

In this chapter four cases will be investigated, again using the mathematical model SWAN. For these four cases a finer grid has been used, especially in order to better see the wave penetration through the entrance channel.

Two main scenarios have been created, a north-western storm and a scenario with waves from the northwest and wind from the northeast. For each scenario two simulations have been done, one for a return period of 50 years and one for a return period of 225 years. Sea level rise is taken into account for both scenarios (17.5 cm over a period of 50 years, see also paragraph ‘H.2.2 Sea level rise’.)

This investigation into extremes is less relevant for the design of the marina and the ferry terminal. It is however interesting to do these simulations to gain a better general understanding of the hydrodynamic behaviour of the bay.

K.4.1 INPUT

North-western storm:

This scenario involves both waves and wind from a north-western direction. The physical background to this scenario is a north-western storm, which has generated waves in the Gulf of Florida and moves across Havana.

The input conditions for the two scenarios are summarized in table K.10. The values for waves have been determined in this appendix, those for wind in paragraph ‘H.4.3 Data from GeoCuba’ in appendix H.

table K.10 – input conditions for north-western storms

Scenario number	Return period [years]	Waves			Wind	
		Direction	Sign. wave height [m]	Peak period [s]	Direction	Velocity [m/s]
1	50	northwest	11.46	12.8	northwest	41.2
2	225	northwest	14.84	13.8	northwest	48.1

Wind set-up:

For a north-western storm, wind set-up can play an important role due to the extreme wind speeds in combination with the orientation of the coast relative to this wind. However, it is expected that due to the steep shore profile in combination with deep waters, the wind set-up will be limited. In order to obtain a value for wind set-up, use has been made of the program CRESS²¹. With this program, the set-up can be calculated as a function of fetch length (F), water depth (h), wind speed (u) and an approach angle towards the coast (φ). In case of open sea, the formula given below has been used:

$$\text{total wind setup} = 0.5\kappa \frac{u^2}{gh} F \cos \varphi$$

²¹ Coastal and River Engineering Support System, developed by Delft University of Technology, Rijkswaterstaat, Unesco-IHE and Royal Haskoning

in which κ is defined as:

$$\kappa = c_w \frac{\rho_{air}}{\rho_{water}}$$

In case of a storm with a return period of 50 years (wind speed of 41.2 m/s), an average wind speed of 30 m/s has been used for an average speed persistent during the entire storm and fetch length. The fetch length is assumed to be 150 km with an average water depth of 1000 m. Because the Havana Bay is orientated perpendicular to the northwest, the approach angle (ϕ) is taken to be zero.

With CRESS, also a shallow zone can be specified, in which the set up in shallow water can be calculated. Because of the steep shore profile, the length of this shallow zone has been set to 1200 m with an average water depth of 30 m. With values of $c_w = 2.72 * 10^{-3}$, $\rho_{air} = 1.21 \text{ kg/m}^3$ and $\rho_{water} = 1030 \text{ kg/m}^3$, the resulting wind set-up will be **0.04 m**, which is relatively low.

In case of a storm with a return period of 225 years (wind speed of 48.1 m/s), an average wind speed of 35 m/s has been used. The same method used above yields a wind set-up of **0.06 m**.

North-western waves combined with a northeaster wind:

This scenario is a combination of the worst cases from the sensitivity analyses. The physical background to this scenario is that the same storm that has created the waves will have changed in characteristics and is now blowing from the northeast.

The input conditions for the two scenarios are summarized in table K.11. In case of a northeaster wind, wind set-up is not taken into account. This is because wind direction and coastline orientation are almost parallel to one another.

table K.11 – input conditions for storm combinations

Scenario number	Return period [years]	Waves			Wind	
		Direction	Sign. wave height [m]	Peak period [s]	Direction	Velocity [m/s]
3	50	northwest	11.46	12.8	northeast	41.2
4	225	northwest	14.84	13.8	northeast	48.1

K.4.2 CONCLUSIONS

The output of scenario 1 to 4 can be seen in section K.4.3, figure K.8 to figure K.15. Scenario 1 represents a north-western storm with a probability of exceedance of 1/50 per year. The incoming wave of 11.46 m will quickly decline due to wave breaking and near the entrance channel the wave height has a value of about 4 m. At the end of the entrance channel, the wave height is considerably smaller and a maximum value of 1.6 m has been found. In the bay itself, maximum wave heights of 1.4 m occur.

The same results have been obtained for scenario 2 (north-western storm with a probability of exceedance of 1/225 per year), but with higher wave heights in both the entrance channel as in the bay itself; 2 m waves occur in the entrance channel and maximum wave heights of 1.8 m can be found in the bay. It is remarkable that near the coast, still very high waves can occur (12 m). However, at the entrance of the channel, these waves are quickly dissipated resulting in much lower wave heights.

Scenario 3 simulates a north-eastern wind with north-western waves, both with a return period of 50 years. The offshore waves do not differ much in comparison with scenario 1. However, wave patterns inside the bay are significantly different. In scenario 1 and 2 the highest waves will occur in the eastern part of the bay, whereas in this scenario the western part has more severe waves (1.4 m). This is the consequence of the north eastern wind only and from this it can be concluded that the wave conditions *inside* of the bay are determined by *local wind conditions*. Penetration of external waves is of minor importance, because of high wave dissipation in the entrance channel. This again confirms that a north-eastern wind is the most critical for the ferry terminal and marina.

A north-eastern wind in combination with a north-western wave, both using a probability of exceedance of 1/225 per year is simulated in scenario 4. The same conclusion can be drawn as in scenario 3, but in this case higher magnitudes are found. In the western part of the bay maximum wave heights of 1.8 m can occur. In addition, it is notable that at the end of the entrance channel, the wave height is less in comparison with scenario 2. It is highly likely that this is due to the different directions of the external wave and the internal (wind generated) wave.

K.4.3 OUTPUT

Scenario 1:

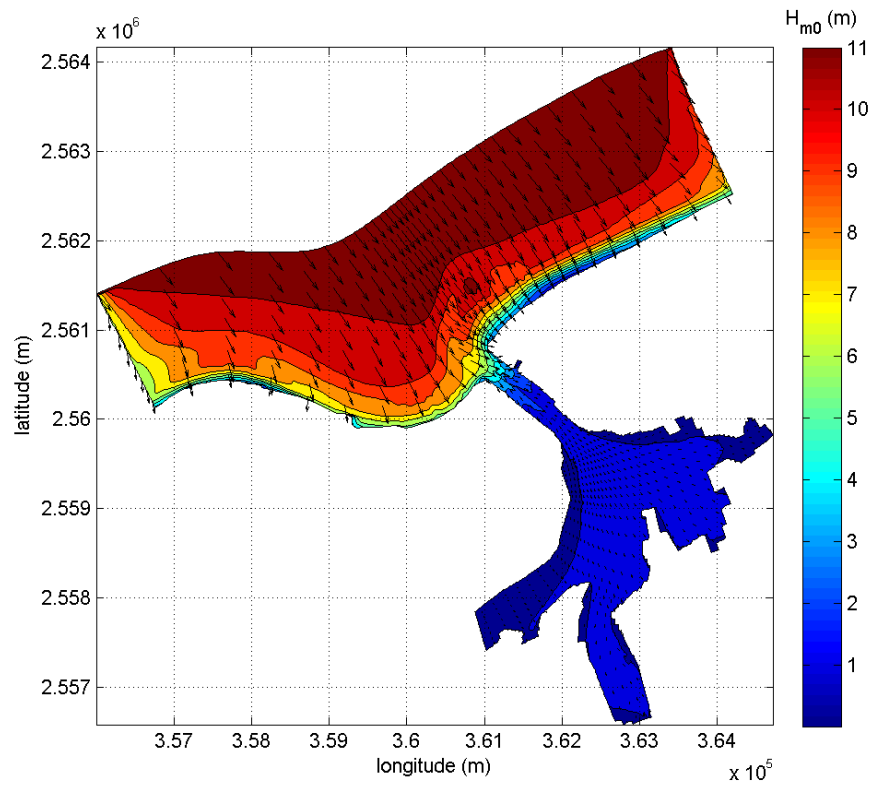


figure K.8 – scenario 1, significant wave heights

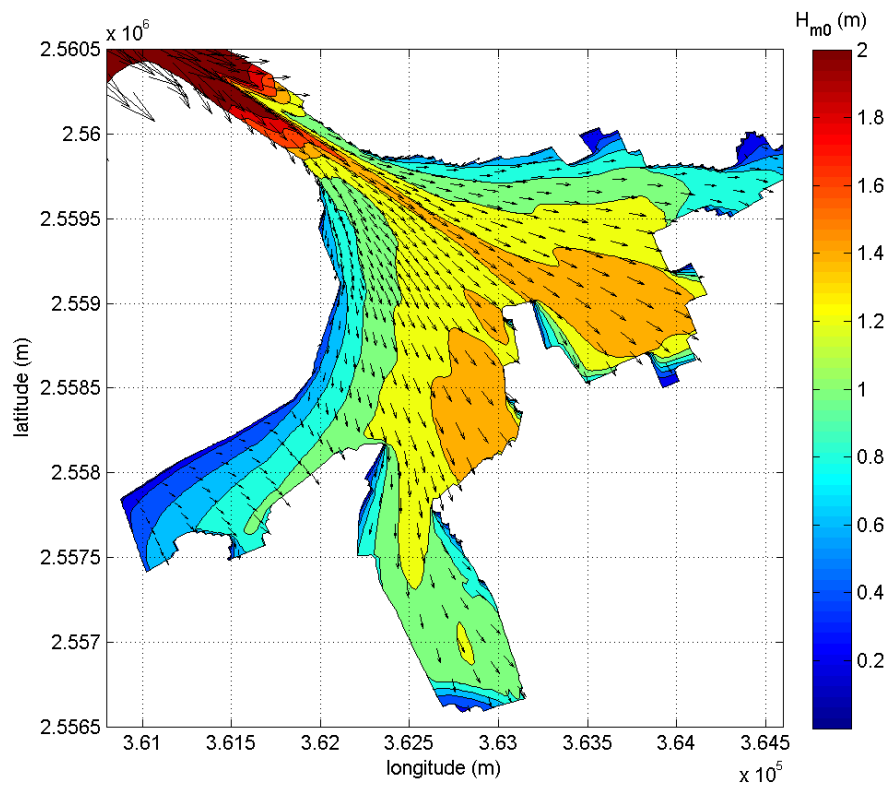


figure K.9 – scenario 1, significant wave heights in the bay

Scenario 2:

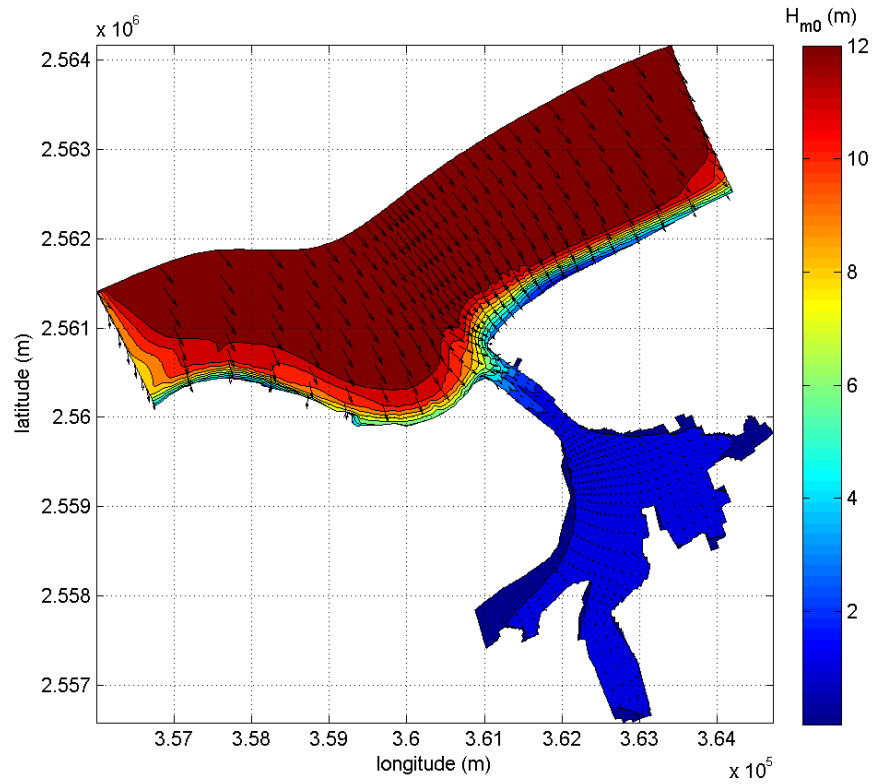


figure K.10 – scenario 2, significant wave heights

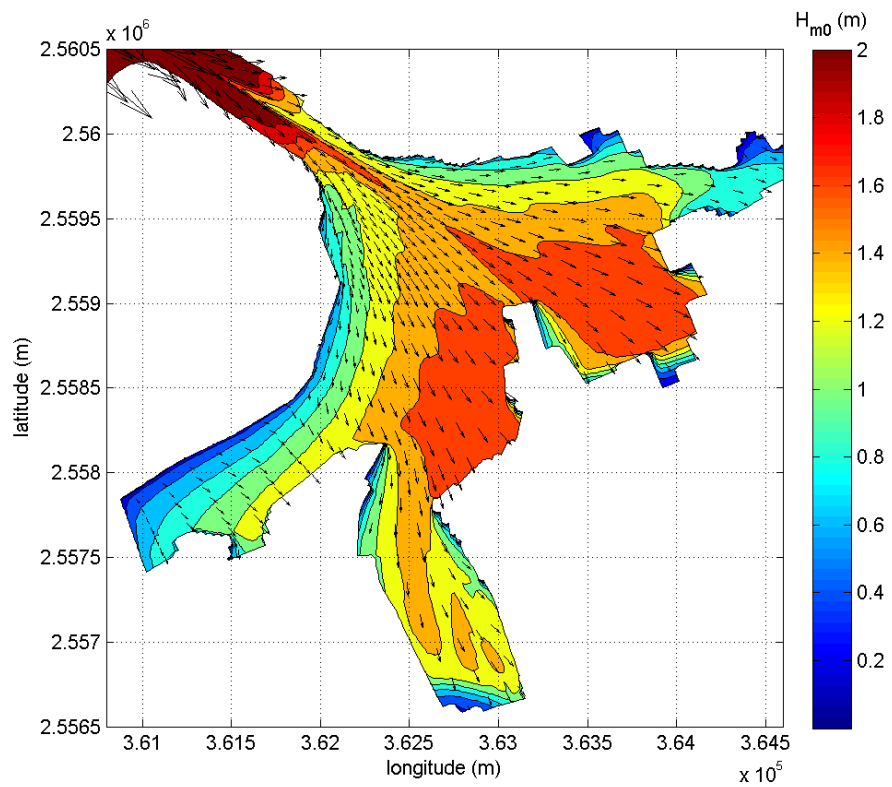


figure K.11 – scenario 2, significant wave heights in the bay

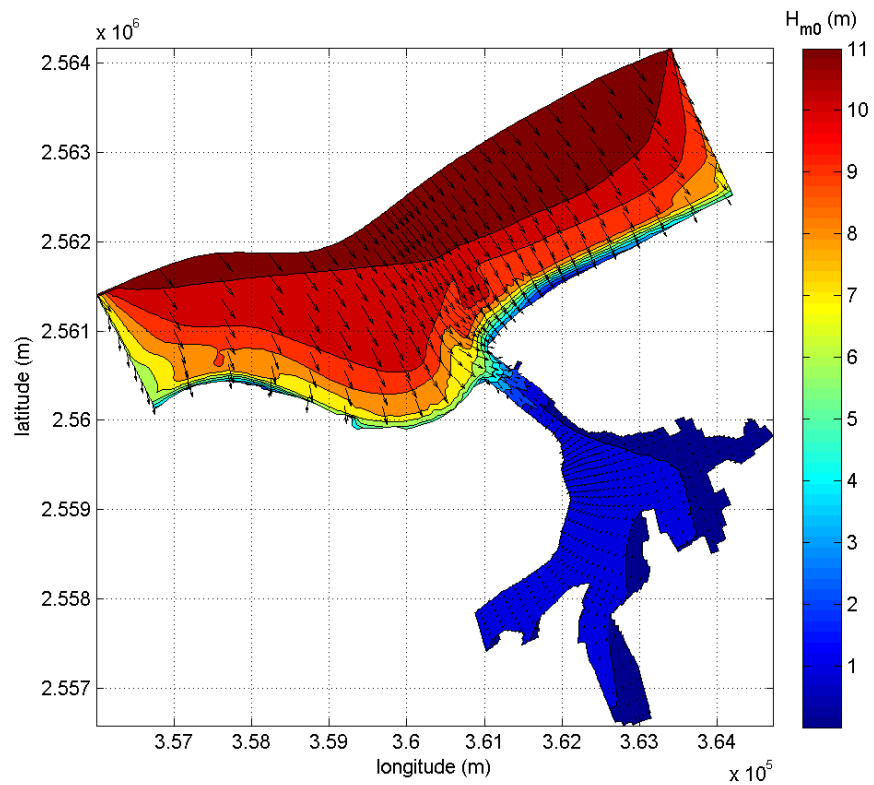
Scenario 3:

figure K.12 – scenario 3, significant wave heights

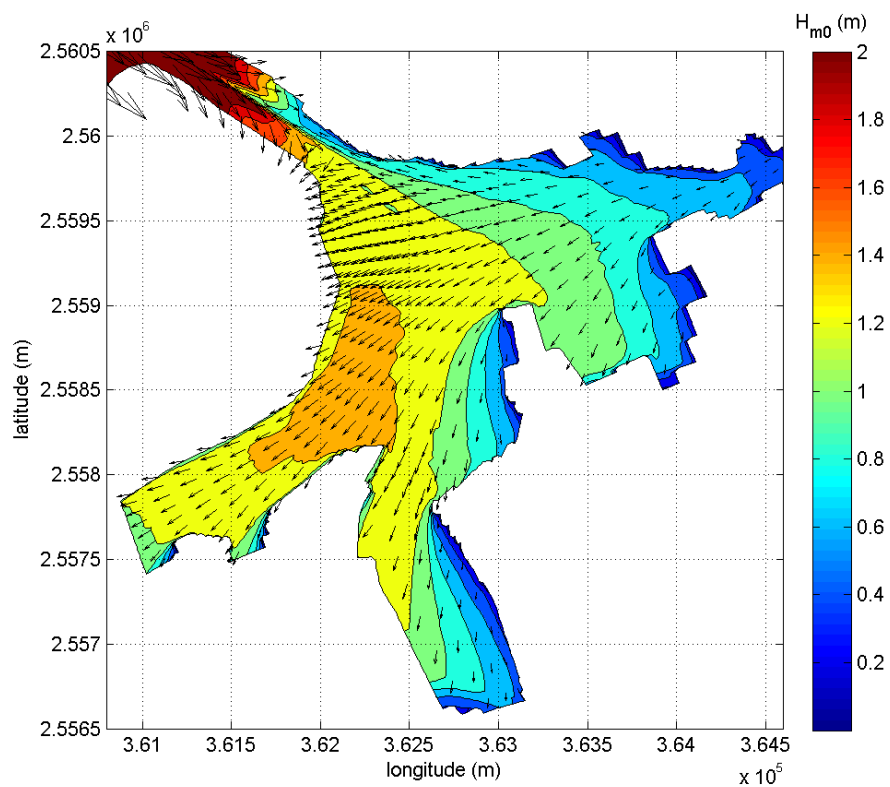


figure K.13 – scenario 3, significant wave heights in the bay

Scenario 4:

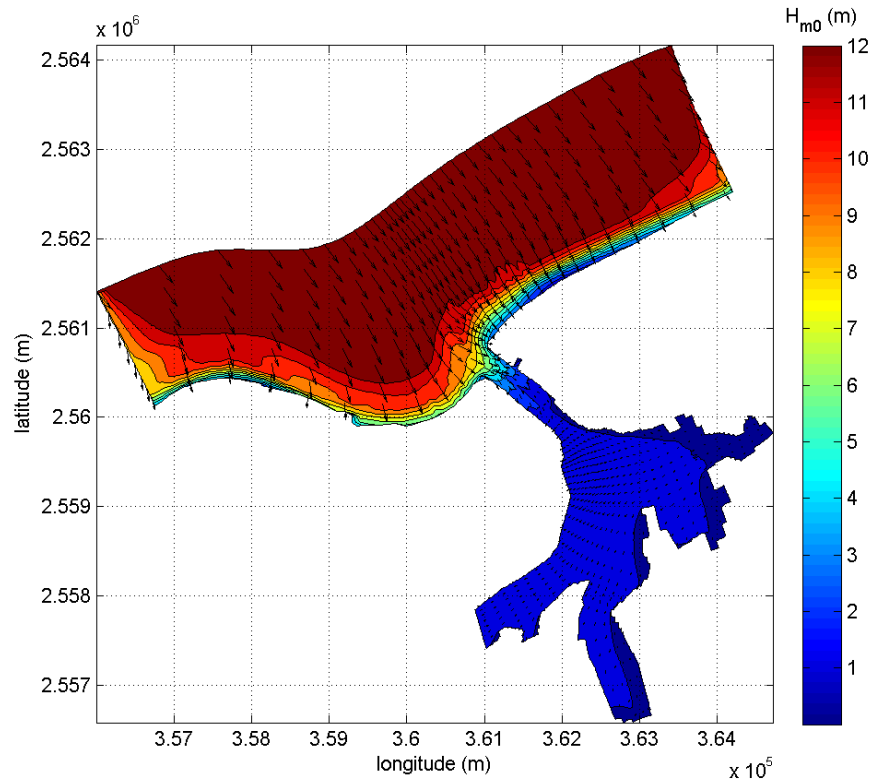


figure K.14 – scenario 4, significant wave heights

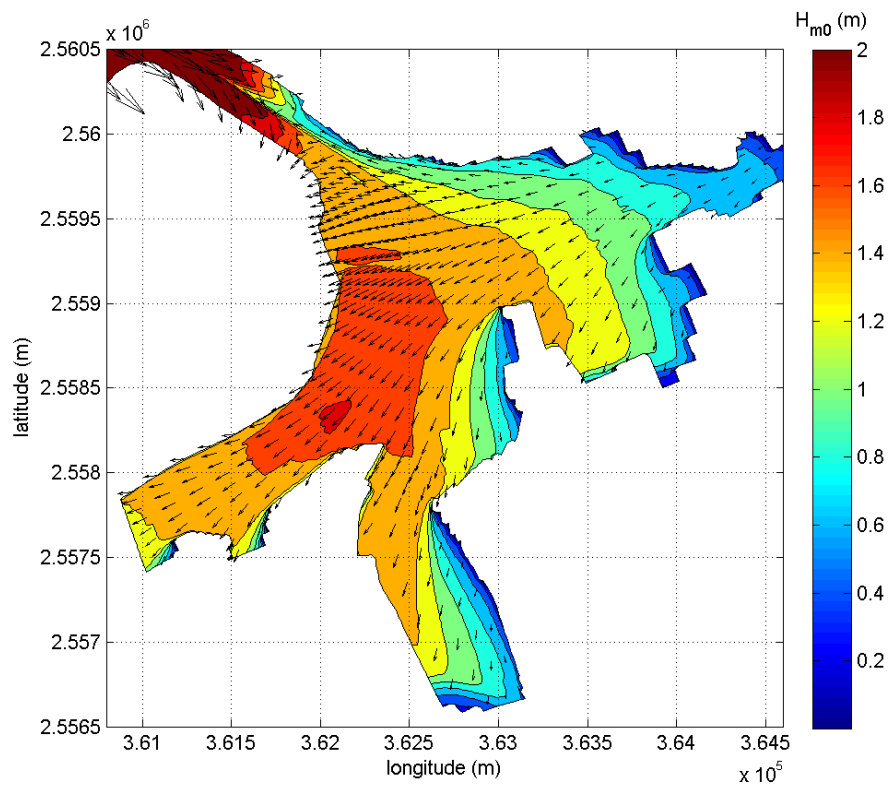


figure K.15 – scenario 4, significant wave heights in the bay

K.5 RECOMMENDATIONS

Larger model

As wind forms the foundation of the forcing on the model, it might be useful to better incorporate this in the model. This could be done by using two models, a larger one and a smaller one, with more detail. By imposing a wind field on the larger model a wave field is created, which is used as input for the detailed model. The use of two models like this is called nesting; SWAN is suitable for this method.

Local wind field

For the SWAN model runs in this report a uniform wind from a single direction is used. As the wind is one of the most important input values, especially for internal waves, it is necessary to use more dynamic wind input data.

Boundary locations

The way the current model is set up, it might be the case that the boundaries are too near to the areas of interest. In some of the outputs the boundary effects are nearly noticeable in the entrance channel. A solution for this is to enlarge the computational grid and place the boundaries further away from the areas of interest.

Wave conditions

The current wave input is determined from ARGOSS data. The ARGOSS data is from a point 90 km to the north of Havana. It is however better to use a different location as the base for a statistical analysis. The current data is not perfectly representative of actual wave conditions for the Bay of Havana, because of the proximity of the Florida Keys. These islands are especially influencing the wave data from the northwest, and this is the most valuable input for the Havana Bay. A data location more west would be better suitable.

Wave spectrum

In the SWAN runs the default JONSWAP wave spectrum is used. A further investigation into wave conditions could better define the actual wave spectrum. It might be necessary to fine-tune the parameters of the JONSWAP spectrum to better match the actual occurring wave spectrum.

Swell and wind waves

In this report no distinction has been made in the analysis of ARGOSS data between swell and wind waves. A more thorough analysis of the data including this distinction is advisable.

Local fetch length

As the hydrodynamic study has shown, the locally generated waves are the most important factor. By nature the bay is surrounded by elevated areas, especially on the eastern shore. These 'hills' would influence fetch length and thus wave conditions. For further research it would be useful to analyse the influence of these geographical surroundings of the bay.

Appendix L: BOUNDARY CONDITIONS AND DESIGN REQUIREMENTS

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L.1 INTRODUCTION

This appendix holds the boundary conditions and design requirements for the design of the ferry terminal and marina, as well as the requirements for the design of the connections of both components to the network.

The boundary conditions are divided in internal and external boundary conditions, given in chapters L.2 and L.3. The requirements are divided in functional and spatial requirements, found in chapters L.4 and L.5.

L.2 INTERNAL BOUNDARY CONDITIONS

The internal boundary conditions are the boundaries for the execution of this project. A distinction is made between time related boundaries, resource related boundaries, organizational boundaries and quality boundaries.

L.2.1 TIME RELATED BOUNDARIES

- Since the future of Cuba is heavily dependent on several unpredictable factors it is necessary to maintain a high flexibility in the planning and construction;
- All preparations should be made to be able to execute the project when the time is appropriate;
- The project should be feasible to be executed in phases.

L.2.2 RESOURCE RELATED BOUNDARIES

- Profits should be maximised;
- Expenditures must earn themselves back within the planning horizon of 50 years.

L.2.3 ORGANISATIONAL BOUNDARIES

- The design must be approved by the Oficina de Historiador;
- Other stakeholders have to support the design to create a strong basis for implementation and minimize bureaucratic fuss.

L.2.4 QUALITY BOUNDARIES

- Traffic hindrance during construction should be minimized;
- Environmental hindrance (noise and pollution) during construction should be minimized;
- The quality of the design has to meet the international norms.

L.3 EXTERNAL BOUNDARY CONDITIONS

External boundary conditions are those conditions that are outside the influence of the project. These conditions are for example:

- The political situation of Cuba;
- The economy and resulting welfare level of Cuba;
- The level of bureaucracy and consequently the influence on project planning;
- The availability of a skilled labour force, domestic or foreign;
- The availability of sufficient materials with a sufficient quality;
- The availability of specific pieces of equipment necessary to implement certain components of the design.

L.4 FUNCTIONAL REQUIREMENTS

The functional requirements form the foundation of the design done on this project. A distinction is made between general requirements for the project area, which are applicable to all components of the design, and specific requirements for individual components.

L.4.1 GENERAL REQUIREMENTS FOR THE PROJECT AREA

- All designs should match with the general perspective the of Tourist Port Havana master plan;
- The design must improve the accessibility of the port to increase the value of the Tourist Port Havana master plan;
- Underground cables and lines should be bundled as much as possible;

L.4.2 SPECIFIC REQUIREMENTS FOR THE MARINA

- The capacity of the marina should be at least 272 berths with the following subdivision of length classes:
 - 2 berths for mega yachts with a length of 50 – 120 m
 - 60 berths for super yachts with a length of 24 – 50 m
 - 160 berths for yachts with a length of 10 – 24 m
 - 50 berths for yachts 4.5 – 10 m
- Cleats and bollards should provide a minimal movement of berthed yachts to ensure the safety;
- The walking distances from the berth to the service facilities should be minimized;
- The berths should have at least the dimensions as given in the guidelines;
- The design of the marina should be flexible in order to anticipate on changes in the demand;
- Fairways should have at least the dimensions as given in the guidelines to guarantee the manoeuvrability of the yachts;
- The marina and the entrance channel should have at least the water depth as given in the guidelines;
- The berthing arrangement should be orderly arranged;
- Yachtsmen should retain their privacy;
- Yachts should not hinder other vessels in the bay;
- The design should have little maintenance;
- The wave climate of the marina should be at least 'good';
- The walkways should have at least the dimensions as given in the guidelines;
- Berths should be equipped with a service bollard for the connection of electricity and water;
- A fire extinguisher should be present every 50 m;
- A safe egress from the water should be available every 20 m;
- Walkways should be illuminated at night;
- Walkways and piers should be protected from mooring forces by fenders;
- The gasoline filling station should be easily accessible by yachts;
- Gangways should have a slope exceeding the maximum values as given by the guidelines;

- The marina should be easily accessible by public transport, by car and by foot;
- The marina should be easily accessible for tankers and supply trucks;
- The marina should provide the following facilities with the given surface area:

table L.1 – required facilities of the marina

Facility	Required area (m ²)
Hotel (shared with marina)	5 000
Parking area and dry berthing area (can be shared with marina)	2 000
Recreational services (like sport courts, fitness)	300 – 3 000
Catering services	200 – 500
Repairing facilities and sail store	250 – 400
Yachting club	250 – 300
Supermarket	100 – 300
Customs services	100 – 150
Money exchange service	100 – 150
Shops for food, drinks, souvenirs and gadgets	50 – 100 (each)
Fuel supply	50 – 100
Sewage and waste water pump out	50 – 100
Vehicle ramp	50
Garbage collecting service	25 – 50

L.4.3 SPECIFIC REQUIREMENTS FOR THE FERRY TERMINAL

- A daily ferry service connection should have a dedicated berth;
- Ferries should be able to perform turning manoeuvres in front of the terminal;
- The ferry terminal and the entrance channel should have at least the water depth as given in the guidelines;
- The sailing route should be as short as possible;
- The berthing method should be suitable given the wave conditions;
- The ship to shore method should be suitable given the tidal conditions;
- Quay wall structures should be able to withstand the loads generated by a vessel;
- The orientation of the berthed vessel should have a minimal angle to the prevailing wind direction;
- Bollards should provide a minimal movement of berthed yachts to ensure the safety of the (un)loading processes;
- The sailing schedules of the different ferries should be able to accommodate the required capacity;
- Quays and piers should be protected from mooring forces by fenders;
- The ferry terminal should be easily accessible by public transport and by car;
- An emergency lane must be implemented for breakdown and emergency services;
- The following facilities should be available at the ferry departure terminal (PIANC, 1995):
 - Long term parking;
 - Short term parking;
 - Setting down lanes for taxis, personal cars and busses;

- Marshalling lanes for taxis and personal cars;
- Marshalling area for vehicles to be transported;
- Buffer area for vehicles waiting for ticket control;
- Ticket sales and control, preferably combined;
- Open service lane for breakdown vehicles and emergency vehicles;
- Public conveniences for travellers waiting in the marshalling area.
- The following facilities should be available at the ferry arrival terminal (PIANC, 1995):
 - Free through fare lane for inbound traffic;
 - Passport control;
 - Waiting area for vehicles with cargo submitted for document clearance;
 - Customs hall with facilities for examination;
 - Premises for customs and forwarding agents;
 - Entering area for inbound busses;
 - Waiting area for vehicles selected for customs research;
 - Transfer area for cargo;
 - Short term parking;
 - Setting down lanes for taxis, personal cars and busses;
 - Short stay parking for busses.
- The following facilities should be available at the piers (PIANC, 1995):
 - Marshalling area for cargo;
 - Storage building
 - Pumps and discharge facilities for sewage and garbage;
 - Passenger bridge to the terminal building.
- The ferry should provide the following facilities with the given surface area:

table L.2 – required facilities of the ferry terminal

Facility	Required area (m ²)
Terminal building / Waiting lounge	30 000
In and out going traffic	10 000
Hotel (shared with marina)	5 000
Parking area (shared with marina)	5 000
Supply shed (at the piers)	300 per pier
Catering services	200-500
Marshalling area (at the piers)	150 per pier
Customs services	100-150
Money exchange service	100-150
Cafeterias, restaurants and bars	50-200 (each)
Shops for food, drinks, souvenirs and gadgets	50-100 (each)
Fuel supply	50-100
Sewage and waste water pump out	50-100
Vehicle ramp	50
Garbage collecting service	25-50
Walking bridge	25
Aprons (at the piers)	15 (m)

L.4.4 SPECIFIC REQUIREMENTS FOR THE CONNECTIONS TO THE NETWORK

- The network must be able to handle the peak hour flow in the year 2060;
- The arterial roads should have a design speed of 50 km/h;
- A green light wave system must be installed to increase the capacity and to minimize waiting times;
- The network should be able to handle disruptions appropriately, i.e. alternative routes must be available when a stretch of road is unavailable due to maintenance or crashes (network robustness);
- A uniform traffic sign system must be implemented;
- Rain drainage must be able to handle 1 hour of heavy rain;

L.4.5 SPECIFIC REQUIREMENTS FOR THE AVENIDA DEL PUERTO AT SIERRA MEASTRA

- Pedestrians must be protected at Plaza San Francisco de Assis;
- Enough shadow has to be provided, preferably with trees;
- The following facilities should be available in this area:
 - Pedestrian crossings;
 - Medical post;
 - Bus stops;
 - Taxi stands;
 - Seats;
 - Playground for kids;
 - Food stands;
 - Tourist information.

L.5 SPATIAL REQUIREMENTS

L.5.1 GENERAL REQUIREMENTS FOR THE PROJECT AREA

- The currently existing piers should be reused as much as possible;
- The arterial roads should have at least 2 lanes per direction with a minimal width of 3.5 m in the entire project area;
- The design has to be flexible to add lanes, public transport stops and/or parking space in the future;
- New facilities should be connected to the water supply network and the sewage system properly;
- New facilities should be connected to the electricity net properly.

L.5.2 SPECIFIC REQUIREMENTS FOR THE AVENIDA DEL PUERTO AT SIERRA MEASTRA

- Pedestrian crossings should be implemented every 50 meters;
- The Avenida del Puerto must have sidewalks of at least 2.5 m wide on both sides of the road;
- A central separator of at least 1.5 m width should be implemented between the lanes in different directions.

Appendix M: ALLOCATION ANALYSIS

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M.1 INTRODUCTION

In this appendix an elaboration is made on the locational planning of the marina and ferry terminal. In order to do so the location dependent issues are analysed first. Two possible variants are proposed considering these issues. After comparison, one of them will be approved to be the starting point of the more detailed marina and ferry terminal designs.

M.2 LOCATION DEPENDENT ISSUES

M.2.1 VISITOR DESTINATIONS

Tourists that visit Havana are mainly attracted by the colonial buildings and (squares of) Havana Vieja. Besides, also the view on the bay from the future boardwalk will attract many tourists. These attractions are both situated north-northeast of the area dedicated for the marina and ferry terminal. Therefore a northward flow of people from the marina and ferry terminal is to be expected.

However, not all ferry passengers will have a touristic destination. A part of them will visit Havana for other purposes, for instance business or for visiting family. For these people it is very important to provide sufficient hinterland connections. Road and transit networks are demanded to meet this requirement. It is concluded that it is sensible to locate the marina as close as possible to the touristic attractions and the ferry terminal as close as possible to the transit systems.

Moreover, the ferry lines will transport vehicles that intensify the traffic in the direct area around the ferry terminal. It is therefore recommended to keep this traffic separated from the tourist attractive sites in the city centre.

M.2.2 NAUTICAL ISSUES

Relatively considered, a ferry is a big and powerful vessel compared to an average yacht. The flow and waves generated by the ferry sailing in the bay has its influence on the smaller yachts, as is elaborated upon in 'Appendix G: Nautical analysis', paragraph 'G.6.2 Vessel generated waves'. This could cause uncomfortable oscillations of the yachts and/or the floating infrastructure. Moreover, yachts can also hinder ferries in their sailing route. These possible problems can be solved with for instance a vessel traffic control service.

Furthermore, it is recommended to minimize the number of turns the ferry vessels have to perform to enter the terminal. First to simplify the mooring processes, and secondly to minimize unrest by currents, flows and noise generated by the ferry. Furthermore, a simple and short sailing route to the terminal minimizes the sailing time in the bay.

From the above it is concluded that it is sensible to locate the marina and ferry terminal in a way that the ferry causes as few as possible hindrance to the marina. Moreover, a mooring straight in line with the sailing route minimizes the time required to moor as well as the hindrance induced during the mooring process.

M.2.3 SPATIAL ISSUES

Both marina and ferry terminal require to house several facilities and infrastructure, both on land and on water. This is elaborated upon in 'Appendix L: Boundary conditions and design requirements', from which is learned that a ferry terminal requires in general more space on land than a marina. It is also stressed that the marina and ferry terminal require shared facilities. It could be an advantage to build only one of these facilities once and use it for both services.

The required nautical area of the basin of the marina depends basically on the number of yachts the marina has to accommodate. For the ferry terminal this

nautical area mainly depends on the number of ferry line connections and thus berths. Dependent on the decisions made in the design process, either the marina or the ferry terminal requires more water area.

Furthermore, it is sensible to design both the marina and ferry terminal on individual locations. Spreading over two or more locations complicates the processes involved in the marina and ferry terminal. More space is required for double facilities and logistic problems will be worse.

M.2.4 REUSE AND REHABILITATION

Special attention should be paid to the possibilities of reusing existing structures. Doing this will have influence on investments, building time and environmental impact. In short, the required financial resources can be limited with the reuse of the existing facilities. Ferry vessels and mega-yachts require a pier structure, therefore the reuse of existing piers, probably rehabilitated, may be interesting opportunities for either the marina or the ferry terminal. This for a great part depends on the dimensions, orientation and level of needed rehabilitation of the piers.

M.3 VARIANTS

It can be concluded from the above analysis that the marina and ferry terminal must be located next to each other. As a result, two variants are thinkable with either the marina or the ferry terminal located in the north-eastern part of the area. From now on, the two locations in the area will be denoted as area one (north-eastern part) and area two (south-western part). The total hatched area is designated for both the ferry terminal and marina. The exact boundary of these parts is not fixed here as this is part of the design process (see also 'Appendix N: Preliminary design of the marina' and 'Appendix P: Design of the ferry terminal').

M.3.1 VARIANT A

Area one (northeast), adjacent to the shopping centre Almacén San José, will be occupied by the marina in this variant. As a consequence, area two (southwest) will be occupied by the ferry terminal. This subdivision is called Variant A and is illustrated in figure M.1.

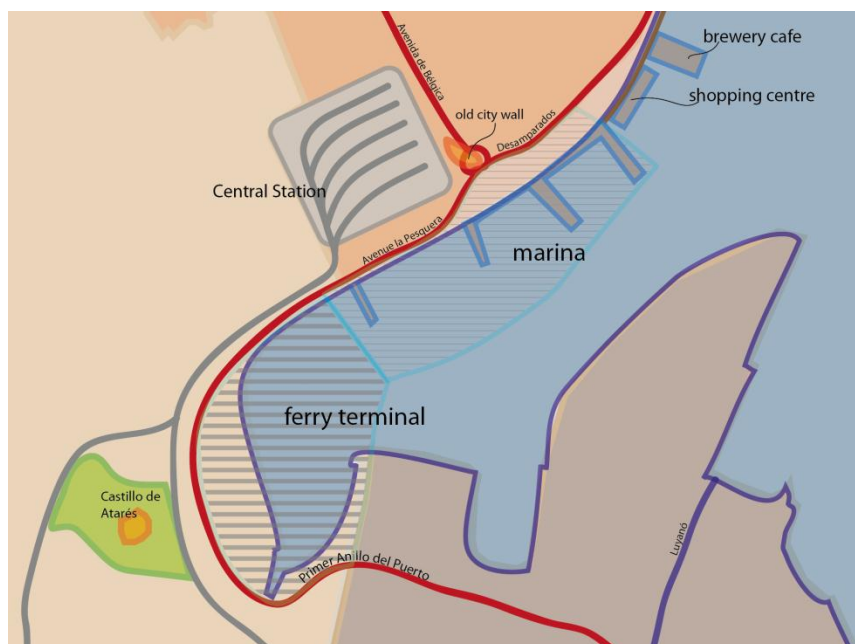


figure M.1 – Variant A

Advantages

- The marina is situated close to the city centre. This short distance is attractive for both yachtsmen and other tourists that will visit the city.
- The possible reuse of piers decreases costs and building impact.
- The marina can be sheltered from waves by the reuse of the piers
- The ferry terminal location minimizes logistical problems in the city.
- Sufficient on-land space is available for a ferry terminal on the muelle Osvaldo Sanchez.
- No turns are needed for the ferry to moor at the ferry terminal.
- The water depth at the location of the marina is larger than at the location of the ferry terminal. Super yachts have a larger draught than ferry vessels.
- Both the ferry terminal and marina are close to arterial roads, which is beneficial for distributing the traffic.
- The location of the ferry terminal provides possibilities to create extra access roads.

Disadvantages

- The ferry passes the marina at arrivals and departures which causes wave penetration in the marina.
- When a ferry is about to arrive or depart, sailing manoeuvres are prohibited from yachts to ensure the safety.
- The ferry terminal is located away from the railway station.
- The ferry terminal is located near the end of the basin. Wind generated wave heights are the highest at this location
- Although the marina is located near the city centre, there is not much space to create new access roads to the marina.

M.3.2 VARIANT B

This variant is the other way around compared to Variant A: area one is occupied by the ferry terminal and area two is occupied by the marina. This situation is illustrated in figure M.2.

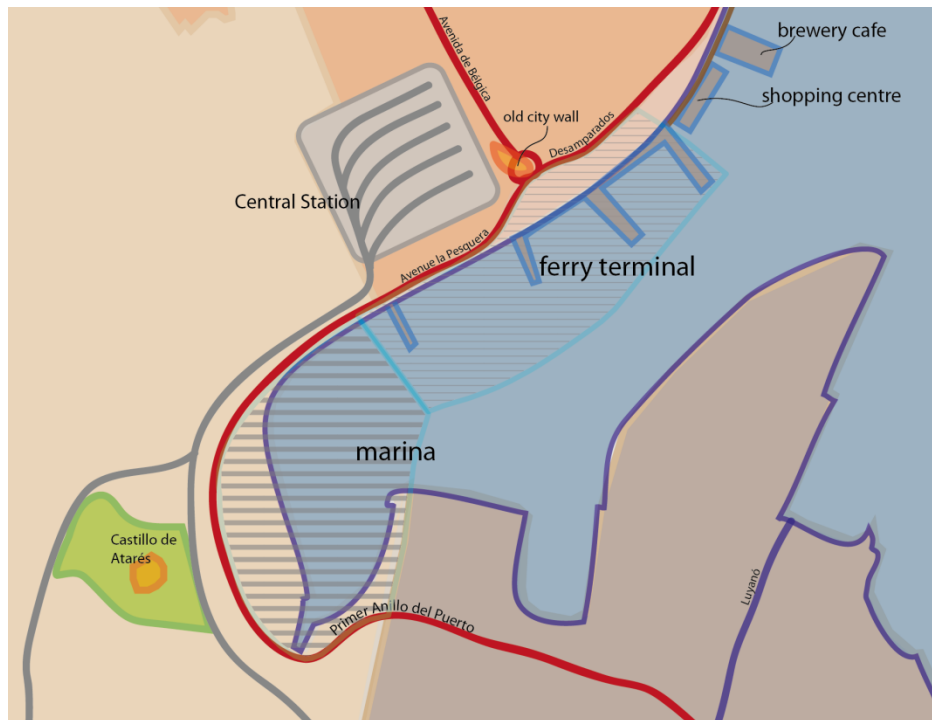


figure M.2 – Variant B

Advantages

- The marina is situated behind the sailing route of the ferry, so it experiences less wave penetration from vessel generated waves.
- The ferry terminal is located close to the station and city centre.
- The possible reuse of piers decreases costs for the ferry terminal.

Disadvantages

- The marina is located relatively far away from the city centre.
- The marina is located near the end of the basin. Wind generated wave heights are the highest at this location
- The reuse of piers is more difficult as many adjustments are required to accommodate the large flow of passengers and vehicles.
- The orientation of the piers makes mooring more difficult, as ferries are moored perpendicular to the prevailing wind direction.
- The sailing route to the mooring facilities of the ferry terminal requires a lot of manoeuvring.
- The traffic of passengers to and from the ferry terminal induces logistical problems in the city centre, since there is little space to create decent traffic connections.
- Visual and non-visual pollution is expected to be concentrated in area two. The prevailing wind direction is northeast, thus driving drifting pollution in the direction of area one and two, eventually concentrating in area two. For a marina this is of more importance than a ferry terminal.

M.4 CONCLUSIONS

Reconsidering the in section M.2 outlined issues it is concluded that Variant A is to be recommended. Considering the destinations of the visitors, the location of the marina close to the city and location of the ferry terminal close to the railway station is an advantage for both. Regarding the nautical issues, a more or less status quo is attained. The passing of the marina by the ferry at its arrivals and departures is a disadvantage for both. However, the manoeuvring of the ferry vessel is minimized with variant A.

The hydrodynamic conditions are more precarious in the marina than in the ferry terminal because of the smaller vessels. These conditions are better for the marina in variant A as well.

Regarding the spatial issues variant A is preferred. Most available on-land space is located in the bend of the railway near Castillo de Atarés. The wet area is not determined yet. This will be done by fixing the boundary of the two areas. Considering reuse and rehabilitation a slight preference is given for variant A. More piers can be reused and fewer adjustments are required.

Appendix N: PRELIMINARY DESIGN OF THE MARINA

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N.1 INTRODUCTION

The design of the marina consists of multiple components. At first, the type of mooring system is chosen in order to know the mooring method of yachts that is most suited given the conditions of the location. Afterwards, it is decided whether the existing piers will be reused or not, as these decisions determine the arrangement of the on-land facilities. The berthing arrangement depends on the decisions made about all these three components and are therefore discussed last. Three variants will be made which will be analysed by a Multi Criteria Analysis to determine which berthing arrangement is the most suitable.

N.2 MOORING SYSTEMS

Several mooring systems are considered in this paragraph. Regarding the conditions of the Bay of Havana an evaluation is made on these mooring systems. This paragraph finally concludes with the approval of the most sufficient mooring system.

According to the rapport of PIANC, 'Mooring systems for recreational crafts' (2002), the following mooring systems are considered:

- Anchorages
- Buoyed moorings
- Piled moorings
- Pontoons
- Drying berths
- Newly developed 'US' buoyed mooring system
- Jetties and fixed stagings
- Opportunist moorings
- Marina berths
- Dry stacking
- Stern to pier system

The rapport provides tables that per hydraulic system (estuarial, river, coastal) prescribe whether a certain mooring system is feasible or not, and if so, under what conditions. The future marina of Havana is located in a natural bay with low exposure to the coastal system. This means the wave pattern consists of low and short waves and the tidal range is relatively low in Havana as well. Moreover, the river discharge in the bay is low. Considering this hydraulic system, the following mooring systems are possible²²:

Anchorage

An important disadvantage of the system is that it requires a lot of space as only 23 vessels of 10 metre length can be accommodated per hectare. The project site has a possible berthing area of about 12 hectares. Given the required number of berthing places for different length classes, anchorages are not applicable in this situation.

Buoyed moorings

This system has the same disadvantage like the anchorage system. This therefore means that the buoyed mooring system is not applicable because it requires too much space.

²² In the hydraulic system used, 'estuarial with non-tidal waters and rivers', every option is at least 'possible' according to PIANC

Piled moorings

The most important advantage of this system is the relevant space effectiveness: up to 50 vessels of 10 metres length can be accommodated per hectare. In combination with pontoons ('Solent' method) even up to 70 vessels can be berthed per hectare. Moreover, the system is very maintenance friendly as few inspections are needed. Piled mooring has however two important disadvantages. The system is relatively costly and specific mooring knowledge from the yachtsmen is required. The mooring arrangement is furthermore poorly organized. However, this system is possible to apply in the marina.

Pontoons

The most important advantage of this system is that it provides traditional and easy mooring and easy access to and from the craft. This system is therefore preferred by yachtsmen, especially when sailing with families. Moreover the system is very versatile at designing berthing layouts. The system can be used in tidal and non-tidal areas and relatively unsheltered conditions. Moving and (re)attaching the pontoons is easy as a result of flexible installing systems. Disadvantages of the system are its relatively short lifetime of 25 years and its required annual inspections. In combination with finger piers, the system is very space effective: 100 vessels of 10 metre or 70 vessels of 12 metre length can be accommodated per hectare.

Drying berths

This system is not applicable since drying of the basin will never occur. The most important advantage of this system is the low building costs.

Newly developed 'US' buoyed mooring system

This system is relatively environmentally friendly and requires only a few anchors. Unfortunately this system is very recently developed, so applying this technique contains a high level of risks. It is decided to avoid these risks since care at funding is a very important demand.

Jetties and fixed stagings

This system is very traditional and therefore presumably convenient in use for most yachtsmen. Another advantage is the possibility to accommodate relatively high vertical loads. The possibility for use is restricted to a maximum tidal range of 1.0 metre. In this case a maximum tidal range of 0.66 metre is expected; therefore no problems are caused as a result of this restriction. Most important disadvantage is the inflexibility of the berths as a result of the rigid elements. Besides, the system requires much care at material choice and frequent inspections.

Opportunist moorings and alongside moorings

This system is also called linearly mooring: vessels are moored in a row in lengthwise configuration. This system is therefore ideal along river or canal banks. Furthermore this configuration blocks the possibility to accommodate berths further inward the water basin. Since the number and sizes of berths that must be accommodated this configuration therefore is not applicable.

Marina berths

Marina berths are berths left vacant by permanent holders at the height of the season. Since (at least initially) few berths are permanently held this system is not taken into account.

Dry stacking

This system accommodates the vessels on land. It is a solution in situations of wide seasonal variations. As the Havana conditions are very seasonal independent and temperate, this system is not wanted. Also the system requires much on-land space is that is not available.

Stern to pier system

The stern to pier system, also called Mediterranean mooring provides a relatively economical solution since few structures are required: only a pier or jetty to moor the vessels stern (or sometimes bow). The solution is relatively space efficient as up to 112 vessels of 10 metre length can be accommodated per hectare. Furthermore this system has a lot of properties in common with the buoy system. A combined system with for instance small finger piers is a possibility. The relatively unusual way of mooring may cause problems for yachtsmen unfamiliar with the system.

N.2.1 ANALYSIS OF THE MOST SUITABLE OPTIONS

From the above it is concluded piled moorings, pontoons, jetties and fixed stagings and the stern to pier system are possibly solutions for the marina in Havana. In order to decide which solution is most suitable, more information on these particular systems is given in the next sections.

Jetties and fixed stagings in combination with alongside mooring arrangement

Fixed staging and alongside mooring is further elaborated on in a combined way; the systems only provides a suitable solution together. Alongside mooring at the quays is not an option since this arrangement blocks the possibility to moor further inside the basin with as a result a very low accommodation rate. Alongside mooring is therefore only advisable at structures perpendicular to the quay orientation. The existing unused piers can provide these moorings.



figure N.1 – alongside pier mooring system

Furthermore this combined system is an attractive alternative for larger class vessels. In general, larger vessels generate larger mooring forces that require rigid structures. Also the hull of the vessel can be supported along its whole length to provide sufficient stability. Besides, alongside mooring is required in case of larger vessels since for perpendicular berthing too much space is required. The orientation of the existing piers in combination with alongside mooring however causes the mooring vessels to be orientated perpendicular to the predominant wind directions which will result in higher mooring forces.

Alongside mooring in combination with a pontoon system is also a possibility, although it limits the capacity of the marina when used by large yachts, see figure N.2.



figure N.2 – alongside mooring at a pontoon as used in Port Hercule, Monaco

Piled moorings

Pile moorings consist of a pile founded on the bottom of the basin. The part of the pile that reaches above water level provides equipment like brackets and cables to moor multiple vessels. This way of mooring is not usual to the majority of yachtsmen.

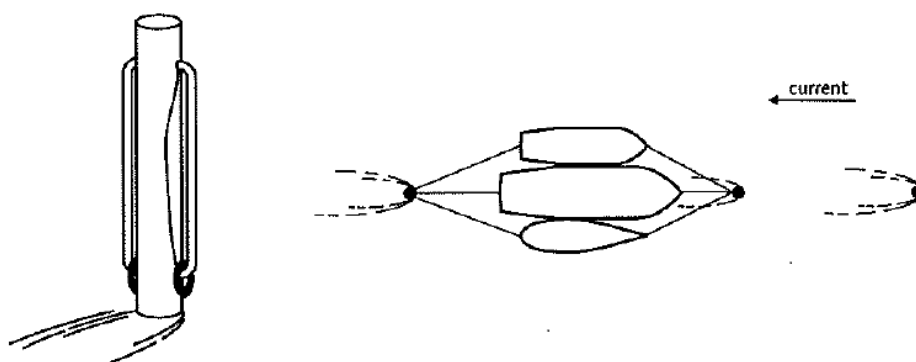


figure N.3 – Piled mooring system

In figure N.3 the system is depicted. It is clear that the space effectiveness is high but also the arrangement may require a lot of rafting²³ and thus social discomforts to the yachtsmen arriving and departing. Rafting problems can be mitigated by using a more structured mooring arrangement and/or by using pontoons.

An important disadvantage of piled mooring is furthermore the relative high initial costs, due to the water depth in the basin of about 7.5 to 12 metres. Including the needed length for mooring and freeboard the piles must have lengths of about 10 to 15.0 metres, which is rather long. This generates relatively high costs and technical

²³ Rafting is when boats are tied together, side by side and is considered a 'social phenomena' due to the lack of privacy (Schwarzenegger, et al., 2005)

complications. Heavy foundations must be designed to be prepared for great moment forces. At the other hand, costs are saved by the low necessity for inspections and maintenance.

Moreover, the system is space efficient, but piled moorings do not generate the highest accommodation rate compared to pontoons and fixed structures.

Pontoons

An example of a pontoon system is presented in figure N.4. It consists of walkways and finger piers that are attached to floating elements, pontoons. Some 'light pier' structures with parallel berths along finger piers can be designed in this way. This system therefore is very space efficient and provides a convenient arrangement.

The pontoon system requires in general high attention to its behaviour in currents, waves and winds. Due to the relative calm current conditions in the Bay of Havana, only problems caused by wind waves will presumably occur (see also the hydrodynamic analysis, Appendix H to Appendix X. These problems are however relatively easy mitigated; a pontoon system is therefore considered as suitable.

Since the system is frequently used around the world, it is familiar to most yachtsmen. Also the system provides easy mooring and access to and from the vessel. Besides, the finger piers provide some sense of privacy. The pontoon system provides relatively high comfort as a result. To reduce finger piers and thus costs and space, it is possible to apply double berths instead of a single berth. With this method, two vessels share a single finger pier. Even more cost efficient is the Mediterranean mooring method. This process however is appreciated less by yachtsmen, as vessels are only accessible via the stern.

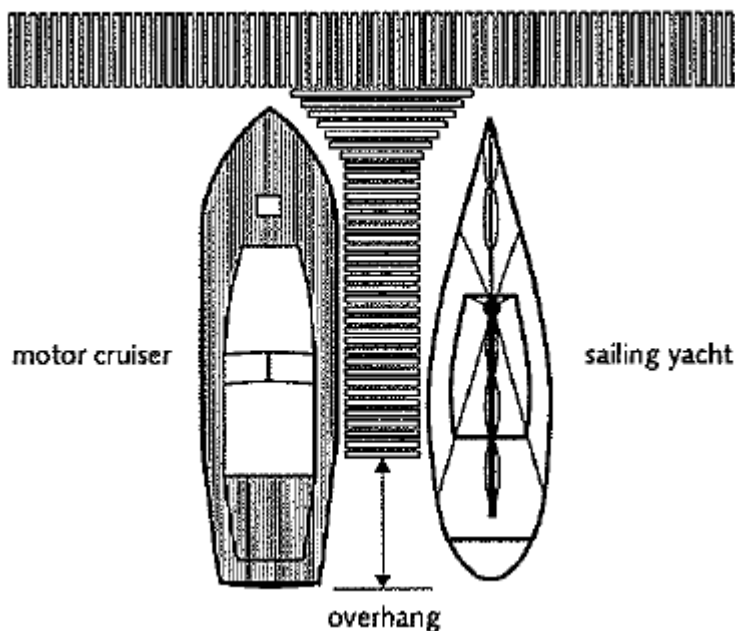


figure N.4 – Pontoon system

The construction can be done with a great variety of material, as long as they provide sufficient buoyancy and durability. This is an attractive feature since materials from Cuba can be used to keep down costs.

The system is also easily (re)installable as the system consists of floating elements that can be connected to each other and the quay. As a result the system can be flexibly installed and expanded if wanted. Also, pontoons can be removed and be inspected and maintained on land. As pontoon structures require a lot of inspections this is welcome. The most important disadvantage of the system is its lifetime, which is rather limited with its 25-30 years.

N.2.2 CONCLUSIONS

Taking all the (dis)advantages of the different berthing structures into account, it is decided to apply the pontoon system with double berths for the smaller and intermediate vessels up to the length of super yachts. This choice is attributed to its space effectiveness, relatively low costs and high flexibility. For the largest class of vessels, the mega-yachts, the alongside-pier system is recommended which can be applied along the existing piers.



figure N.5 – side-view of an example of a pontoon system

N.3 EXISTING PIERS

Four piers are currently located in the design area: Iglesias, Díaz, La Coubre and el Vaciadero (from north to south). Because of economic motives, it is desirable to reuse these existing piers. However, the feasibility of reuse also depends on other factors:

- The **functionality** of the pier should add value to the marina. For example, when the deck of the pier is too high above the water level or when the width is too small, the added value of the reuse is low. It could therefore be more profitable to demolish the pier and build a new construction.
- The **current state** of the piers should be of such quality that reuse of the pier is worthwhile. If a pier is too dilapidated, demolition and subsequent construction of a new pier or walkway could be less costly than renovation of the existing pier.
- The **position** of the pier has to fit in the marina. The orientation or location of the pier could be unfavourable, so it will stand in the way of the berthing structures of the marina.
- A pier could **provide** the marina **shelter** from wind and waves. Reuse of the pier is therefore more useful than purely the functionality of a berthing structure.

Evaluating the feasibility will prove whether rehabilitation and reuse of the piers is economically attractive and to be retained or not.

Espigón Aracelio Iglesias

The position of the pier has many advantages: it gives the marina shelter from waves and wind and it forms a logical boundary between the marina and the Almacén San José. The pier also has the functional properties to berth mega yachts with the alongside mooring method. Together with its position, it could give this berthing place of mega yachts a prominent place in the port. The current condition of the pier is however not well. Because of the value the pier will be able to add to the marina, it is decided that the Espigón Iglesias will be rehabilitated and reused.

Espigón Juan Manuel Díaz

This pier is the only one of the four that is currently in operation, the current condition is therefore at least reasonable. However, the orientation of the pier, directed slightly northwards compared to Espigón Iglesias and not parallel, is a disadvantage as it limits the capacity of the berthing area. Also, the distance of the pier to the Espigón Iglesias limits the possibilities of the arrangement of the berthing area. It is therefore chosen to discard the pier.

Espigón de la Coubre

The Espigón de la Coubre is currently not operational and therefore not in a good condition. Its position of about 400 m from the Espigón Aracelio Iglesias gives La Coubre a central place in the marina, while it limits the design of the berthing place less than the Espigón Díaz. Moreover, the pier has a proper connection with the Avenue de la Puerta, it can easily be reached by for instance supply lorries. The pier could therefore be useful and is decided to be rehabilitated and reused.

Espigón del Vaciadero

The current state of this pier is dilapidated and is located leeward of the marina. Moreover, the pier has currently a rising height in the direction of the head of the structure, which is not suited for use in a marina. The upper part of the pier has thus to be demolished in any case, which makes a total demolition relative less costly. Therefore, the demolition of the Espigón del Vaciadero seems the most economical solution, hence this pier will not be used in the design of the marina.

N.4 ON-LAND FACILITIES

A list of facilities required at the marina has been given in 'Appendix L: Boundary conditions and design requirements'. The decision on which location these facilities will be accommodated depends mainly on the space required, the need to roof a facility or not and the proximity or walking distances to the berths.

N.4.1 REQUIRED SPACE

Only an estimation of the required area for the facilities is necessary for a preliminary design. The facilities required for a marina are listed in table N.1 in order of decreasing required space. An expectation of the required area is given where possible.

table N.1 – required facilities of the marina

Facility	Required area (m ²)
Hotel (shared with marina)	5 000
Parking area and dry berthing area (can be shared with marina)	2 000
Recreational services (like sport courts, fitness)	300 – 3 000
Catering services	200 – 500
Repairing facilities and sail store	250 – 400
Yachting club	250 – 300
Supermarket	100 – 300
Customs services	100 – 150
Money exchange service	100 – 150
Shops for food, drinks, souvenirs and gadgets	50 – 100 (each)
Fuel supply	50 – 100
Sewage and waste water pump out	50 – 100
Vehicle ramp	50
Garbage collecting service	25 – 50

Facilities that have to be covered by a roof are: hotels, customs services, shops and stores, yachting club, bathrooms and restrooms and laundry services. Facilities that need to be covered but in the same time prefer some uncovered space are: catering, repairing and car rent services. Facilities that need no cover are: recreational services, boat launching and trailer ramps, fuel supply, parking areas, sewage water pump outs and garbage collecting services.

N.4.2 WALKING DISTANCE

Several of the facilities that are desired most in the proximity of each berth are: bathrooms, restrooms, laundry services and showers. It is therefore sensible to design multiple blocks containing the services and locate these on several places in the marina. Small kiosks or stands for the sale of for instance mineral water can be placed near the berths that are located relatively far from the supermarket. The other facilities are preferably at one location only. Facilities like sports courts and a fitness centre have the least priority and should only be constructed if sufficient space is available.

Besides the above facilities the marina must be equipped with electricity and water networks. These networks must be connected an available to use on every berth. Therefore along each walkway taps must be installed sufficiently frequent. Also safety measures like fire extinguishers must be provided along the walkways.

N.4.3 CONCLUSIONS

Considering the minimum required area for the basic facilities of a marina, the terminal Díaz 2 with an available area of 8 250 m² and the terminal Díaz 1 with a surface area of 12 000 m² will be amply sufficient to house all the facilities. In this design stage, it is decided to locate the catering services and the yachting club in the terminal building Díaz 2. The other facilities, like the supermarket, hotel, ship repair and bank will be located in the building of Díaz 1. The warehouses on the Muelle de la Coubre will be partly demolished and rebuild for the smaller purposes of sanitary facilities and kiosks. The Hines can be used as an exclusive club and entrance for the mega yacht owners. The La Coubre building will be demolished to make way for a tank supply lorry. It is assumed that no problems occur with the displacement of the current owners of these buildings, as discussed in 'Appendix B: Stakeholder analysis'.

The marina has probably not enough free land area to locate the parking area. The parking area, with the car-rent service, will therefore have to be placed on the ferry terminal.

N.5 BERTHING ARRANGEMENT

The required capacity of the future marina has been evaluated in paragraph 'N.4.1 Required space'. To determine the berthing arrangement that best suits the given conditions and the capacity, the preliminary design of three variants is made. For these designs, the dimensions of a berth are used as given in table N.2. The design width is determined by figure N.6, and the required minimum widths of a berth place are determined with the preliminary design formulas given below. The maximum values of these widths are used to determine the total width of a double berth, which also includes the width of a finger pier. For the convenience of the preliminary design, the widths are conservatively rounded up.

table N.2 – dimensions of the berth slips of different length classes

Length class, length berth	W_s (m)	$W_{b,c}$ (m)	W_{sb} (m)	Width double berth (m)
< 10 m (<33 ft)	3.5	4	4.3	10
< 12 m (<39 ft)	4.0	4.5	4.9	11
< 24 m (<79 ft)	6.0	7.0	6.4	14
< 36 m (<118 ft)	9.0	10.5	7.8	22
< 50 m (<164 ft)	10.0	11.5	9.6	24

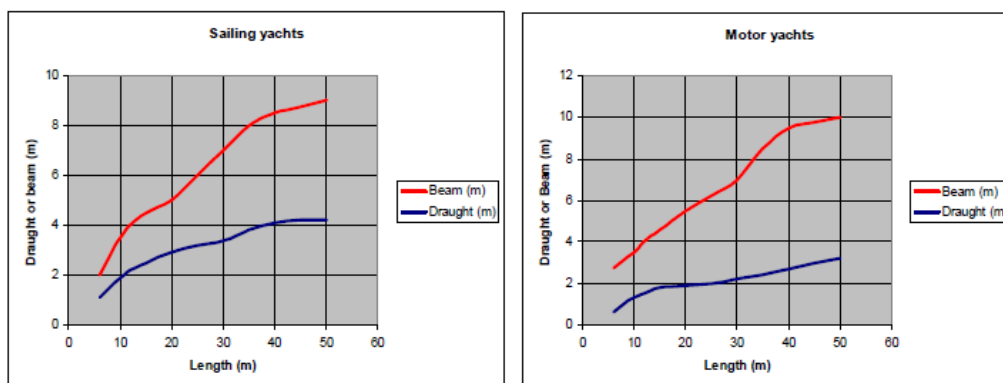


figure N.6 – the design widths and draughts of yachts (de Jong, 2012)

Berth width (de Jong, 2012):

$$W_{b,c} = W_s + W_c$$

With W_c between 0.5 and 1.5 m, depending on length.

Minimum width of a single berth for a powerboat and sailboat (Schwarzenegger, et al., 2005):

$$W_{sb,p} = \frac{L_b}{4} + 6 - \begin{cases} 0.2(30 - L_b), & L_b < 30 \\ 0.125(L_b - 40), & L_b > 40 \end{cases}$$

$$W_{sb,s} = \frac{L_b}{5} + 5.5 - \begin{cases} 0.125(30 - L_b), & L_b < 30 \\ 0.075(L_b - 40), & L_b > 40 \end{cases}$$



figure N.7 – fingers with double berths in Batavia Coast Marina (Department of Transport)

Using the conclusions from the berthing method, the reuse of the existing piers and the on-land facilities, three variants for the berthing arrangement are designed. The preliminary design dimensions for the berths are applied. Within these variants, the berthing arrangement is varied. In the first variant, 'Grupo', length classes are as much grouped as possible at a single walkway. The second variant, 'Intermedio', mixes length classes at a walkway, although a class is still clustered. The third variant, 'Familia', mixes all classes without clustering.

All variants take a possible design of the breakwater into account by allocating space for this breakwater in the design. The actual design of the breakwater is discussed in 'Appendix O: Design of the marina'.

Variant 'Grupo'

In this variant, illustrated in figure N.8, berths of the same length class are grouped at a single walkway. The Espigón de la Coubre forms the boundary between the eastern part of the marina with berthing places for super yachts and the western part for medium and smaller yachts. The eastern side of the Espigón Iglesias will be used to moor the biggest (mega) yachts.

A pontoon berthing structure with double berths is chosen to decrease construction costs. The berths of the super yachts are placed at the eastern end of the marina, close to the historical centre and the most important on-land facilities. This class consists after all of the most important customers. The eastern side of the Espigón

Iglesias will be used to moor the biggest yachts. With its length of 155 m, the pier gives place to one or two mega yacht and multiple super yachts. The length classes decreases westwards, with eventually the berthing places of vessels up to 10 m at the western end of the marina. An advantage of this arrangement is that vessels can be assigned a berth place close to the shore when the capacity of the marina is not fully used, so walking distances can be reduced. Also, when the capacity is structurally not fully used the walkways can be shortened because of the flexible construction method of pontoons. The berths have the same orientation as the direction of the prevailing winds, so berthed yachts have a minimal area that is affected by this wind.

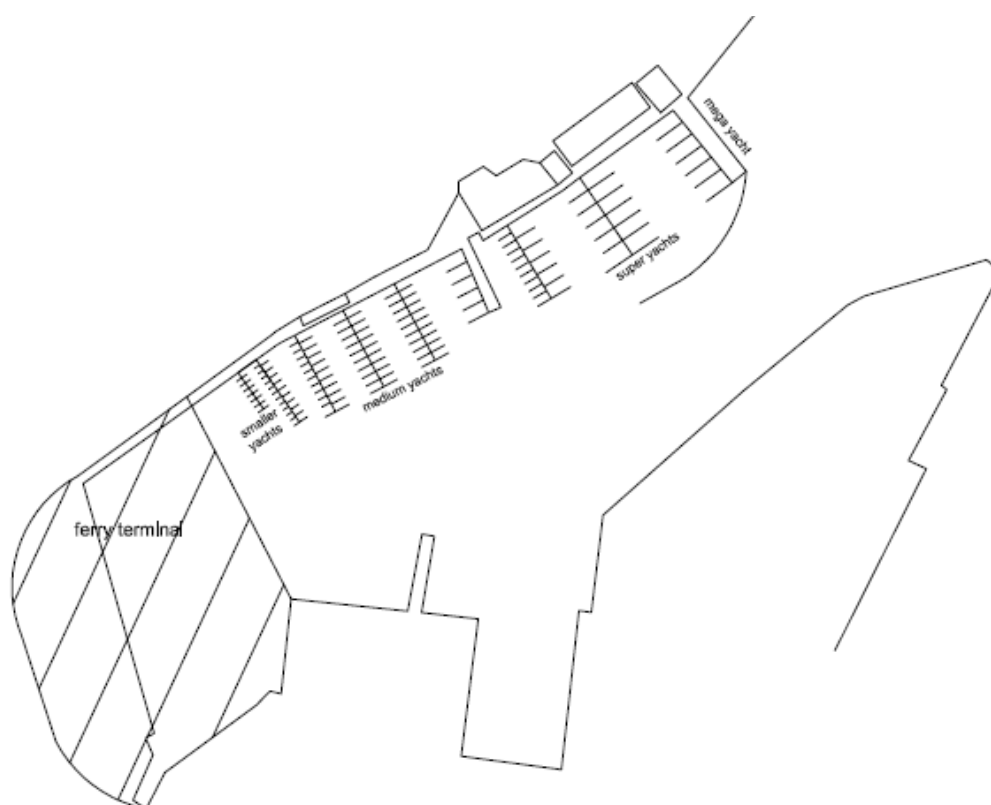


figure N.8 – variant 'Grupo'

The Espigón de la Coubre will also contain the gasoline filling station and the boat ramp. The Espigón Díaz will be removed to minimize the berthing area of the marina. The terminals on the Muelle Díaz will be retained and will house the facilities as described in N.4.3. One of the two warehouses on the Muelle de la Coubre will be reused as sanitary facilities and small shops, while the second will be demolished.

The location southwest of the marina has been assigned to the ferry terminal. The design of this area is elaborated on in 'Appendix P: Design of the ferry terminal'. Whether this whole area will be reclaimed land, or only a part, is dependent on the design of the ferry terminal. It is however to be recommended that an area at the north side of the Muelle Osvaldo Sanchez will be assigned as a parking area.

The total area would be about 900x150 m².

Variant 'Intermedio'

The same berthing structure as with the first variant is used for the variant 'Intermedio'. Also, the same existing piers will be reused with the same considerations. The berthing arrangement is however different, as can be seen in figure N.9. No division will be made between the berthing areas for super yachts and normal yachts: the different classes are mixed. The berths of super yachts are indicated in the figure with an 'A', medium yachts (15-24 m) with a 'B' and the smaller yachts with a 'C'.

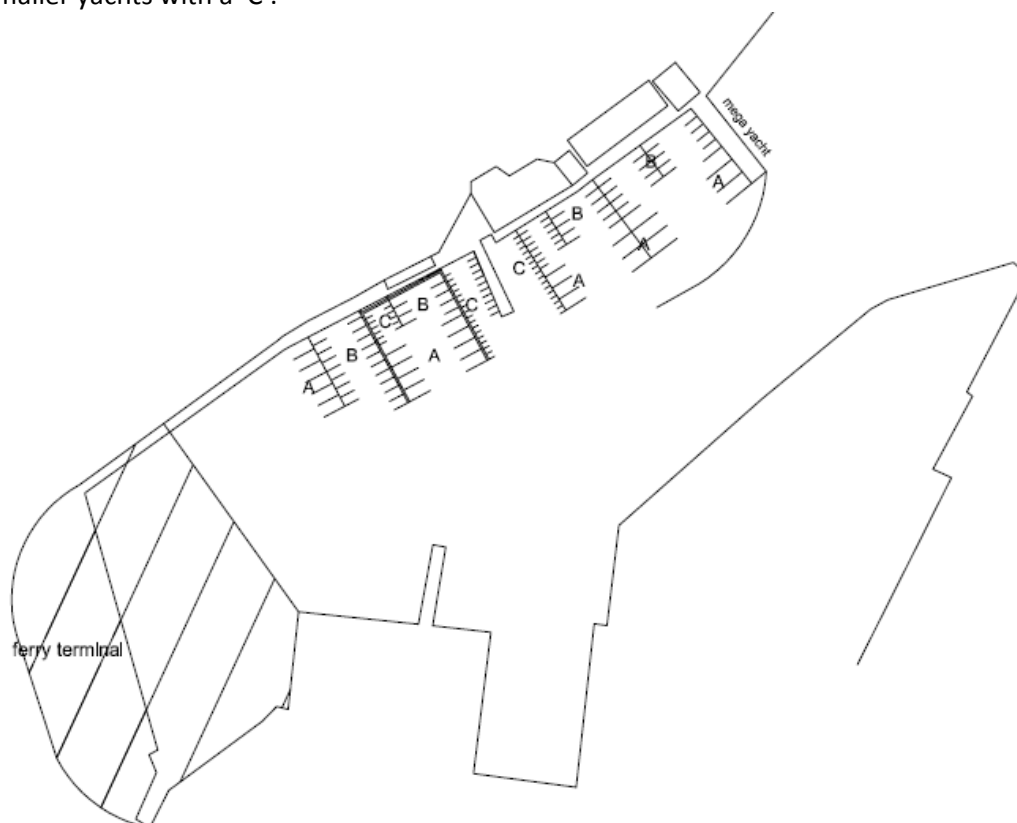


figure N.9 – variant 'Intermedio'

Not only are the super yachts located close to the most important on-land facilities with this design, but so are also the smaller yachts. However, when these berths are already occupied, a yacht has to be assigned a berth place further away from these facilities to the west. The length classes are still clustered however, and when multiple classes are located at one walkway, the smallest length class will be located close to the shore. This increases the capacity (or decreases the required area) and the privacy of the owners of the super yachts. This however also increases the walking distance to the facilities ashore for the owners of the bigger yachts. In the early stages of the marina, when the full design capacity is not yet required, only the part west of the Espigón de la Coubre has to be constructed.

Because of the more compact arrangement, more area is available for the ferry terminal compared to variant 'Grupo'. The parking area will have to be located on this terminal as well.

The total area required by the marina is about 850x150 m².

Variant 'Familia'

This variant is mostly characterized by its fancy way of arranging vessel classes. Only the mega yachts are separated from the other vessels, as can be seen in figure N.10. Again the Iglesias pier is dedicated to receive these mega yachts. Super yachts and smaller vessels are situated in a more or less 'chaotic order'. In this way the different vessels and yachtsmen will form one collective 'family'. However to provide privacy, it is decided to apply single berthing in this variant. The area required per vessel is indicated in the figure.

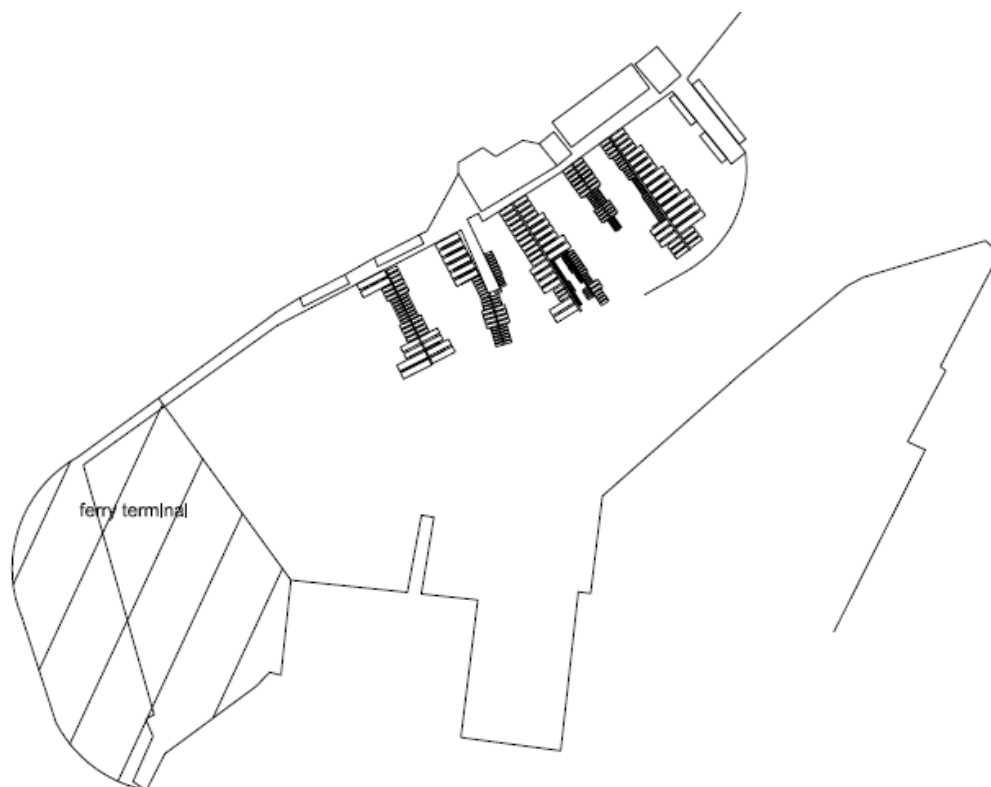


figure N.10 – variant 'Familia'

As a result of this way of arranging berths, wide interior channels are required at each pier, since every pier needs to be able to receive super yachts. Besides, because of the great variety of length classes at one walkway, a confusing arrangement could be the result. Moreover walking distances are larger as a result of a higher quantity of finger piers at a single pier and the wider lay out of the piers. It is the question if the 'chaotic' arrangement is appreciated or not. It can be experienced cheerful at the one side but also as too little private at the other. Furthermore in this variant again the Espigóns de La Coubre and Iglesias are reused. To conclude, the arrangement is not very flexible in construction.

The required wet area is about 700x175 m².

N.6 MULTI CRITERIA ANALYSIS

A multi criteria analysis (MCA) is performed on these variants in order to determine the best berthing arrangement. In the following, the criteria that will be used are elaborated on.

N.6.1 CRITERIA

Eight criteria are used to determine the best berthing arrangement:

Walking distance

The length and arrangement of a walkway influences the average distance yachtsmen has to walk to reach the shore. With short walkways, or with an arrangement at which it is often possible to berth close to the shore, the walking distance is obviously shortened.

Flexibility

It is hard, if not impossible, to predict the number of vessels that will visit Cuba in the near future as it largely depends on the political situation (see also 'Appendix D: Tourism analysis'). In the current situation, the needed capacity is lower than the design capacity. It is however not easy to predict when this design capacity will be needed. It is therefore desirable that the marina has a flexible capacity, so it can offer a low number of berthing places in the first phase when the demand is still low. When this demand will rise, the marina will expand to a higher capacity.

The advantage of flexibility is for a great part also an economic one. The current financial means in Cuba are not sufficient to construct the entire marina at once. With a high flexibility, a part of the marina will be constructed later, so a part of the investments will be postponed as well. Moreover, the generated income of the marina can be invested in the future expansion.

Manoeuvrability

A dense berthing arrangement has a high capacity, but leaves little space to fairways and thus decreases the manoeuvrability in the marina. A better manoeuvrability increases the accessibility of the marina and decreases the possibility of collisions. For yachtsmen, relatively inexperienced sailors, this would be an important advantage of a marina. The number of bends and turns and the width of interior channels influence the manoeuvrability.

Orderly arranged

With an orderly arranged lay-out of a marina, a yachtsman can easily find its berthing place. The grouping of (length) classes, the number of walkways and the presence of turns or bends influence this criterion.

Privacy

When a yachtsman lives on board, it could be inconvenient if his vessel would be clearly visible for other people. Especially the wealthy owners of the super and mega yachts could hold its privacy dear, as these vessels attract attention of other people. When a small number of vessels are berthed at a single walkway, and when a vessel is berthed near the end of a walkway, the privacy is increased.

Accessibility of facilities

Several facilities on a marina provide services to a vessel, like the supply of gasoline or the shipyard. These services should be easily accessible for boats, as they will be used often.

Proximity to ferry terminal and channel

A yachtsman would prefer a berthing place close to Habana Vieja. However, at the south side of the marina the ferry terminal and, more to the east, the shipyard and container terminal are located. If a berthing place is located close to these terminals, the yacht would not experience the marina as 'close to the historical centre'. Also, if the gangways of the marina will expand too much in the basin, the hindrance of ferries will be higher.

However, a marina and a ferry terminal also require communal facilities like a restroom, hotel, supermarket, etcetera. It would be advantageous to share these facilities.

Maintenance

When a design demands a high rate of maintenance, the costs and downtime will be higher. This is of course not desirable. The amount of maintenance depends mainly on the type of berthing structure.

N.6.2 COMPARISON

These criteria are compared to each other in order to determine the importance of each individual criterion. When the criterion in a row is considered to be more important than the criterion in the column, it will receive a '1', while the less important criterion will receive a '0'. When a criterion has received no points, the total score of 1 will be assigned, while the total score of the other criteria will be doubled. Afterwards, the total points will determine the weigh factor of a criterion. The results are given in table N.3. It is stressed that the comparison is made with the eyes and preferences of the client and not of the customer.

table N.3 – determination of weight factors

	Walking distance	Flexibility	Manoeuvrability	Orderly arranged	Privacy	Accessibility	Proximity of ferry	Maintenance	Total	Weight factor
Walking distance	-	0	0	1	1	1	1	1	10	0.17
Flexibility	1	-	1	1	1	1	1	1	14	0.25
Manoeuvrability	1	0	-	1	1	1	1	1	12	0.21
Orderly arranged	0	0	0	-	1	0	1	0	4	0.07
Privacy	0	0	0	0	-	0	0	0	1	0.02
Accessibility	0	0	0	1	1	-	1	1	8	0.14
Proximity of ferry	0	0	0	0	1	0	-	0	2	0.03
Maintenance	0	0	0	1	1	0	1	-	6	0.11
Total									57	1.00

The three variants are evaluated regarding these criteria and are assigned a score for each criterion on the scale of 1 to 5, with 5 the highest possible score. This score has been multiplied with the weight factor from table N.3 to get the eventual value of each variant. The final result is presented in table N.4, after which the explanation of the assigned scores is given for each variant.

table N.4 – score assignment of MCA

	<i>Wf</i>	Grupo		Intermedio		Familia	
		<i>Score</i>	<i>Total</i>	<i>Score</i>	<i>Total</i>	<i>Score</i>	<i>Total</i>
Walking distance	0.17	3	0.51	4	0.68	4	0.68
Flexibility	0.25	5	1.25	3	0.75	2	0.50
Manoeuvrability	0.21	4	0.84	3	0.63	4	0.84
Orderly arranged	0.07	4	0.28	5	0.35	1	0.07
Privacy	0.02	3	0.06	2	0.04	2	0.04
Accessibility	0.14	3	0.42	3	0.42	1	0.14
Proximity of ferry	0.03	2	0.06	4	0.12	4	0.12
Maintenance	0.11	5	0.55	2	0.22	3	0.33
Total			3.97		3.21		2.72

Variant ‘Grupo’

The walking distances from the berth to the shore are minimized, as the berthing place closest to land is assigned to a recently arrived vessel. However, the walking distances to the main on-land facilities and the city centre increase with decreasing boat length.

The variant is very flexible since each walkway can be expanded when a bigger capacity is needed. In the early stages of the marina, when the needed capacity is below the design capacity, only a part of the designed walkways can be constructed. The straight berthing arrangement can be seen as very orderly and has also a positive influence on the manoeuvrability since few turns are needed to sail to the berthing place.

The privacy of yachtsmen is relatively low because yachts are berthed as close to the shore as possible. It is however possible to demand a berthing spot further away from shore. Moreover, the owners of super yachts are grouped among themselves, and are therefore not mixed with owners of smaller yachts.

The accessibility of the boat launch and the fuel tanks are reasonable. The variant is the closest located to the ferry terminal of the three variants. This is especially unfavourable for the owners of the smaller yachts who have to be berthed close to the terminal.

Because of the flexible arrangement, pontoons can be taken out of the water when less capacity to decrease wear or to be maintained.

Variant ‘Intermedio’

The walking distance to the main on-land facilities is relatively low for all classes. However, the walking distance increases with increasing boat length, so the owners of super yachts have to walk longer than with variant ‘Grupo’.

In the early stages of the use of the marina, only the eastern part has to be constructed. The western part will be constructed only when the capacity of the eastern part is not sufficient anymore. The variant is therefore relatively flexible.

The manoeuvrability is somewhat lower than with ‘Grupo’, as smaller yachts have to make two extra turns in the berthing area. The arrangement is however very orderly, as almost no mistakes can be made by a yachtsmen by choosing the right walkway.

The privacy of super yacht owners is relatively high, as they are located far from the shore. However, they are berthed on the same walkway as the owners of smaller yachts. The privacy of these owners of smaller yachts is lower than with ‘Grupo’, as the owners of yachts from longer classes will always pass their berthing spot. It is however higher than with ‘Familia’.

The ferry is located further away than with 'Grupo', but not so far as with 'Familia'. Moreover, the berthing places close to the ferry terminal will be assigned last. The pontoons are relatively hard to be maintained, as walkways cannot easily be shortened by removing a single pontoon.

Variant 'Familia'

The walking distance to the shoreline is relatively large, although the walking distance to the on-land facilities is relatively small as all classes can be berthed on the most eastern walkway.

The flexibility depends on the demanded capacity per length class. When the demand for berthing places for super yachts exceeds the given capacity, the entire walkway will have to be constructed. It is therefore not very flexible.

The manoeuvrability is the relatively high because of the relatively large widths of the walkway. However, the arrangement is not straight, so sometimes bends have to be made. The arrangement is also relatively cluttered.

The privacy of the owners is low because all classes are mixed; so much walking movement on the walkways is to be expected.

Also the accessibility of the boat launch and fuel tanks is relatively low.

The ferry terminal is located the furthest away of all classes, although walkways extend relatively far in the basin and thus close to the sailing line of the ferry.

The pontoons are also relatively hard to be maintained, as walkways cannot easily be shortened.

N.6.3 CONCLUSIONS OF THE MCA

The variant 'Grupo' has received the highest score with the Multi Criteria Analysis, mainly because it is very flexible and easy to maintain. This variant will therefore be designed in more detail in 'Appendix O: Design of the marina'.

N.7 CONCLUSIONS AND RECOMMENDATIONS

It is decided that only the Espigón Iglesias and de la Coubre will be rehabilitated en reused, the other piers will be demolished, just as the terminal building of La Coubre. The other buildings will be reused to accommodate the facilities of the marina.

The yachts will be mainly berthed according the pontoon system in the arrangement as depicted in figure N.8. The east side of the Espigón Iglesias will be used as an alongside mooring place for a mega yacht. The marina will be designed in more detail in 'Appendix O: Design of the marina'.

N.7.1 RECOMMENDATIONS

The following recommendation is made to increase the certainty of the conclusions made:

Current state of piers

It is assumed that the Espigón de la Coubre and Iglesias can be rehabilitated and reused with relatively low costs. The current state of the foundations and the sections below water has to be investigated more closely to confirm the assumptions.

Appendix O: DESIGN OF THE MARINA

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0.1 INTRODUCTION

A design of the marina based on the decisions made in ‘Appendix N: Preliminary design of the marina’ will be given in this appendix. First, the required breakwater will be designed and allocated in the marina. Afterwards, the detailed lay-out of the marina will be explained. The dimensions of the walkway, including the utility services, will be discussed subsequently. At last, the lay-out ashore shall be elaborated on, both the location of the on-land facilities as the connection with the existing infrastructure outside of the marina.

0.2 BREAKWATER

Although the marina is sheltered from sea waves by the natural Bay of Havana, strong winds can generate short-crested waves in the bay itself, as discussed ‘Appendix K: Hydrodynamic analysis – SWAN’. It is therefore necessary to design a breakwater to defend the berthing area from these waves.

0.2.1 CONDITIONS

The design of the breakwater depends on the wave conditions at the location of the marina and the criteria of the wave climate inside of a marina. The significant wave heights and peak periods at the location of the marina, for different wind speeds and directions, are obtained from ‘table K.1 – significant wave height and peak period for the location of marina’. The maximum occurring wave height, period and corresponding wave length, with wind from the NE direction, are given in table O.1 as well.

table O.1 – significant wave height, peak period and wave length at the marina

Wind speed [m/s]	H_s [m]	T_p [s]	L [m]
5.5	0.15	1.59	3.95
10.7	0.32	2.12	7.02
21.7	0.71	2.96	13.7
27	0.89	3.31	17.1
40	1.34	3.93	24.9

The wind speed of 5.5 m/s corresponds with a regular situation at which the marina should operate. The wind speed of 10.7 m/s is the upper limit of 5 Bft, the highest wind speed at which manoeuvres of a vessel are allowed in the entrance channel. The average annual maximum wind speed is about 27 m/s. The probability of occurrence for different wind speeds is given in ‘table H.3, Appendix H’. The wind speed of 21.7 m/s corresponds with the wind conditions with a return period of one year. The wind speed with a return period of 50 years is about 40 m/s, see also ‘table H.1 – return periods and corresponding wind speeds’.

Next to wind generated waves, vessel generated waves also occur in the marina. As determined in ‘Appendix G: Nautical analysis’, the maximum height of a primary stern wave is 4.8 cm and 1.1 cm for a secondary wave for a sailing speed of 4 kn.

0.2.2 DESIGN CRITERIA

Although no criteria exist about the maximum wave conditions in a marina, recommendations have been made (Department of Fisheries and Oceans, 1981). These recommendations for a ‘good’ wave climate with a wave direction parallel to the berthing orientation of a vessel are given in table O.2. These permitted wave heights should be multiplied by 1.25 for a moderate wave climate. For vessels of less than 20 m in length, the marina should satisfy for the conditions for a moderate

wave climate. The wave climate may be even more severe for larger vessels (De Jong, 2012). However, it has been decided to satisfy the conditions for a good wave climate to ensure the quality of the conditions in the marina.

table O.2 – criteria for a good wave climate

T_p [s]	H_s per return period [m]		
	1 in 1 week	1 in 1 year	1 in 50 years
< 2	0.30	0.31	-
> 2	0.15	0.30	0.61

It is clear that the marina cannot have a good wave climate without mitigations by for example a breakwater. However, the marina has a water depth of about 10 m, which brings high costs to the construction of a breakwater. By contrast, a floating breakwater is very cost efficient compared to a normal breakwater given this relatively large water depth. Moreover, the waves occurring at the location of the marina have a relatively short peak period and a floating breakwater is the most efficient with a short-period wave climate. Although a floating breakwater transmits more energy into the marina than a conventional breakwater, it is considered to be the best solution for a wave defence for the marina.

0.2.3 DIMENSIONS OF THE BREAKWATER

The different types of floating breakwater can be divided in two groups, reflective and dissipative structures (PIANC, 1994). A reflecting floating breakwater reflects incoming waves so only a small part of the wave energy is transmitted. With dissipative structures, this wave energy is dissipated by friction or turbulence. Two types of reflective and one type of dissipative breakwater are illustrated in figure O.1.

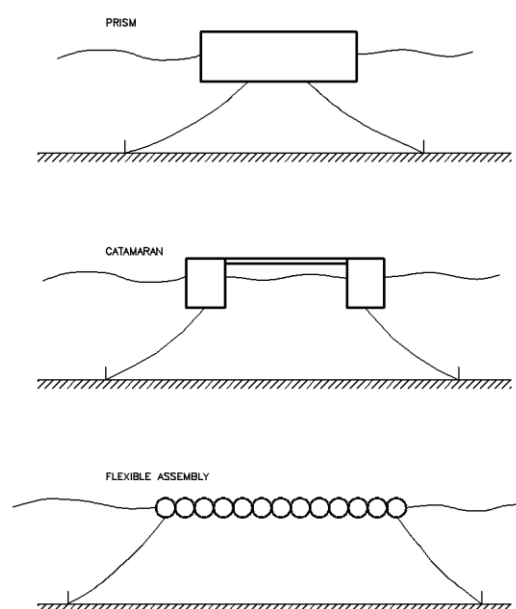


figure O.1 – three types of floating breakwater

Because of a possible secondary use of the floating breakwater as a waiting pontoon for the marina, a reflective breakwater will be used. Even though it is called a reflective breakwater, waves are still transmitted. The relation between the incoming significant wave height and the transmitted wave height²⁴ is given by:

²⁴ The reflective wave height is not important for the wave conditions of the marina.

$$H_T = C_T * H_S$$

with C_T as the transmission coefficient.

The value of the transmission coefficient can be achieved in multiple ways. An analytical approach is given by (Macagno, 1953):

$$C_T = \frac{1}{\sqrt{1 + \frac{\pi W}{L} \frac{\sinh(d)}{\cosh(d-D)}}}$$

However, this approach is not accurate with small numbers of W/L . Experimental research can also be used to determine C_T . Some experimental results and the analytical approach are illustrated in figure O.2 to figure O.4. The results in figure O.4 are obtained with a depth of 7.6 m and a reflective prism of a width of 4.9 m and a draught of 1 m.

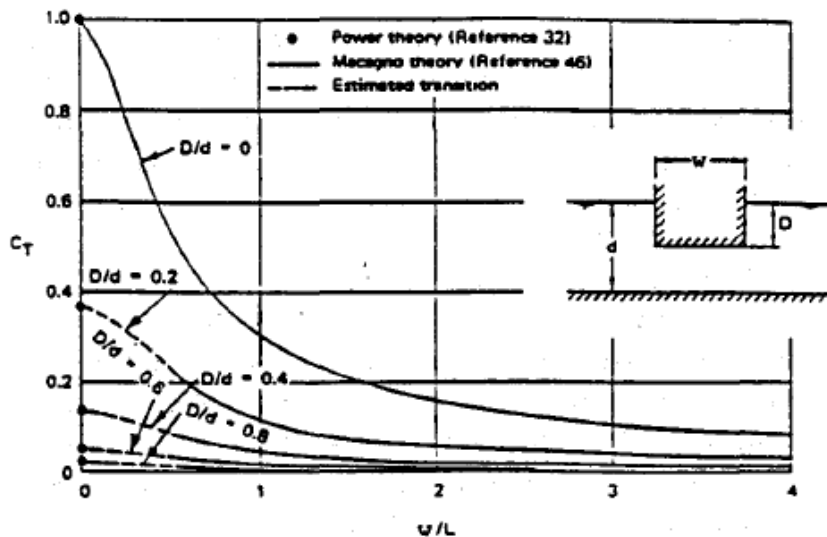


figure O.2 – Transmission coefficient for $L/d = 1.25$ (PIANC, 1994)

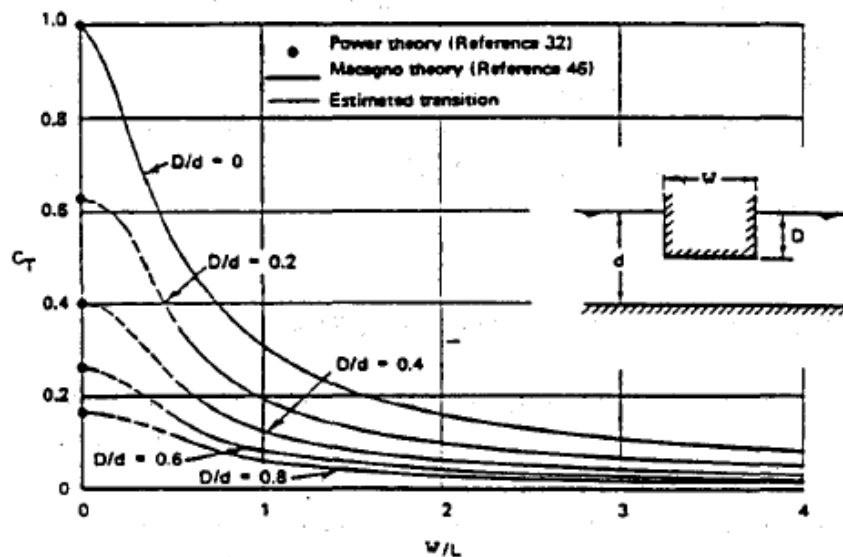


figure O.3 – Transmission coefficient for $L/d = 2.5$ (PIANC, 1994)

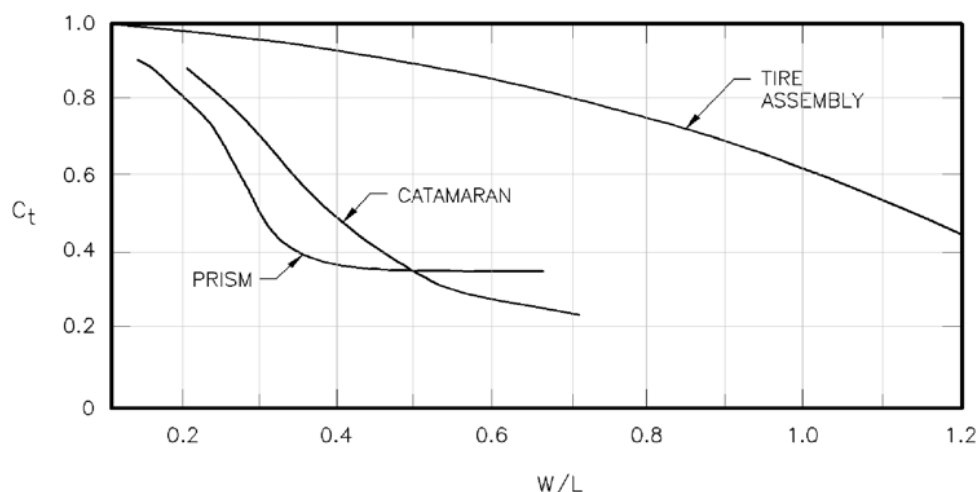


figure 0.4 – Transmission coefficient for selected floated breakwaters (Coastal Engineering Manual, 2006)

Criterion of 1 in 1 year

The maximum transmission coefficient of the floating breakwater to achieve a maximum wave height of 0.30 m with a return period of once a year can be derived from $C_{T,max} = 0.3 / 0.71 = 0.42$.

With a water depth of $d = 10$ m and a wave length of $L = 13.7$ m corresponding to this scenario, an approximation of the required ratio of width and wave length of the floating breakwater can be acquired with figure O.4. This leads to a ratio of about $W/L = 0.33$, which in turn leads to a width of $W = 4.5$ m. From the analytical approach, a required draught of 1.51 m can be obtained with these values of W and L . With the values from table O.3, these dimensions can also be found in figure O.2, with a small correction because the value of $L/d = 1.37$ does not fully correspond with the used value of 1.25. So a floating breakwater with a width of 4.5 m and a draught of 1.5 m will be considered to be sufficient to obtain a 'good' wave climate for waves with a return period of once a year.

table O.3 – dimension values with a wind speed of 21.7 m/s

L/d	W/L	D/d
1.37	0.33	0.15

Criterion of 1 in 50 years

A floating breakwater with these dimensions, a width of 4.5 m and a draught of 1.5 m, can however not satisfy the requirements of a transmitted wave height of 0.6 m with a return period of 50 years. These waves will have the dimensions as given in table O.4. With these values, a value of $C_T = 0.7$ can be derived from figure O.3. This will mean a transmitted wave height of 94 cm. It has however been decided that the floating breakwater will not be designed for these extreme storm conditions, since the marina will not be operational as the extreme wind forces will prevent the functional use of the facilities. Moreover, these wind forces will probably cause more damage to the vessels and infrastructure than waves with a height of less than a metre.

table O.4 – dimension values with a wind speed of 40 m/s

L/d	W/L	D/d
2.5	0.18	0.15

Criterion of 1 in 1 week

The third criterion for a good wave climate is that the wave height with a return period of once per week, considered to be the day-to-day situation, should not exceed 15 cm. With the given dimensions and a wave length of $L = 3.95$ m, a value of $C_T = 0.24$ is obtained from the analytical solution. Together with the waves generated by a sailing ferry, the total wave transmission would therefore be 9.5 cm, which satisfies the criterion for even an 'excellent' wave climate.

During a storm with the upper limit of 5 Bft (10.7 m/s) waves occur of 32 cm. With the corresponding wave length of $L = 7$ m, the analytical solution gives $C_T = 0.32$. This would give a total wave transmission, together with the vessel induced waves, of 16.1 cm. This is higher than the day-to-day criterion. However, these wind speeds occur only about 5% of the time, so a floating breakwater of 4.5 m by 1.5 m will suffice as well.

0.2.4 LOCATION OF THE BREAKWATER

The location of the breakwater should be chosen in such a way that the breakwater protects the berthing area for waves. The breakwater should however not obstruct the manoeuvring possibilities of the yachts or the passing ferry. The fairway width between the breakwater and the berthing ships should be large enough for the use of super yachts on the one hand, but on the other hand the breakwater should not obstruct the sailing route of the ferry. Therefore, two breakwaters will be designed with an entrance fairway for super yachts in between. In this way, super yachts can still enter the berthing area relatively easy while the required width of the channel of the ferry can still be maintained. A turning basin with a diameter of 132 m is located near the entrance which allows yachts with a length of up to 75 m to turn and enter the berthing area comfortably. The positions of the two floating breakwaters are illustrated in figure O.5.

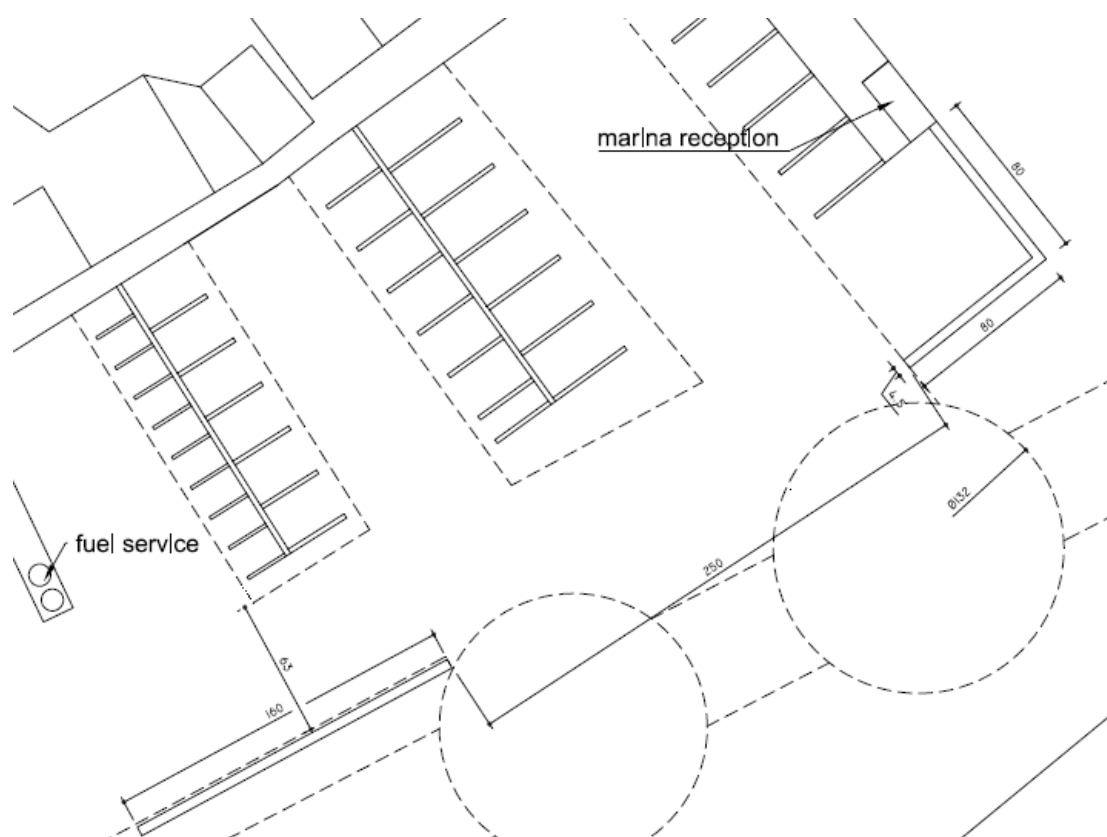


figure O.5 – detail of the floating breakwaters of the marina (see 'Technical Drawing W3')

This design has the advantage that the floating breakwaters can be used as waiting pontoons as well. The most eastern breakwater can accommodate yachts waiting for the marina reception, while the western breakwater can be used for vessels waiting for the fuel service. The width of the fairway between the western breakwater and the berthing slips is 63 m, the recommended width of a fairway for yachts with a length of 36 m, as given in table O.7.

0.3 BERTHING AREA

The preliminary design of the berthing arrangement 'Grupo' will be used as a starting point for the design of the berthing area. The requirements for the minimum dimensions of the berths, walkways and fairways will have to be satisfied to become a marina of excellence.

0.3.1 MINIMUM REQUIRED DIMENSIONS

The system of double berthing is chosen to decrease the construction costs of the marina. A standard layout of a double berth is illustrated in figure O.6, with W_b the width of a single berth, L_b the length of a berth and F the width of a finger pier.

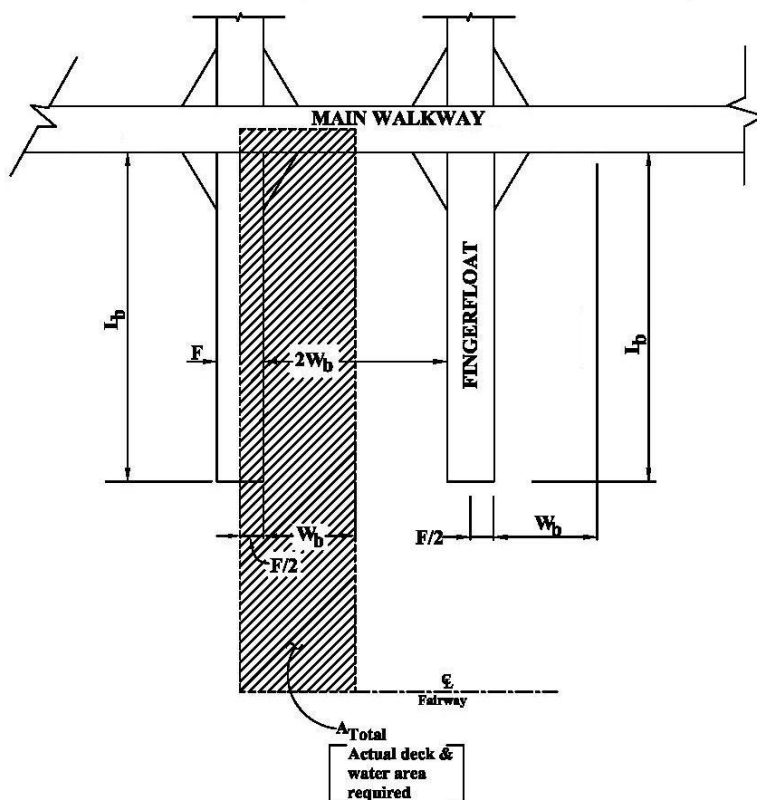


figure O.6 – double berth layout scheme (Schwarzenegger, et al., 2005)

The width of a single berth can be calculated using the following design formulas, see also ‘Appendix N: Preliminary design of the marina’.

Minimum design width of a single berth for a powerboat and sailboat in feet (Schwarzenegger, et al., 2005):

$$W_{sb,p} = 8 \ln L_b - 14$$

$$W_{sb,s} = 6.5 \ln L_b - 10.5$$

Berth width (De Jong, 2012):

$$W_{b,c} = W_s + W_c$$

With W_c between 0.5 and 1.5 m, depending on the length of a yacht

The minimum design width given by Schwarzenegger, et al is only accurate for smaller yachts. The method given by De Jong is therefore used for yachts bigger than 24 m. The results are given in table O.5.

table O.5 - dimensions of the berth width of different length classes

Length class, L_b	W_s (m)	$W_{b,c}$ (m)	$W_{b,s}$ (m)	$2W_b$ (m)
< 10 m (<33 ft)	3.5	4	4.3	8.6
< 12 m (<39 ft)	4.0	4.5	4.7	9.4
< 24 m (<79 ft)	6.0	7.0	6.4	14
< 36 m (<118 ft)	9.0	10.5	7.4	21
< 50 m (<164 ft)	10.0	11.5	8.2	23

The required minimum width of a finger pier is given in table O.6.

table O.6 – minimum width of a finger pier (Schwarzenegger, et al., 2005)

Length class	F (ft)	F (m)	F_{net} (m)
< 24 m (80 ft)	5	1.5	0.9
> 24 m (80 ft)	6	1.8	1.2
> 36 m (120 ft)	8	2.5	1.9

The given width includes the width of a waler, a triangular part in the corner of a finger float and the walkway which accommodates a small utility supply station, see figure O.7. A single waler adds about 30 cm to the width, so 0.6 m has to be subtracted from the widths given in table O.5 to obtain the net width of the walkway of a finger pier. The length of a finger pier can be limited to $0.8L_b$ in order to reduce construction costs.

The minimum width of the main walkway should be between 1.8 m (Ligteringen, 2009) and 2.5 m (Schwarzenegger, et al., 2005). Given the relatively large dimensions of the seagoing vessels berthed in the marina, a walkway width of 2.5 m is chosen.



figure O.7 – an example of a waler (Schwarzenegger, et al., 2005)

The minimum width of a fairway is $1.5L_b$, but it is preferred to use $1.75L_b$ (Ligteringen, 2009). The results obtained for the given length classes are given in table O.7.

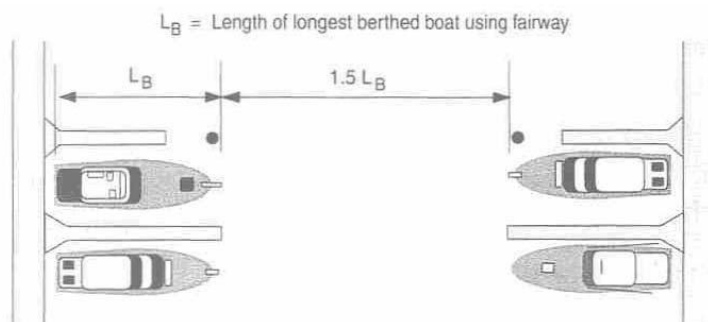


figure O.8 – minimum fairway width (De Jong, 2012)

table O.7 – minimum and preferred fairway widths

L_b (m)	$1.5L_b$ (m)	$1.75L_b$ (m)
10	15	17.5
12	18	21
24	36	42
36	54	63
50	75	87.5

The required depth of the main access channel of a marina is given by (De Jong, 2012):

$$h_{req} = D_{max} + 0.5H_s + 0.5$$

This required depth is conservatively also taken as the depth of the interior fairways and at a berth. With an $H_s = 0.32$ m with winds of 6 Bft, the results are given in table O.8. This is the significant wave height generated by the maximum wind speed at which manoeuvring through the entrance channel is allowed.

table O.8 – required depth of the marina

Length class (m)	D_{max} (m)	h_{req} (m)
< 10 m (<33 ft)	2	2.7
< 24 m (<79 ft)	3	3.7
< 36 m (<118 ft)	4	4.7

As can be seen in figure O.9, the minimum depth at the location of the marina is close to the current Espigón del Vaciadero with 5 m. This is the location at which only the smallest vessels are berthed, so it can be concluded that the water depth of the marina is sufficient and no dredging activities will have to be done. It is recommended to prohibit the sailing of yachts larger than 30 m in this most shallow area. Moreover, no significant sedimentation occurs in the Bay of Havana, so the water depth is assumed to be retained in the future as well.

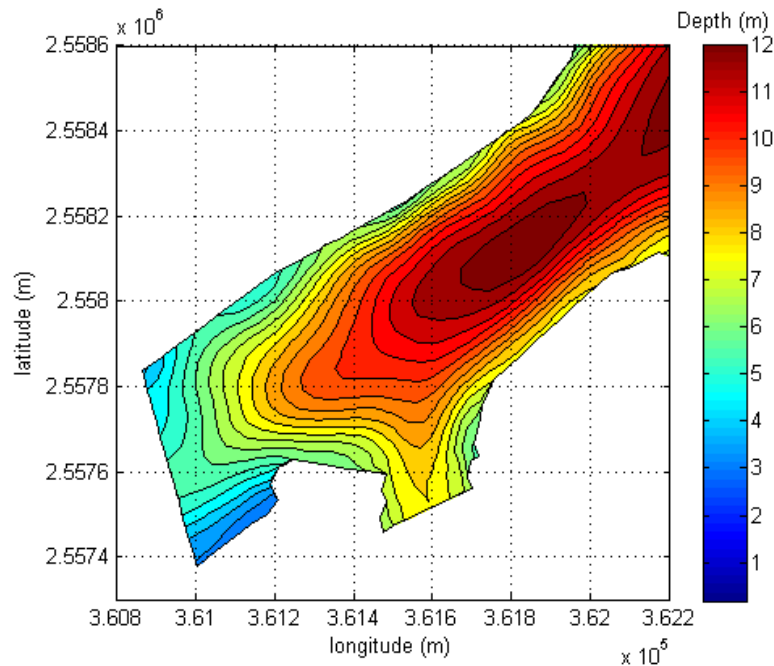


figure O.9 – depth profile of the Ensenada de Atarés

The yachts can use the same entrance channel and fairways inside the bay as the other vessels. The minimum width of the entrance channel is five times the largest beam, although six times is preferred (De Jong, 2012). According to 'figure N.6 – the design widths and draughts of yachts', the maximum beam to be expected in the marina is about 10 m. The width of the entrance channel of the bay is therefore more than sufficient for the use of yachts. The width of the interior channel of the ferry is required to be 55 m, which will be sufficient as well. The dimensions of these

fairways are elaborated on in more detail in 'Appendix R: Design of nautical infrastructure'.

0.3.2 DESIGN OF THE BERTHING AREA

The design of the marina can be found in 'Appendix W: Technical Drawings', drawing number 2 to 6. Details of the marina will be elaborated on independently. The on-land facilities will be discussed in O.5. Almost all berths are designed in a direction parallel to the wave direction in order to minimize the frontal area affected by wind forces of a berthed vessel.

The first 120 m of the Espigón Iglesias will be used as a berthing place for one mega yacht or two super yachts, see figure O.10. The last 35 m is assigned as the marina reception, after which the floating breakwater continues.

Six double berths are located on the western side of the pier. These berth slips have a length of 50 m, with finger piers of 40 m, so twelve super yachts with a maximum length of 50 m can be berthed. The width of a double berth is 23 m and the width of the fairway is 77 m.

The second pier from the east will have an orientation of 145° and will be 154.4 m long. It will have twelve berthing places for super yachts up to 50 m at the eastern side and thirteen places for yachts up to 36 m at the western side. Only the berth slip of 36 m at the head of the pier will be a single berth. This single berth will have a width 10.5 m and subsequently a double berth a width of 21 m. These slips will have a finger pier that will extend for 30 m. The fairway width will be 60 m. At the head of the pier, a mega yacht with a maximum length of 75 m can be berthed.

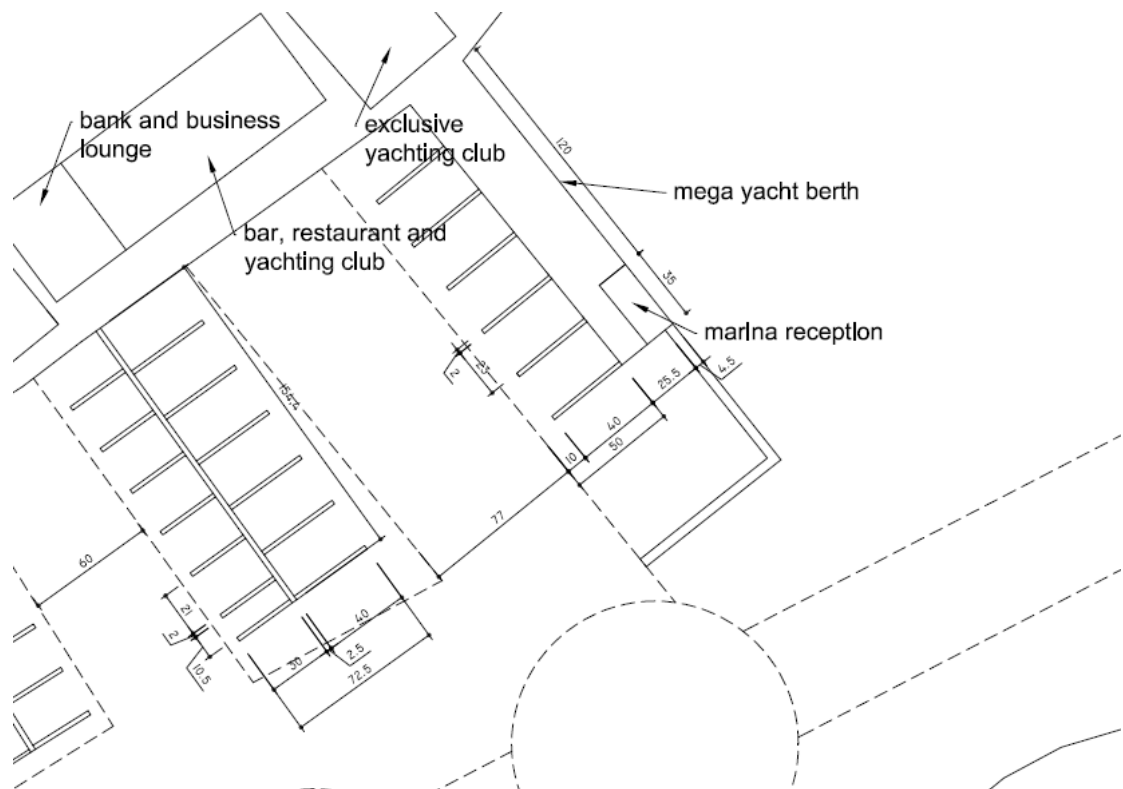


figure O.10 – detail of eastern part of marina (see 'Technical Drawing W4')

The second walkway, at the eastern side of the Espigón de la Coubre, see figure O.11, provides berthing places to twelve super yachts of <36 m and 18 yachts of <24 m. The length of the walkway is 144.6 m and has a width of 52.5 m. A double berth with a length of 24 m has a width of 14 m and its finger pier extends for 20 m. The orientation of the walkway will be 149°. A super yacht can be berthed at the head of the walkway.

The sale of fuel will take place at the head of the Espigón de la Coubre. Seven berths, three double berths and one single berth, for yachts of up to 36 m are located closer to shore at the same pier.

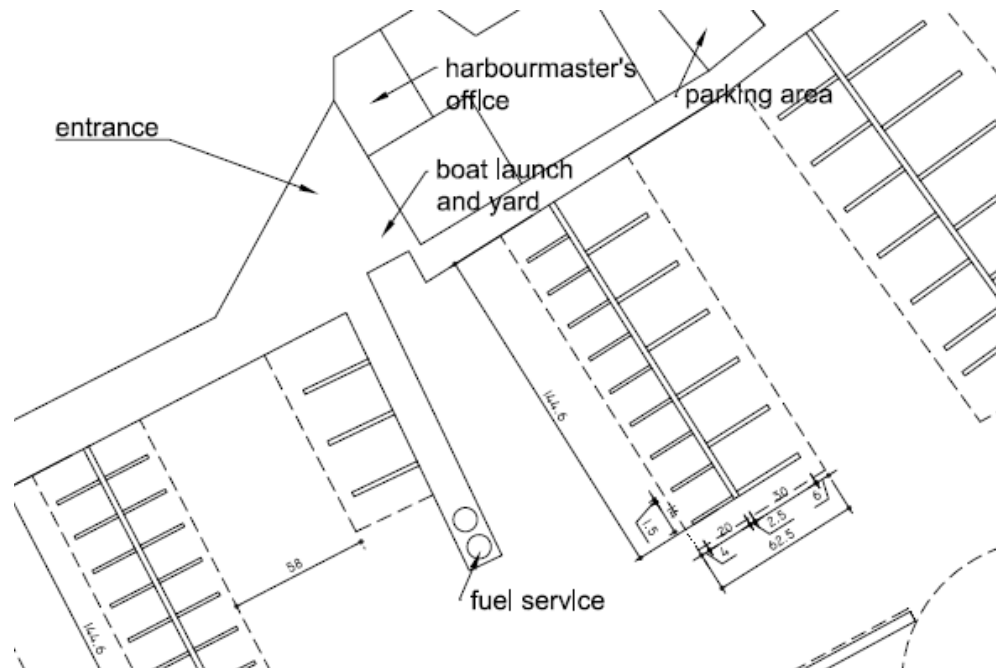


figure O.11 – detail of the part at the Espigón de la Coubre (see 'Technical Drawing W5')

More to the west, two similar walkways with a length of 144.6 m, a width of 42.5 m and an orientation of 153° will be constructed, see figure O.12. Both piers can accommodate 36 yachts of up to 24 m in length. A fairway with a width of 40 m is located between the berth slips. At both piers, a super yacht can be berthed at the head of the walkway.



figure O.12 – detail of the two similar walkways (see 'Technical Drawing W5')

The subsequent walkway to the west consists of again nine double berths for yachts up to 24 m at the east side and thirteen double berths for yachts up to 12 m on its west side. This walkway has a length of 144.6 m as well, but a width of 32.5 m. A double berth with a slip length of 12 m has a width of 9.4 m and the finger pier has a length of 10 m. A super yacht with a maximum length of 36 m can be berthed at the head of the walkway as well.

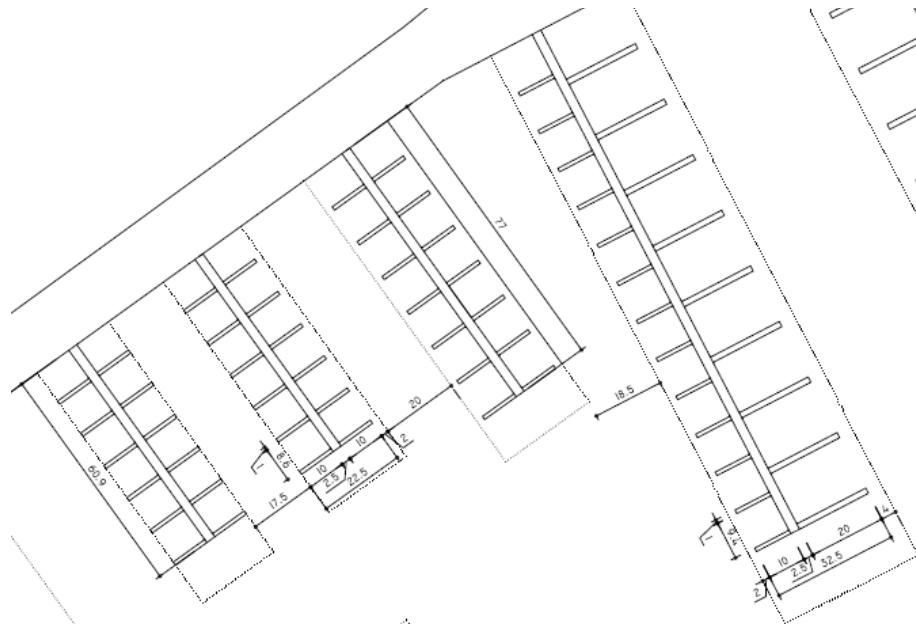


figure O.13 – detail of the western part of the marina (see 'Technical Drawing W6')

At the three western walkways, the smallest yachts are berthed. These walkways have an orientation of 146° . The walkway most to the east gives place to 14 double berths for yachts up to 12 m. The fairway has a minimum width of 18.5 m to the adjacent walkway. The walkway has a length of 77 m and a total width of 22.5 m, so only a 'normal' yacht can be berthed at the head of the walkway.

After a fairway with a width of 20 m, two similar walkways are located. Each of them will be able to accommodate 24 yachts with a length of up to 10 m. A double berth has a width of 8.6 m and the finger piers are stretched over the entire length of the slip of 10 m. The fairway between two berth slips has a width of 17.5 m.

This arrangement leads to a total number of berths as given in table O.9.

table O.9 – number of berths in the marina

Length class, L_b	Number of berths
< 10 m (<33 ft)	36
< 12 m (<39 ft)	66
< 24 m (<79 ft)	112
< 36 m (<118 ft)	32
< 50 m (<164 ft)	28
mega yachts	2
total	276

An extra walkway is located at the western end of the marina which can be used as a berthing place for service vessels. Examples are boats available for rent or vessels used for round-trips or sport fishing trips.

0.4 WALKWAYS

The dimensions of the floating walkways depend on the length of the berthed yachts. Services and utilities such as cleats, service bollards and fire extinguishers should be located on the walkway as well.

0.4.1 DESIGN OF THE FLOATING WALKWAYS

The width of the main walkway is 2.5 m everywhere in the marina. The width of the finger piers depends on the width of the berths. A detail of a finger pier between two berths with a width of 12 m is given in figure O.6. The net width of the finger pier is 1 m, the total width is 1.6 m. The width of each finger pier is given in table O.10. The width used in the design is somewhat larger than the required minimum, but is chosen to ease the construction with regular lengths of the wooden boards. It is recommended to use multiple connected, relatively small pontoons instead of a single pontoon as the walkway. The length of the walkway is in this way more flexible and it also simplifies the maintenance of the pontoons. This is considered of relative importance, as the life time of a floating pontoon is about 25 years. Pontoons will therefore have to be maintained and replaced during the design life time of the marina of 50 years.

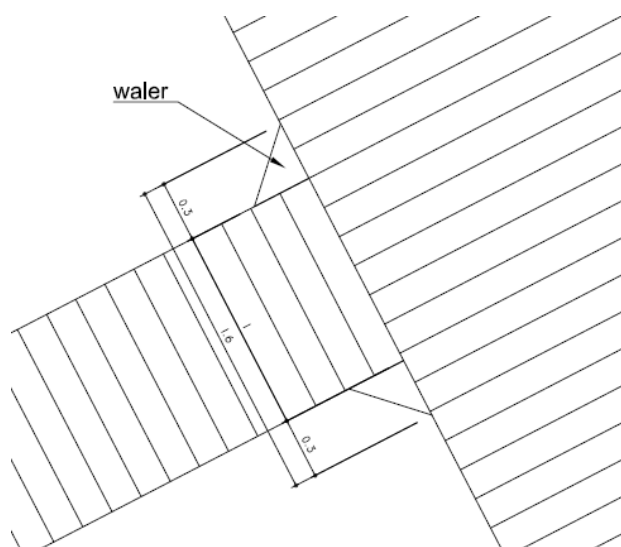


figure O.14 – detail of a finger pier and its walers

table O.10 – width of the finger pier in the marina

Length class	F (m)	F_{net} (m)
< 24 m (80 ft)	1.6	1.0
> 24 m (80 ft)	2.1	1.5
> 36 m (120 ft)	2.6	2.0

The connection between the walkway and the shore will be made with a gangway; an example can be seen in figure O.15. Because the tidal range is relatively small, the expected slope of the gangway will probably not exceed the maximum slope of 1:4 (Civil Engineering Department, 2007).



figure O.15 – an example of a gangway (Schwarzenegger, et al., 2005)

Floating pontoons have to be prevented from moving out of their design position due to currents, waves or impacts from vessels. This can be done by a mooring system. Piles are not recommended because of the relative great water depth that will lead to high moments and high construction costs. These problems do not occur when an anchor system is applied. With such a system, floating pontoons are connected to an anchor with a (galvanized) steel cable (Civil Engineering

Department, 2007). This can be a gravity based anchor of steel or concrete placed on the seabed that will limit the movement of the floating pontoons. The disadvantage is that the allowable vertical motion is relatively small compared to the other systems. Because the tidal range is relatively low, the allowable vertical motion will be small as well, so this will be of no problem.

0.4.2 UTILITY SERVICES ON THE WALKWAY

Next to the services provided onshore, a marina should also accommodate facilities on the floating walkway to ensure a safe and comfortable residence for yachtsmen. Examples of services that have to be provided are mooring facilities like cleats and fenders, fire extinguishers and service bollards.

Cleats and bollards

Cleats or bollards will be located on the finger, on the walkways and on the pier. An example of a cleat is given in figure O.16. Cleats will be located in any case at the both ends of a berthing slip, while the number of cleats on the finger pier, divided up proportionally along the length, depends on the length of the slip. The total number of cleats for each length class is given in table O.11.

table O.11 – required number of cleats

Length class, L_b	Number of cleats
< 12 m (<39 ft)	4
< 24 m (<79 ft)	5
< 36 m (<118 ft)	6
< 50 m (<164 ft)	7

On the Espigón Iglesias, the pier at which mega yachts are moored alongside, small bollard should be placed every five metres to ensure the flexible mooring possibilities. This is needed because multiple super yachts with variable length can be berthed at this pier as well.



figure O.16 – an example of a cleat, Marina Hemingway (02/22/2013)

An estimation of the required pulling capacity of the cleats can be acquired when it is assumed that the maximum berthing forces are caused by the wind loads with a direction perpendicular on the orientation of the berthed vessels. These winds can occur during for instance sures, see paragraph 'H.4 Wind conditions'. This wind load is given by (see also paragraph 'P.3.2' about 'berthing forces'):

$$F_w = \frac{1}{2} \rho A_w u_{10}^2$$

The estimated maximum frontal area for each length class is given in table O.12. This area corresponds with the length of the ship multiplied by the estimated height.

table O.12 – frontal area perpendicular to the wind direction per length class

Length class, L_b	A_w [m ²]
< 12 m (<39 ft)	25
< 24 m (<79 ft)	75
< 36 m (<118 ft)	140
< 50 m (<164 ft)	250

A wind blast speed with a return period of 50 years is 44 m/s, see paragraph ‘H.4 Wind conditions’. This leads to the estimated maximum berthing forces as given in table O.13. It is assumed that only the cleats along the side of the berthed vessel will have to deliver the required pulling forces. This leads to the required pulling capacity as given in table O.13 as well.

table O.13 – maximum berthing forces per length class

Length class, L_b	F_w [kn]	F_w [tons]	Pulling capacity per cleat [tons]
< 12 m (<39 ft)	31	3.2	1.0
< 24 m (<79 ft)	93	10	2.5
< 36 m (<118 ft)	173	18	3.6
< 50 m (<164 ft)	310	32	5.3

Considering these values, it is recommended to acquire two types of cleats, one for the smaller yachts with a pulling capacity of 3 tons and one for the super yachts with a pulling capacity of 6 tons. This corresponds to the recommended values found in literature (Civil Engineering Department, 2007).

Fender constructions

Every pier, walkway and finger should be protected by a fender construction. The fenders in the berthing area can be made up of rubber or tropical hardwood and should cover the entire outer edge of a berthing construction (Civil Engineering Department, 2007). The fender construction of the Espigón Iglesias requires extra attention, as berthing and mooring forces are higher due to the larger vessels and the adverse orientation perpendicular to the direction of wind and waves.

Other utility services

Service bollards will be placed on each waler to provide the berthed yachts electricity and water supply. A potable water connection is preferable; if this is not possible, bottles of mineral water should be available close to the berthing places. An example of a waler with a service bollard is given in figure O.7. A service bollard can also provide secondary services as an internet, telephone or TV connection. Larger service bollards will be located on the Espigón Iglesias every 30 metres, as mega yachts require a high supply of electricity.

Each walkway should be illuminated at night to ensure the safety on the walkways. Fire extinguishers will be present every 50 m on the walkway. A ladder will be located on the walkway at every double berth slip to ensure a safe egress from the water.

0.5 ON-LAND FACILITIES

The official entrance of the marina will be located at the old La Coubre terminal entrance gate. The retained relation with the disaster of La Coubre gives historical value to the marina and is honour to the victims of the tragedy. Besides, the train station and remains of the historic city wall are located close to the entrance. Moreover, the site is central in the marina. The current terminal building will be demolished to make room for fuel supply lorries as near the head of the Espigón de la Coubre the sale of fuel will take place.

The exit of the marina will be located near the parking area on the eastern side of the terminal building at the Muelle Díaz no. 1 to connect to the Avenida del Puerto, see also 'Appendix Q: Design of the connections to the transport network'.

The terminal building at the Muelle Díaz no. 1 will be renovated for the use of main building in the marina. The two lowest storeys will be combined as single spacious base floor. It will have a transparent style to decrease the instinctive border between the marina and the city that the current building creates.

The information service desk, surveillance guard and harbourmaster's office will be placed on this base floor close to the entrance at La Coubre. The boat launch installation will be located at the east side of the Espigón de la Coubre. The southwest corner of the terminal building will therefore have the destination of a small boat yard, where minor repair activities can take place. Some sanitary facilities will be placed in this building as well.

The eastern part of the building, close to the warehouse on Díaz no. 2, will be a covered parking area for costumers of the hotel or restaurant. When needed, a number of parking spots can be used as covered dry berthing place.

On the second floor (the current third floor), a supermarket will be located that will sell boat gear as ropes, canvas et cetera as well. A fitness gym and small spa will be placed next to the supermarket.

A hotel will be placed on the top floor of the building. This hotel can be used by costumers of the marina that do not want to stay on the vessel during the night. Also visitors of the country arriving by ferry can use the hotel.

The old warehouse at the Muelle Díaz no. 2 will be used to house a restaurant, bar and yachting club. Sufficient area is available to give these facilities a spacious layout. It is therefore also recommended that the restaurant and bar will not only provide for the basic needs of the costumers of the marina, but that they will become a full addition to the existing gastronomic supply of the city. The authentic atmosphere of the old warehouse will be preserved, although some adjustments will have to be made to make the building functional for its new purposes. Some sanitary facilities will be placed in the building as well.

Other service related facilities, like the money exchange and customs service, can be located in the western part of the warehouse.

The old Hines building will be reused as an exclusive club for super and mega yacht owners. Several shops for luxurious products will be located in this building as well. The Espigón Iglesias will be accessible for the owners of the berthed super yachts, his guests and for employees of the marina.

At the head of the pier the marina reception will be located, where newly arrived yachts will have to check-in to be assigned a berthing place. The initial customs and immigration services can take place here as well. Because these services are often time-consuming, the floating breakwater can also be used as a temporary mooring place for waiting vessels. When a more extensive immigration and/or customs service is needed, this can take place in the main building on the Muelle Díaz no. 1. Another fuel supply will be located at this pier as well. This facility will only supply fuel to the larger classes of vessels, which are berthed here. This fuel service will have to be supplied by a tank vessel, because the pier is not accessible by road. It is stressed that only a few vessels will use this fuel supply.

On the strip along the Muelle de la Coubre small kiosks containing cafeteria, bar and shop activities will be located in the then former western warehouse. Only this western building will be reused, the eastern warehouse will be demolished. In this way also this section of the marina takes part in the marina as a whole. Also some sanitary facilities will be placed in this warehouse for owners of the yachts berthed in the western part of the marina.

Some parking places dedicated for customers of the marina will be placed on this strip as well.

Facilities that require relatively great surface areas are the parking area, car rent service, recreational services and the dry berthing area. As mentioned above, a small parking area is located in the eastern part of the old terminal building on the Muelle Diaz no. 1 and a parking strip on the Muelle de la Coubre. Since the majority of the car owners is coming from the ferry and only a minority of the marina visitors will have a (rented) car, it is more sensible to locate a large parking area at the ferry terminal which can be used by customers of the marina as well when the current parking area will prove to be temporary insufficient, see also 'Appendix P: Design of the ferry terminal'. As no sufficient land area is available for a car rent service inside the marina, this service is also located at this parking area. Sufficient space is available at the ferry terminal area for these services. Furthermore, car renting is already situated at the cruise terminal and car renting is in general demanded more by ferry passengers than yachtsmen. Two car rent services in the close proximity of the marina is assumed to be sufficient.

It is also assumed that the marina of Havana will mainly be a port-of-call; negligibly little customers of the marina will use it as a homeport. Therefore it is plausible to state that only a small minority of the yachtsmen will want to put their vessel on dry land. The parking area in the terminal building can be used as a small, temporary dry berthing area for these yachtsmen. If in future more people choose Havana as their home port, the dry berth facility must be expanded, possibly outside the marina terrain. It is however recommended to make the marina in the Bay of Havana a tourist marina for short-stay purpose. Yachts that will be berthed for a longer period are recommended to move to Marina Hemingway.

The entire marina will be connected by a walking promenade that will be connected to the marina walk at the Almacén San José. This will decrease the instinctive distance between the marina and the city centre and will increase the attractiveness of the marina for other visitors as well.

The sewage water, chemical waste and garbage treating facilities will be situated at one place, to cluster these wastes. To minimize hindrance caused by smell and noise, the building is located at the very south-western end of the marina.

0.6 TRAFFIC

The construction of the marina will cause traffic flows in the area. This traffic will mainly be of pedestrians, but, to a lesser degree, also cars and supply trucks. The connection to the infrastructural network is discussed in more detail in 'Appendix Q: Design of the connections to the transport network'.

0.6.1 PEDESTRIAN TRAFFIC

Most yachtsmen will visit Havana with the purpose to discover the (old) city of Havana. It is wanted that the connection between the marina and the city is therefore transparent to create an attractive and convenient reception to the city. On the other hand it will be interesting for other, 'regular', tourists to visit the marina as well. Care has to be taken on this concept as the privacy of the yachtsmen should be preserved. This means that the apparent paradox of transparency and shielding are both wanted regarding the connection with the city.

The La Coubre terminal entrance gate has a very attractive location to serve as the main entrance and the connection of the marina with the city. This building reminds to the La Coubre incident and therefore has its historical prestige. In front of the La Coubre entrance gate a remnant of the ancient city wall and public gardens are situated around a roundabout. This place is very near to the (monumental) railway station building and the Almacén San José shopping centre. This means that leaving the marina is at the same time entering the city.

The Juan Manuel Diaz no. 1 terminal building is located next to La Coubre. This building is rather immense and blocking the view. Moreover, the building is narrowing the Avenida del Puerto which leads to insufficient space to handle pedestrian traffic in the current situation. The solution to this problem is to make the ground floor passable for pedestrians. In order to do so the non-essential walls of the building at the ground floor will be removed so that pedestrians can walk freely in and out of the building. More transparency between marina and city is created by the construction of this inner courtyard. Since the building itself has relatively little aesthetic and cultural-historical value, this solution seems justified.

When following the Avenida del Puerto further northwards, the terminal Juan Manuel Diaz no. 2 is the next blockade of pedestrian traffic. The road is still narrow at this location which means that no sufficient space for a walking promenade is available at the landside of the warehouse. The terminal building itself is in a reasonable shape and is dedicated for facilities demanded by the marina. The continuation of the promenade will therefore take place at the side of the marina of the former warehouse.

The promenade is continued past the Aracelio Iglesias pier further northwards and is connected to the apron behind the 'San Jose'-shopping centre. Eventually the promenade will connect with the floating boardwalk at the brewery café.

The promenade will be continued in southward direction on the Muelle de la Coubre. The wall along this part of the marina will be lowered to eye level to increase the transparency of the marina and the city. The wall will however also form a physical boundary between the city and the marina, which will increase the feeling of safety and privacy of the customers of the marina.

0.6.2 **MOTORIZED TRAFFIC**

The marina will have to be accessible for motorized traffic as well. Several customers of the marina will use a (rented) car that has to be parked near the berthing area to limit the walking distance. Moreover, supply lorries will have to have access to their destination, for instance for the restaurant, supermarket and the gasoline filling station on the Espigón de la Coubre. The entrance of the marina will therefore have to be safely connected to the Avenida del Puerto. This connection is discussed 'Appendix Q: Design of the connections to the transport network'.

0.7 IMPRESSIONS

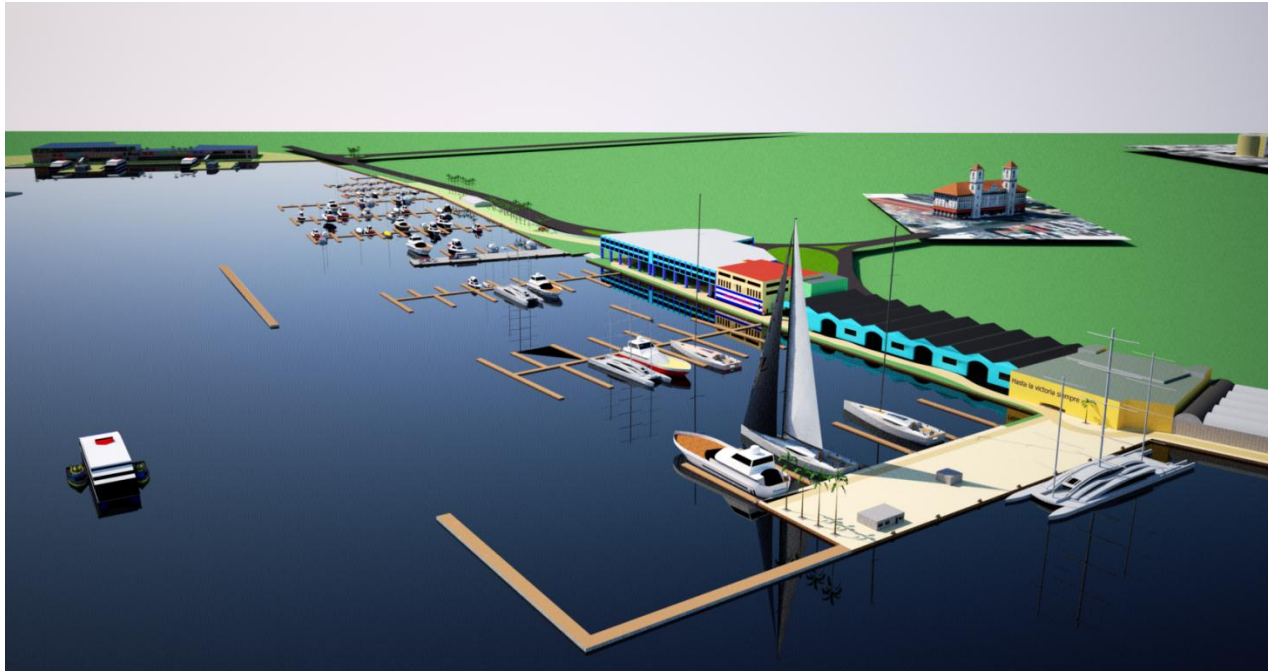


figure O.17 – artist impression marina (1)



figure O.18 – artist impression marina (2)

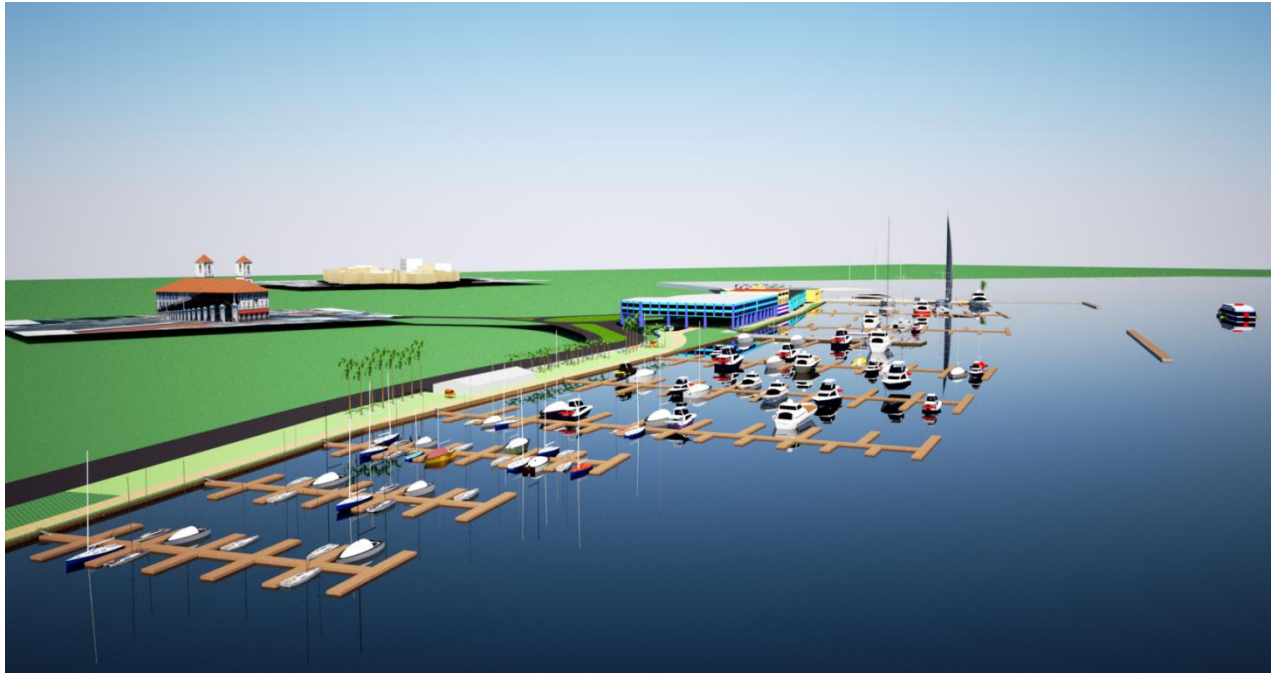


figure O.19 – artist impression marina (3)

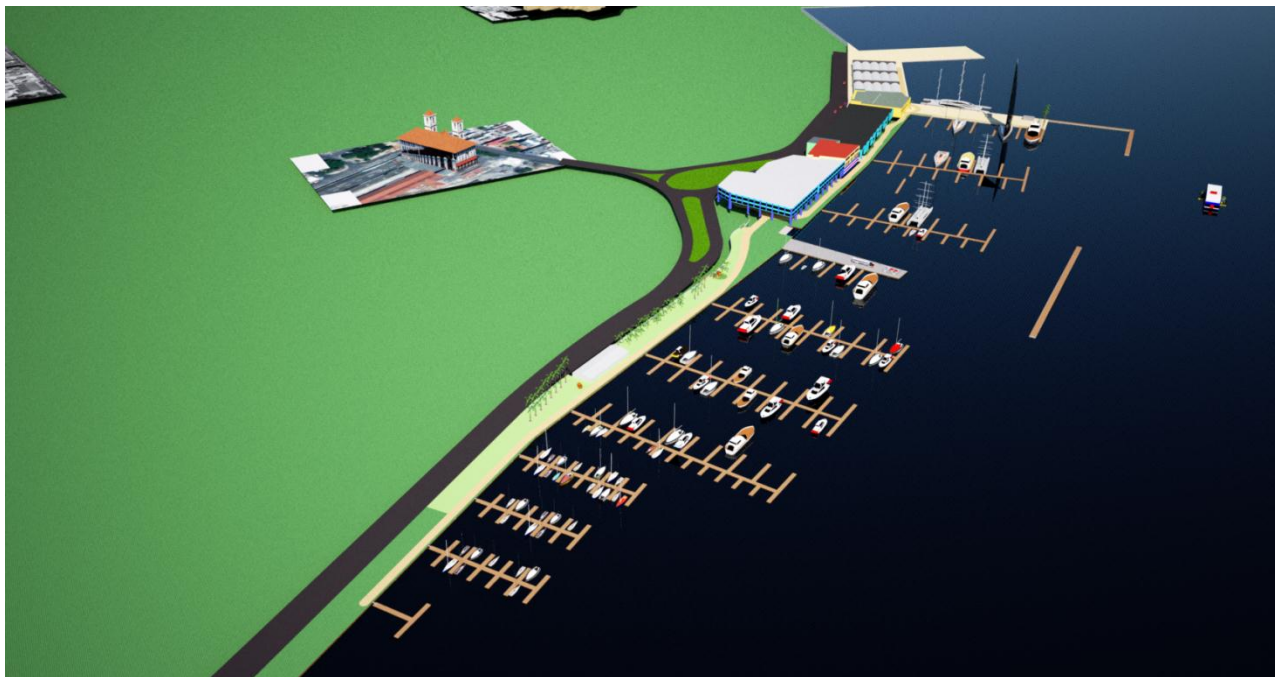


figure O.20 – artist impression marina (4)

0.8 CONCLUSIONS AND RECOMMENDATIONS

0.8.1 CONCLUSIONS

A breakwater is required to provide a 'good' wave climate in the marina. Because of the lower construction costs and the sole occurrence of short waves at the location of the marina, a floating breakwater will be the best option. These floating pontoons of 4.5x1.5 m² will be located in front of the marina so that manoeuvring of the super yachts and the ferry is still possible in a comfortable way. The location is depicted in 'Appendix W: Technical Drawings', drawing number W3.

The arrangement of the berthing area is designed with the berthing places for the super yachts in the east. The length of the slips is decreasing to the west. The walkways are designed to be a floating pontoon construction with fingers and walers. The arrangement can be seen in 'Appendix W: Technical Drawings', drawing number W2. The marina will have a total capacity of 276 berthed yachts, including two berths for mega yachts.

The walkways are designed with a width that will guarantee safety and comfort for customers of the marina. The connection to the shore is made with a gangway. The walkways are provided with all required utility services.

The two terminal buildings on both Muelles Diaz will be reused to house the required facilities of the marina. The marina reception and the fuel service will be located on the Espigón Iglesias and la Coubre respectively. The official entrance of the marina will be at the entrance gate of the La Coubre terminal. Small parking areas will be located on the marina; from which the parking area in the terminal building Díaz no. 1 can be used as a small temporary dry berthing area as well. The connection of the marina to the Avenida del Puerto is discussed in 'Appendix Q: Design of the connections to the transport network'.

0.8.2 RECOMMENDATIONS

The following recommendations are made in order to make the design of the marina more accurate:

Wind generated wave height

The dimensions of the floating breakwater are based on the results of the SWAN model as described in 'Appendix K: Hydrodynamic analysis – SWAN'. However, it is recommended in the same appendix to investigate these wind waves in more detail as the local fetch length could be influenced by the geographical surroundings of the bay. When the results of this research show different wave heights, the dimensions of the breakwater should be adjusted.

Forces on the breakwater

The forces acting on a breakwater consist of a complex combination of wind, wave, mooring and berthing forces. These forces should be investigated with a computer model in order to determine the maximum force combination acting on the breakwater. Subsequently, the related reaction forces of the anchors can be derived, after which the dimensions of the anchor system can be determined

Anchor system of the floating walkways

The forces acting on the floating walkways are as complex as the forces on the breakwater. These forces should be researched further in order to determine the properties of this anchor system as well.

Mooring forces

It has been assumed that only wind forces act on a moored boat. The exact forces should however be investigated in more detail in order to determine the pull capacity of the cleats and bollards, especially for the larger yachts.

The same holds for the berthing forces in order to determine the forces acting on the fenders and the floating pontoons.

Reuse of existing buildings

The terminal buildings on the location of the marina will be reused to house different facilities. The exact state of these building, and whether it is suited for the new purposes, will have to be examined in more detail.

Short-term and long-term berthing

It is recommended that the marina in the Bay of Havana will be used with the purpose of short-term berthing only. When a yacht has to be berthed for multiple weeks, it is recommended to move to the Marina Hemingway. The long-term dry berthing areas should be located here as well. The Marina Hemingway should probably be adjusted to accommodate these long-term stays.

Contamination

No currents are assumed at the location of the marina and ferry terminal. Because of possible leakage of waste water and oil, a lack of currents can result in contamination of the marina. Marinas without currents use flushing channels to flush out the water in the berthing area once in a while. The possibility of flushing is however limited in this situation. A further research is therefore recommended to prevent contamination of the marina.

Appendix P: DESIGN OF THE FERRY TERMINAL

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P.1 INTRODUCTION

In this appendix the design for the ferry terminal is proposed. First, conditions that form the boundaries to the solution are given. Conditions are created by the demands of the client, spatial issues and hydrodynamic data. It is of vital importance that the solution fits these conditions. In the second section the actual design is proposed in which decisions and considerations are explained.

P.2 CONDITIONS

In this section an overview of demands, spatial requirements, hydrodynamic conditions and ferry dimensions are presented.

P.2.1 DEMANDS

The ferry terminal must provide international services to several cities around the Caribbean. These are daily lines to Key West and Miami and weekly lines to Cancun, Tampa and Nassau, as is assumed in 'Appendix A: General perspective of Tourist Port Havana' and 'Appendix G: Nautical analysis'. A berth is dedicated for each line with a daily service. The weekly lines will share one berth. Logistical, berthing and bunkering processes are simplified in this way.

As a consequence of the high level of uncertainties about future developments in Cuba, the exact demanded capacity of the terminal is almost impossible to determine. Therefore flexibility of the design is considered important. An elaboration on these expectations is given in 'Appendix D: Tourism analysis'.

P.2.2 SPATIAL REQUIREMENTS

The spatial requirements consist of the minimum required area both on land as in the Ensenada de Atarés.

On-land required area

In 'Appendix L: Boundary conditions and design requirements' specific ferry terminal facilities are stated. To allocate these different facilities, an estimation of the required area for each of these facilities is necessary. These estimations are listed in table P.1, in order of decreasing required space.

table P.1 – required facility areas

Facility	Required area (m ²)
Terminal building / Waiting lounge	30 000
In and out going traffic	10 000
Hotel (shared with marina)	5 000
Parking area (shared with marina)	5 000
Supply shed (at the piers)	300 per pier
Catering services	200-500
Marshalling area (at the piers)	150 per pier
Customs services	100-150
Money exchange service	100-150
Cafeterias, restaurants and bars	50-200 (each)
Shops for food, drinks, souvenirs and gadgets	50-100 (each)
Fuel supply	50-100
Sewage and waste water pump out	50-100
Vehicle ramp	50
Garbage collecting service	25-50
Walking bridge	25
Aprons (at the piers)	15 (m)

A total land area of approximately 30 000 - 50 000 m² is required to house all facilities. The required area depends mainly on the waiting lounge as this is the largest facility. Since the quality of traffic processes are improved by an increase of free space on the terminal area, it is recommended to construct the terminal building with multiple stories to limit the area occupied by the terminal. Taking these considerations into account, a two-story terminal building will be constructed, with as a result an estimated required area of about 37 000 m². The available land area is estimated to be about 55 000 m² at present, and is thus sufficient to house the other required service facilities as well.

Required water areas

According to calculations performed in 'Appendix G: Nautical analysis' and 'Appendix R: Design of nautical infrastructure', the required nautical dimensions are obtained and given in table P.2.

table P.2 – required basin dimensions

Approach channel width	58.3 m
Inner channel width	55 m
Required depth	3.5 m
Turning basin diameter	120.0 m
Basin width	97.2 m

P.2.3 HYDRODYNAMIC CONDITIONS

In 'Appendix H – Appendix K', hydrodynamic conditions are acquired by analytical calculations and by computer modelling of the bay. The parameters that influence the ferry terminal design are listed in table P.3.

table P.3 – hydrodynamic conditions

Significant wave height of locally created wind waves, Beaufort 6 (10.8 m/s)	$H_s = 0.32$ m
Significant wave height of locally created wind waves with a return period of one year	$H_s = 0.71$ m
Maximum tidal elevation	+ 0.33 m above MSL
Sea level rise in 50 years	17.5 cm

According to this hydrodynamic study, currents, wave penetration and sediment transport are of minor importance at the location of the ferry terminal. This is due to the sheltered location of the bay. Therefore, these processes can be neglected in the design. According to paragraph 'G.6 Vessel interactions' also ship induced waves can be neglected.

P.2.4 FERRY DIMENSIONS

The design vessel is the Damen Fast Ropax 6016. It is assumed this vessel has sufficient capacity to answer the uncertain demands. This vessel is mainly applied because of the high sailing speed which limits the sailing time. The most important design data, as given in 'Appendix G: Nautical analysis', is listed in table P.4.

table P.4 – Damen Fast Ropax 6016 data

Length	60.0 m
Beam	16.2 m
Draught	2.0 m
Passengers	660
Cars	49

P.3 DESIGN OF THE TERMINAL FACILITIES

In this section a design is proposed that meets the boundaries given in section P.2.1. First, the processes involved when a vessel calls the port are considered. This implies approaching the terminal and berthing. Second, the required structures are designed. The section concludes with the design for the traffic inside the terminal. The solution is obtained by considering and comparing several alternatives for separate components of the line. Dimensions of these components are also calculated.

P.3.1 SAILING ROUTE

Easy approaching and mooring at the terminal is desired in order to minimize mooring time, hindrance to other traffic and collision probabilities. Therefore it is recommended to minimize the sailing distance inside the bay and the number of turns the ferry vessels must perform in order to moor. This means the most direct route to the berth is preferred, see also 'Appendix R: Design of nautical infrastructure'. The total length of the distance inside the bay is about 4.5 km. With an average velocity of 4 kn, the duration for the travel of the interior fairway is about 30 minutes.

The inner approach channel to the ferry terminal is situated along the marina. This channel is also used by yachts. As a result, ferries and yachts will have interacting traffic inside this channel. The interaction of ferry vessels and yachts is minimized to improve safety and prevent hindrance. This is achieved by prohibiting yachts to enter at the same moment as when a ferry sails in the channel. At a sailing speed of 4 knots it takes the ferry about 8 minutes to pass the marina. Three ferry lines providing daily services are responsible for eight passages. Hence, during a total of 64 minutes a day, it is prohibited for yachts to sail in the channel. Although this is of course an estimated minimum, it is considered feasible since ferry lines are subject to a tight schedule, so it is known in advance when yachts are prohibited to sail. See also 'Appendix R: Design of nautical infrastructure', paragraph 'R.5 Traffic intensity'.

Considering the above, the approach route is specified in appendix nautical design and also depicted in figure P.1 and figure P.2.

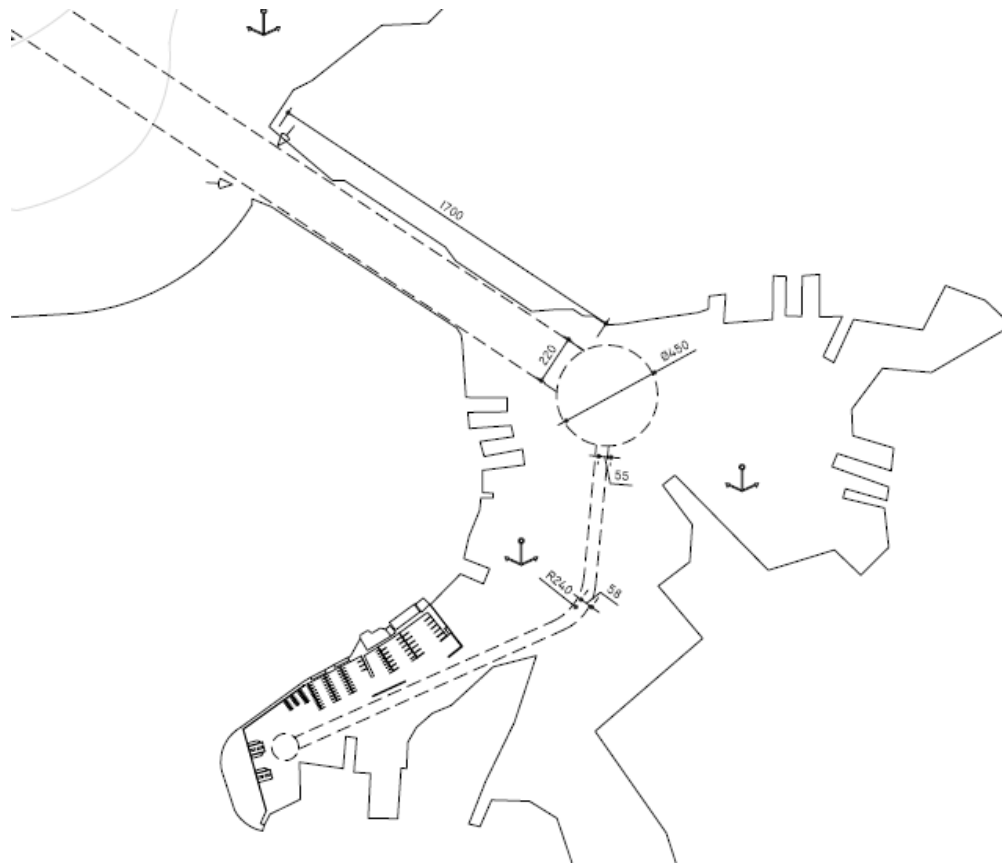


figure P.1 – approach route of the ferry

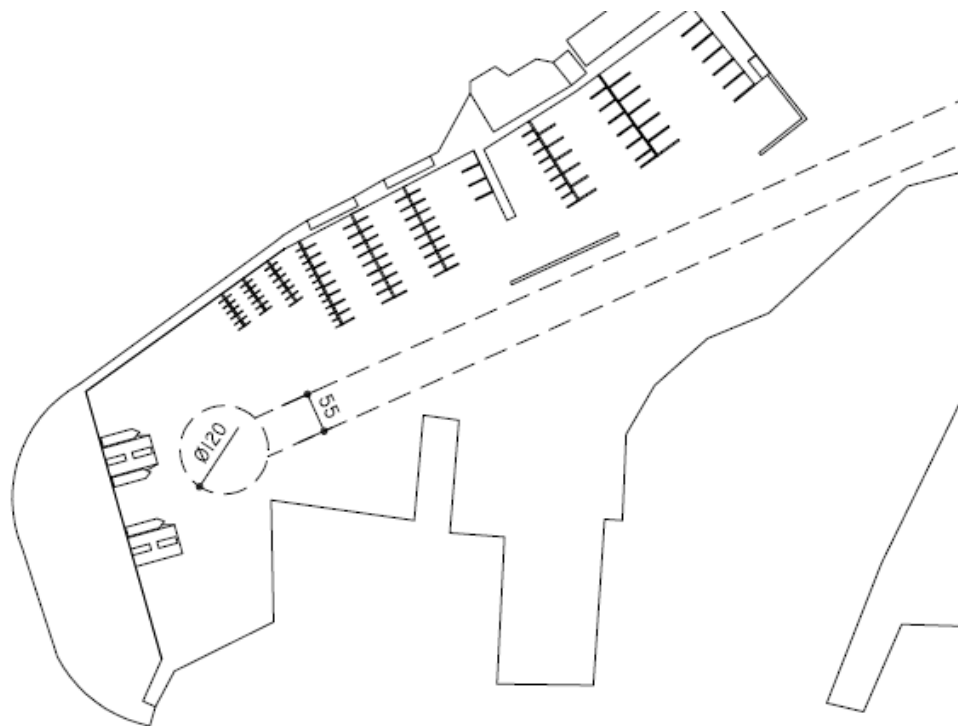


figure P.2 – entrance to the terminal basin

P.3.2 BERTHING METHOD

It is sensible to take into account the possibility that different ferry vessels will be used in the future. Ferries are therefore considered in general to determine the berthing method. They can have a stern ramp, side ramp or both. As a result the berthing structure should provide possibilities to (un)load the vessel at both possible ramp locations. This means that the berth must have at least two sides at which the vessel is able to moor. Because practically no currents or waves are present on a regular day in the Ensenada de Atarés, the ferry can be berthed in a so-called 'corner berth lay-out', see figure P.3 (Ligteringen, 2009). This method is characterized by fenders placed at one side of the vessel; either at the bow or the stern. The ship is held in position by mooring lines.



figure P.3 – corner berth lay-out (PIANC, 1995)

P.3.3 SHIP TO SHORE METHOD

The connection for motorized traffic between the vessel and land is made by a ship to shore system. Three types of ship to shore methods are possible: floating pontoon, fixed ramps and moveable long-span bridge systems (PIANC, 1995). These three systems are discussed next, after which the most feasible method is chosen.

Floating pontoon system

The advantage of this system is the combination of low costs and high flexibility; few adjustments have to be made with the introduction of a different type of ferry. However, the system has only one bridge level. A separate facility for passengers must therefore be installed. Because of the floating pontoon, the system cannot be used in exposed areas, and berthing impact resistance is limited. An example of this system, as used in Boulogne, is given in figure P.4.

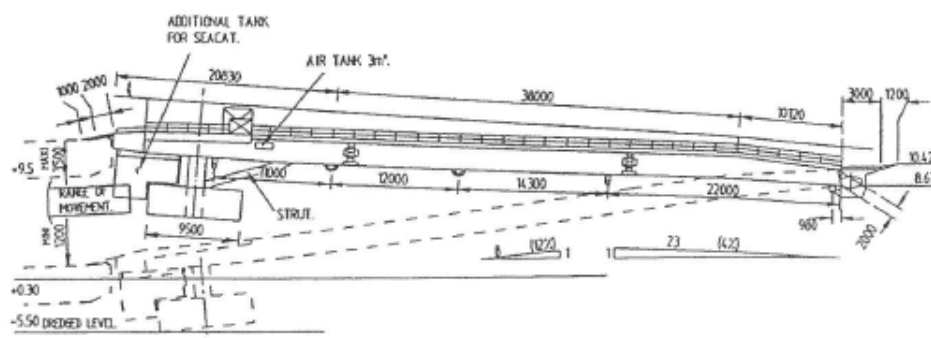


figure P.4 – floating pontoon berth in Boulogne (PIANC, 1995)

Fixed land ramps

This method is only suited for ports with low tidal ranges, where the ship/shore connection can be made with minimal infrastructure; this means in general few maintenance. If necessary, the height of the ramp can be adjusted by a hydraulic system. The system can handle high mooring forces as the ship/shore system is part of the quay. Another advantage is that the system can easily be used for a different

type of ferry. A disadvantage is that it is only suited for ferries with a single level of vehicle loading. An example of a fixed land ramp as it is used in Stockholm is given in figure P.5.

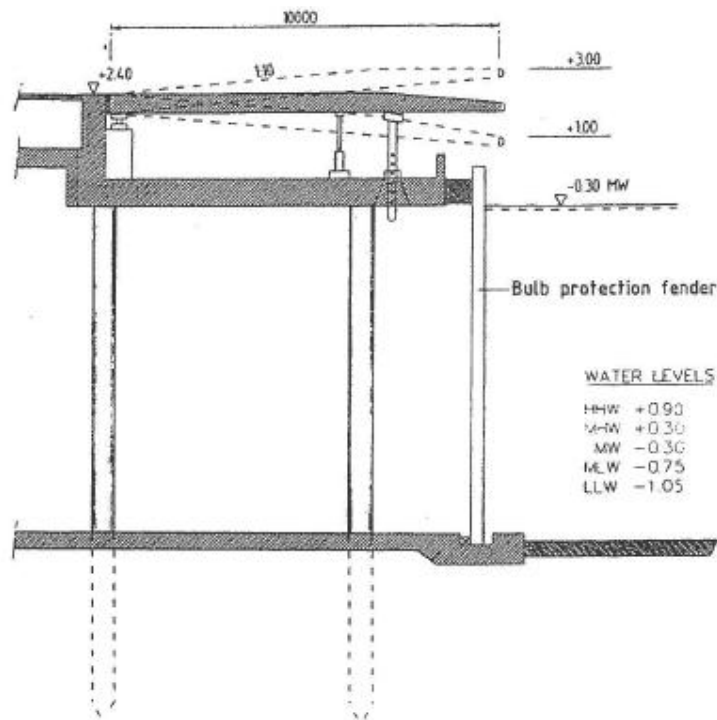


figure P.5 – adjustable fixed land ramp in Stockholm (PIANC, 1995)

Moveable long-span bridge systems

This relatively expensive system is used in areas with large tidal variations. The system is rather inflexible, as it is designed for an individual type of ferry. The advantage is that multiple bridge levels can be used.

Conclusion

Considering the low tidal range in the Bay of Havana and the wish to have as few as possible maintenance, the fixed land ramp has been chosen as the preferred system to use in the Havana International Ferry Terminal. Moreover, the system has the advantage of being flexible and robust. Although initial costs are higher compared to the floating pontoon system, the fixed ramp is expected to be less costly due to the limited maintenance.

P.3.4 PIERS

Berths

In section P.2.1 it is explained that the design must contain three berths. These berths are provided by two pier structures that will provide ship to shore connections at both the stern and side of the vessel. A pier system is more space efficient compared to a quay system as each pier is able to receive two ferry vessels; one at each side. To meet the desired high level of flexibility, initially one pier will be completed. The second pier will be constructed later, depending on the developments and demands. Initially only one side of this second pier will be used as a berth. The other side of this pier can then be used to moor service boats of the ferry terminal. If demanded in the future, this side of the pier can also be used to berth a fourth ferry vessel.

Orientation

The piers are orientated perpendicular to the quay, in the direction of the approach channel. This is done to provide an advantageous orientation to the prevailing wind direction. It is recommended to berth vessels within an angle of 30 degrees to the prevailing winds (Ligteringen, 2009). Moreover this pier orientation minimizes the quantity of manoeuvres the ferries must carry out in order to enter the terminal. However, manoeuvring in front of the piers is still necessary for mooring. The area required given in table P.2 is available at the end of the spacious Ensenada de Atarés.

Mooring

The piers are providing the connection of the vessel to the land and the design has to be performed integrally with the choice of the ferry. Especially the mooring process must be matching: the configuration of the ramps of the vessel and the fixed land ramp must fit. Two configurations are possible:

1. Forward

Forward mooring vessels require a ramp at the bow of the vessel. As a result of the pier configuration, one vessel requires its second ramp at starboard side and one vessel at port side.

2. Rearward

Rearward mooring vessels require a ramp at the stern of the vessel due to their opposite berthing position. Like for forward mooring, one vessel requires a second ramp at starboard side and one vessel at port side.

From a logistic point of view, it is preferred to (un)load motorized traffic at the head of the pier. In this way the traffic flow from the vessel to the terminal and public road system can be handled in a proper and effective way. This arrangement can only be achieved by a side connection. This side connection is located near the bow of the vessel. This implies rearward directed mooring is recommended. The quay structures thus require stern fenders.

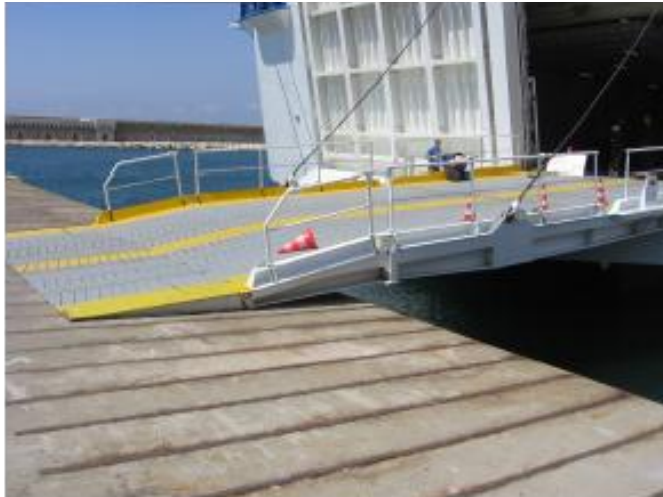


figure P.6 – an example of a stern ramp (Quist, 2012)

Moreover, this decision on the ramp configuration and thus mooring direction determines the arrangement of the motorized traffic on the vessel. Cars have to be placed with the nose directed to the bow to leave the ship at the side ramp. The cars have therefore to be loaded at the stern at the other terminal of the connection in order to achieve this arrangement, see figure P.7.

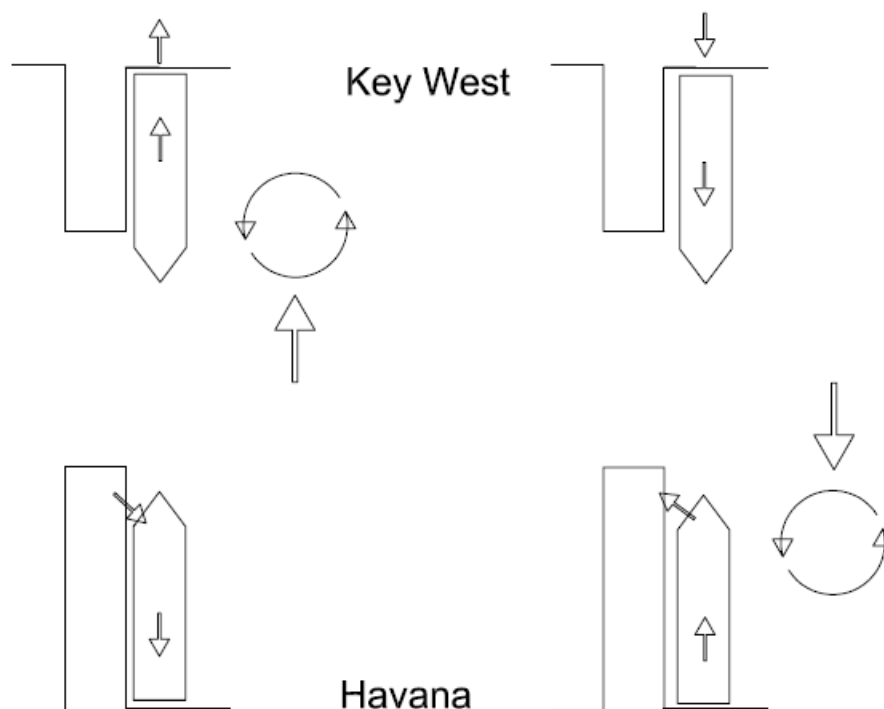


figure P.7 – (un)loading and turning processes of the ferry

Entering the vessel is preferred at the same ramp to organize the logistic processes in an orderly way. As a result, when leaving Havana, the arrangement of motorized traffic is orientated to the stern of the vessel. Abandoning the vessel at the other terminal of the line is done at the stern of the vessel. This means that the other terminals of the ferry lines must require equipment for (un)loading the vessel at the stern.

Both terminals require therefore a turning basin, see figure P.7.

Dimensions

No clear regulations are prescribed for the width of the mooring basin. However, for conventional cargo and container vessels, the recommended width is four to five times the beam of the vessel plus 100 m (Ligteringen, 2009). This distance provides space for the stopping and turning manoeuvre and tug assistance. However, ferry vessels are usually equipped with several powerful (bow)thrusters, hence the stopping distance is limited and manoeuvrability is high²⁵. However, in case of heavy winds, tug assistance is recommended. All things considered, the required width is presumably smaller than the recommended width for cargo vessels.

Considering the above, the space between the piers is designed to be four times the beam of the vessel. Furthermore, the two berths both require a width of the beam of the berthed vessel. To conclude, the basin width in between the two piers is six times the beam of the vessel: 97.2 m. Dimensions of the piers and basin in between are depicted in figure P.8.

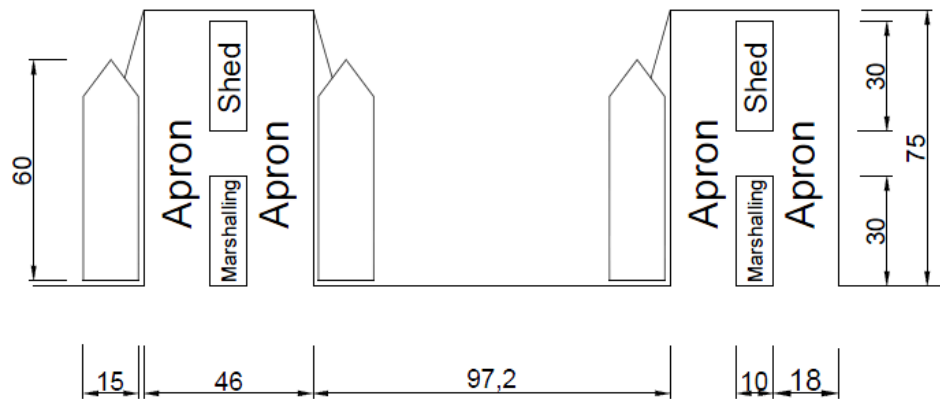


figure P.8 – pier layout

The piers must provide sufficient space to house the facilities required at the piers. These are: a marshalling area, a supply storage building and an apron to moor and provide logistic operations (PIANC, 1995). Since the pier is used for mooring at both sides, it is sensible to locate the supply storage building in the middle of the pier, close to both berths. The required area according to table P.1 is estimated to be about 300 m². This building is designed to have a surface area of 30x10 m².

A minimum width of 15 metres is prescribed for the aprons. Since the building is located in between these aprons and the area required for the building is not known exactly, a width of 18 metres is conservatively assumed for both aprons.

Furthermore the marshalling area is located next to the supply storage building. This area provides space to orderly arrange motorized traffic before entering the ferry vessel. The width of the storage supply building (10 m) is supposed to be sufficient for the marshalling area as well as space for two traffic lanes is available. A pier therefore has a total width of 46 metres.

The length of the pier should be at least the vessel's length (60 m) to support mooring along the whole stretch of the side of the vessel. An additional length of 15 metres is designed to add flexibility and spaciousness to the pier for possibly expected future demands. Also the mooring lines of the vessel can be towed at the

²⁵ As the bottom of the basin consists of solid rock, no risk for scouring and thus instability of the quay is expected due to (un)mooring of the vessel using its thrusters

corner of the protrusion of the quay. In this way the angle of the line is diminished, which increases the capacity for longitudinal berthing forces. This can also be achieved by dolphins constructed in the basin at the heads of the piers. These dolphins may be desired in case bigger vessels will be applied to the ferry line in future. The pier length is therefore set to 75 m. All this together yields required pier dimensions of 75x46 m².

The height of the pier is designed in section P.3.11

Bollards

The vessels are moored to the pier and quay with mooring lines, which are tied up to bollards. In order to minimize hindrance from bollards and lines, these bollards are preferably lowered inside the pier and quay structures as is depicted in figure P.9.

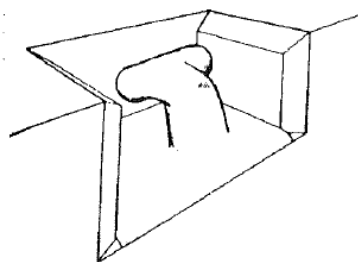


figure P.9 – lowered bollard

P.3.5 QUAY

The choice for the exact location of the quay of the ferry terminal is influenced mainly on three aspects, these are:

1. Required on-land area

As is calculated in section P.2.1, the present on-land area is sufficient to house all terminal facilities. The layout of the terminal can be achieved in a rather spacious manner. This aspect therefore does not lead to the need for a quay position further inside the basin. A position of the quay further landward is also unwanted as this decreases the spaciousness of the design of on-land facilities. From this it is concluded that the existing quay is located in the right position.

2. Required wet area

For manoeuvring it is preferred to design spacious water areas. As given in table P.2 the turning basin requires a diameter of 120 m. This basin must fit between the southern end of the marina and the piers of the ferry terminal. The distance between the existing quay and the marina will be about 300 m. The designed piers have a length of 75 m. As a result, 225 metres will be available. A possible new quay can be constructed about 105 metres further inside the basin considering the required turning basin. Water area is thus spaciouly available.

Furthermore, it is desired that the ferry and marina are not located directly next to each other. This is preferable in order to minimize both nautical and visual hindrance. In addition, the current harbour activities around the Ensenada de Atarés are affected least by a quay location as far as possible at the end of the basin. In this way the services at these quays can continue without adaptations.

From the above it can be concluded that the existing quay is in about the right position.

3. Bathymetry of the basin

According to figure P.10 the greatest part at the end of the Atarés basin has a depth of about 4-5 metres. In front of the quay there is a depth of 5.5 m. At a distance of about 120 m parallel from the Muelle de Osvaldo, the depth is about 6-7 metres in the centre of the basin. Close to the La Coubre quay the depth decreases to about 5 m. According to the required depth of 3.5 m (table P.2) sufficient depth is available at the whole basin.

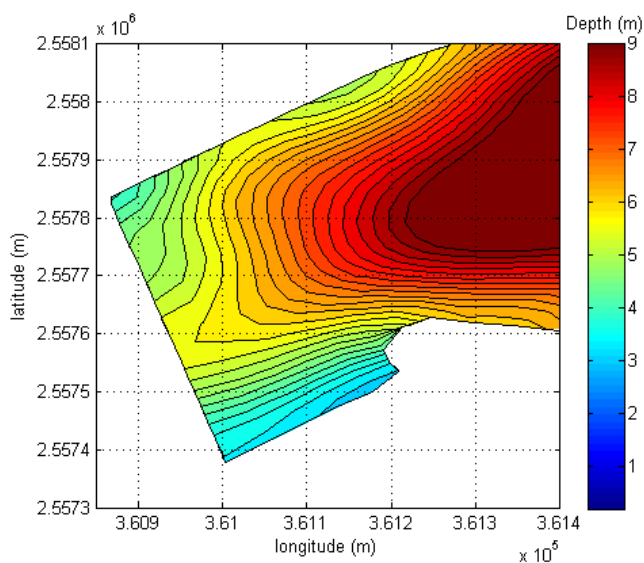


figure P.10 – detailed bathymetry

It has been stated that sediment supply is neglected. As a result the bottom profile is assumed not to change in time.

Conclusion

From the above, it is clear that sufficient depth is available in the whole basin, both initially and at a long term perspective. As a result dredging works are not required.

It is also concluded that the current location of the quay at the end of the Ensenada de Atarés is the ideal location of the future quay. As the present quay is in a reasonable shape and thus little rehabilitation is needed, it is decided to reuse this quay.

It is desired to construct the piers at shallow areas of the basin to decrease construction costs.

P.3.6 TRAFFIC ON THE TERMINAL

The terminal area is characterized by the vehicle traffic system. The layout for this system is determined with the use of the report *Ferry developments and their consequences for ports* (PIANC, 1995).

The traffic inside the terminal contains two different flows that have to be separated: the inbound traffic (arrivals) and the outbound traffic (departures). The quay is the only location where this is impossible, since both loading and unloading of the ships takes place here. Therefore this area must be clearly marked and controlled in order to guarantee safety. The safest solution is to schedule arriving ferries and departing ferries apart so there is no crossing traffic at all. This would be

a limiting factor for the capacity. For the current situation that would be of no problem as intensities of ferries will be low. But to keep the ferry terminal flexible it is recommended to create the possibility of crossing traffic at the aprons. This also makes the terminal more attractive as more ferries can arrive and depart at their preferred time. For crossing traffic, the safest option is to vertically separate inbound and outbound traffic, but this is also an expensive solution. With the low intensities in the near future, this is an unnecessary investment. To keep the option of adding vertical separation available, some space for expansion is left open in the form of a four meter wide strip along the quay. Around the terminal building is another strip for possible expansions in the future. This increases the flexibility of the terminal as the different lanes are easily shifted to new developments.

Outbound traffic

The outbound traffic will be lead from the main road to the apron with the following route as shown in figure P.11.

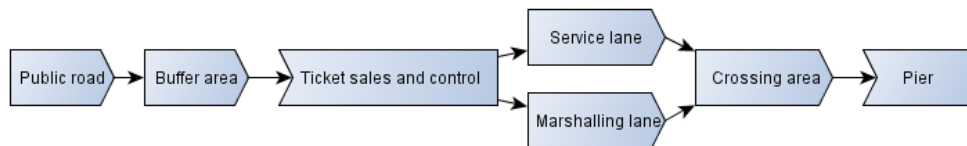


figure P.11 – schedule of outbound traffic

From the public road a diverting lane leads onto the ferry terminal. This lane creates a separation of the merging traffic from the terminal and the through road. From this lane the outbound vehicles enter the buffer area. Here they can arrange in line for the ticket sales and control without creating congestion on the entry lane. The ticket sales and control is done at the same time to minimize waiting times. Once through the ticket control, the outbound vehicles can continue to the marshalling area where they can line up awaiting the entrance of the ferry. The marshalling area is arranged into two lines, which could have a different apron as destination. This will be indicated on electric signs above the road. These lanes are parallel to the quay and the terminal building, along more than 250 meters. In this way all 50 vehicles that can enter one ferry are able to line up here. At the end of the marshalling lanes is a public convenience building for people waiting to enter the ferry. When the ferry is ready for boarding, the vehicles will continue to the crossing area, where the marking on the road will indicate the way to their destination apron.

Inbound traffic

The inbound traffic will be lead from the ferry to the main road according to the schedule presented in figure P.12.

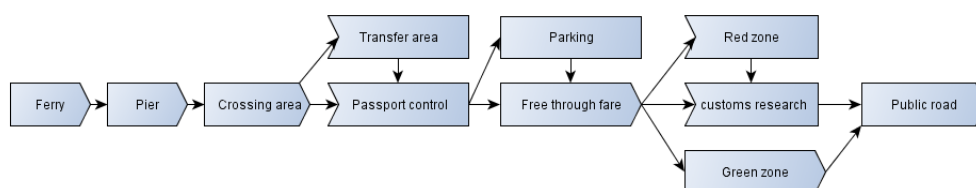


figure P.12 – schedule inbound traffic

The vehicles will unload from the ferry onto the apron. From the apron they will head onto the passport control via the crossing area. Here markings on the road will indicate the direction in order to prevent possible collisions with crossing traffic.

At the passport control the vehicles will form a line. To prevent this line from blocking the unloading vehicles from the ferry, a queue will be made on the apron itself. This is especially important to the apron closest to the passport control since the buffer of the crossing area is smallest here. For vehicles transporting cargo it is possible to enter the transfer area for dropping of or picking up cargo. In the near future this is not expected much as the ferry terminal will mainly transfer tourists, but this might change in the remote future.

From the passport control, the vehicles will go onto the free through fare if the documents are cleared. If not, vehicles must park in the parking area next to the terminal building awaiting document clearance. This is mainly important for vehicles transporting cargo, as document clearance takes considerably longer. At this location it is also possible for coaches to wait while the tourists go through the customs control inside the terminal building. On the free through fare lane vehicles can choose to enter the green zone or the red zone on either side of the customs research building. In front of this building is a parking area for vehicles awaiting customs research. After passing customs, the vehicles will enter the exit lane, leading to the public road.

Service lane

Besides the regular inbound and outbound lanes a service lane is implemented for vehicles with document clearance and for breakdown lorries. It is also accessible for emergency services. For the service lane there is a separate entry lane so emergency services can enter the area quickly.

Pedestrians

The outbound tourists as well as the inbound tourists go through the terminal building where they will undergo customs research. The inbound tourists leave the ferry with an elevated walkway, leading them over the traffic in the terminal area directly to the terminal building. Outbound tourists arrive in the terminal building from the forecourt and leave the terminal building towards the ferry with the walkway. This way pedestrians and vehicles are clearly separated, which results in a safer terminal.

Forecourt

The forecourt is situated in an indentation of the terminal building. In this way the relation with the ferry terminal is emphasized and traffic is urged to reduce its speed. The forecourt is divided into the departure terminal and the arrival terminal. At the departure terminal short-term parking, setting down lanes for taxis, busses and passenger cars are available. The arrivals terminal has the same facilities, plus a short stay parking area for busses. Here, also public transport busses are able to stop and pick up tourists.

P.3.7 LOCATION OF FACILITIES

Facilities that the terminal building should house are: a waiting lounge, customs services, money exchange and ticket selling. For a convenient flow of people it is recommended to group these facilities. Furthermore it is decided to house also catering services, cafeterias, restaurants, bars and small shops. In this way walking distances are minimized and the view of the terminal facilities is clear.

Facilities that are located outside the terminal building are the area to handle traffic flow from ship to shore, both for pedestrians and vehicles. For the motorized traffic an extensive arranging and marshalling area is designed as is explained in section P.3.6. Pedestrian traffic is handled by use of walking bridges. These will be constructed above the motorized traffic. Furthermore parking areas are designed around the terminal building. The piers will house a part of the marshalling area, supply storage shed, fuel supply and aprons. Sewage waste water and garbage collecting services are designed some distance away from the terminal building to avoid smell and visual hindrance.

The ferry terminal will not house its own hotel. The hotel is shared with the marina and is placed at the Juan Manuel Diaz no.1 building. This location has the advantage of being in the vicinity of the old city centre.

The entire layout of the terminal area and its dimensions can be found in 'Appendix W: Technical Drawings', drawing number W8.

P.3.8 CONNECTION TO INFRASTRUCTURAL NETWORK

The ferry terminal will have to be connected to the infrastructural network of the city to ensure that the logistic processes will be safe and quick. This connection should be designed with the complex traffic processes at the intersections of the Avenida del Puerto with Arroyo and Jesus Lopez taken into account. This design will be discussed in 'Appendix Q: Design of the connections to the network'.

P.3.9 SAILING SCHEDULE

It is assumed that the connection with Key West will be performed during the day, while the other services will consist of overnight trips. The sailing schedule will be discussed in more detail in 'Appendix R: Design of nautical infrastructure'.

P.3.10 FENDER DESIGN

Fenders are used to transmit impact energy generated by vessels to the berth structure. This process must be performed in a safe and comfortable way and damage to either the quay or the vessel has to be prevented. The kinetic energy from the vessel is partially absorbed by the fender and partially returned to the vessel that, as a result, is pushed back.

Fender structures must be designed integrally with both the design vessel and the berth structure. The equipment of the ferry must match the fender structure and mooring forces must be transferred to the berth structure in a good way. Damage to the vessel, berth structure or fender itself is not allowed. The resulting costs due to required repair and delays will be unacceptable, particularly in case of a ferry line.

Fenders must be able to handle impact energies in two different stages. These are the mooring stage and the berthed stage. The mooring stage is defined as the process of coming to a standstill from the approaching speed. The kinetic energy of the sailing vessel is then absorbed by the fender structure. At the berthed stage the fender must be able to handle impacts due to wind, waves and currents in a storm. As the hydrodynamic analysis shows, currents are of minor importance and are therefore neglected in this assessment. Only wind pressure and wind induced waves are considered here.

Pre-selection

Fenders are manufactured by many companies. Which to choose is dependent on site conditions, costs, energy absorbance method, mounting method and the mooring manoeuvre itself. The different fender types will not be discussed here. D-shaped types of fenders are recommended to be applied as they have the following advantages:

- Long term durability for frequent mooring
- High loading capacity
- Cost efficient

The fenders manufactured by the company Longwood are applied since this company provides the information required in their brochure. The system is depicted in figure P.13.

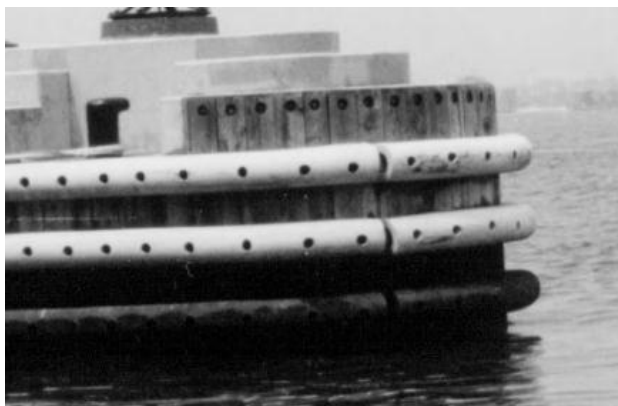


figure P.13 – D-shaped fender

Which specific dimension type of D-shaped fender should be applied, is dependent on the behaviour on both the mooring and berthing impact. These impacts are considered in the following.

Mooring impact

The kinetic energy from a mooring vessel depends on the design vessel characteristics, approach speed and angle, berth layout and specific fender characteristics and is calculated by the following equation

The mooring energy is calculated by the kinetic energy equation multiplied by several case dependent coefficients. This formula reads as follows (PIANC, 2002):

$$E_d = \frac{1}{2} * M_S * v^2 * C_E * C_M * C_S * C_C$$

with:

E_d = Design energy to be absorbed [kNm]

M_S = Mass of the vessel [ton kg]

v = Approach velocity [m/s]

C_E = Eccentricity factor [-]

C_M = Virtual mass factor [-]

C_S = Softness factor [-]

C_C = Berth configuration factor [-]

The Damen Fast Ropax 6016 is selected as the design vessel in 'Appendix G: Nautical analysis'. The mass of this vessel is not known a priori. The mass of the vessel is calculated by the equilibrium of the buoyant force and the gravitational force of the vessel, using the Archimedes principle. The buoyant force is equal to the gravitational force of the displaced volume of water. This volume is approximated by calculating the water displacement of the vessel (Vrijling, et al., 2011):

$$M_S = C_B L B D \rho_w = 0.65 * 60 * 16.2 * 2 * 1025 = 1195.6 \text{ ton}$$

With:

$$C_B = \text{Block coefficient [-]}$$

The block coefficient has a value of 0.55-0.65 dependent on the specific ferry vessel; in this stage 0.65 is conservatively assumed.

It is stated that this is a rough estimation as the block coefficient of this particular type of vessel is not known. This approach is however considered applicable since it yields an upper limit and is therefore expected to be safe.

The approach speed is determined by methods described in PIANC (2002). Mooring must be able to take place in moderate conditions as the harbour authorities prohibit sailing in unfavourable conditions. For this situation a maximum approach speed of 0.45 m/s with tug assistance is prescribed. As it is also desired for ferries to moor without tug assistance (in relatively calm conditions) the approach speed is assumed higher. It is stressed however that approach speed is squared in the formula thus has a quadratic effect on the design energy. As a result a too high assumption for the approach speed may yield unrealistic values for the design energy. The range of the approaching speed reaches to a maximum of 0.60 m/s for unfavourable conditions with tug assistance. This speed is here assumed as the maximum approach speed in moderate conditions without tug assistance. The assumed speed of 0.60 m/s is considered applicable in this preliminary design as it is considered as a safe and hence conservative assumption.

The eccentricity factor takes the effect of angular berthing into account. In order to calculate this coefficient extensive formulas are developed. However, for this assessment, use is made of figures prescribed by a report by PIANC (2002). For ferries mooring at a continued fender system a value for C_E of 0.5 is prescribed.

The 'virtual mass factor' C_M takes the mass of the water into account that is displaced by the vessel when the vessel moors. C_M is calculated as the ratio of the mass of the vessel plus the mass of the displaced volume of water and the mass of the vessel. The virtual mass is now calculated by using two formulas, first is given by Shigeru Ueda (PIANC, 2002):

$$M_v = \rho * L * D^2 * \frac{\pi}{2} = 1025 * 60 * 2^2 * \frac{\pi}{2} = 386.4 \text{ tons}$$

This yields a value for C_M of:

$$C_M = \frac{M + M_v}{M} = \frac{1195.6 + 386.4}{1195.6} = 1.32$$

The average value of these two calculations is 1.26. The second formula applied is given by Vasco Costa (Vrijling, et al., 2011):

$$C_M = 1 + \frac{2 * D}{B} = 1 + \frac{2 * 2}{16.2} = 1.25$$

According to these calculations a value of 1.32 is conservatively assumed for C_M .

The softness factor C_S takes the elasticity of the fender into account when compared to the ship's hull. This factor is dependent on the relative size of the vessel and the chosen fender type. According to PIANC a value of 1.0 is assumed. This means all energy is absorbed by the elastic deformation of the fender and no energy is absorbed by plastic deformation of the ship's hull.

The berth configuration coefficient C_C takes account for the type of berth, either an open jetty structure or a closed quay structure. For the closed structure of both the quay and pier the value of this factor is prescribed as 0.9. This implies the mooring impact is mitigated by the cushion that is formed by the confined volume of water in between the vessel and the quay.

The design mooring energy is determined by:

$$\begin{aligned} E_d &= \frac{1}{2} * M_S * v^2 * C_E * C_M * C_S * C_C = \frac{1}{2} * 1195.6 * 0.6^2 * 0.5 * 1.32 * 1.0 * 0.9 \\ &= 127.8 \text{ kNm} \end{aligned}$$

This energy of 127.8 kNm is the energy to be absorbed in moderate conditions. However higher mooring impacts could occur as a result of for example mishandling, malfunction or exceptionally adverse winds. The abnormal impact factor is dependent on many aspects that are not explained here. For ferry vessels a factor of 2.0 or higher is recommended. This yields abnormal mooring forces of 255.6 kNm could occur. Even higher impacts may occur, however these are not considered here. It is not practical or economically attractive to design for these exceptional impacts. As a conclusion the fender must be able to absorb mooring impacts with energy of 256 kNm.

Berthing forces

Winds, currents and waves produce forces acting on a berthed vessel. These forces are transmitted on the quay wall through a connection with a mooring line and a bollard or cleat. Because little movement of the fast ferry is permitted when it is berthed, the connection should be as tight as possible.

The situation with the highest berthing forces occurs during a storm from the north-east with a sudden wind blast from the south, perpendicular to the orientation of the ferry.

Wind load

The wind load acting on a vessel depends on the wind speed and the frontal area of the vessel and is given by:

$$F_w = \frac{1}{2} C \rho A_w u_{10}^2$$

with:

A_w = frontal area of the vessel perpendicular to the wind direction [m²]

u_{10} = wind speed at 10 m elevation [m/s]

ρ = air density (= 1.28 kg/m³)

C = wind force coefficient [-]

The wind force coefficient C corrects for the shape of a vessel and the conversion of the wind speed to the elevation of the ship. These values of C are determined for different types of vessels, particularly for relatively large ships (Oil Companies International Marine Forum, 1994). These values are however not known for relatively small vessels such as a fast ferry. A conservative value of $C = 1$ is therefore taken in this case to estimate the maximum wind load.

The dimensions of the Damen Fast Ropax 6016 above water level are roughly 60x16.2x10 m³. The transverse and longitudinal frontal area can therefore be given by $A_{w,t} = 162$ m² and $A_{w,l} = 600$ m².

The wind speed with a return period of 50 years is taken as the design conditions. According to paragraph 'H.4 Wind conditions', this corresponds to a wind blast speed of 44 m/s.

The conditions given above results in a wind load on the ferry of $F_{w,l} = 743$ kN = 76 tons for a longitudinal wind and $F_{w,t} = 201$ kN = 20 tons.

Wave load

A berthed vessel is subjected to wave forces in a situation with incoming waves from the northeast. In this situation the ship is berthed, with its bow facing the northeast.

To compute the wave force on the berthed vessel the method of Sainflou is used. This method is originally used to compute the total wave forces on a wall, but is adapted to be applied on a berthed vessel. The wave input for this method is derived from 'Appendix J: Hydrodynamic analysis – Preliminary investigation - Waves'. An internal wave with a return period of 50 years is used, which has a significant wave height of 1.33 m and a peak period of 3.93 m.

In this adaption of the Sainflou method, the wall is replaced by a ship (figure P.14). The main difference is that the ship has a limited draught of only 2 m. For simplicity, it is assumed that the same computation is still valid for this case.

The computation is as follows:

$$h_0 = \frac{1}{2} k H_i^2 \coth(kd) = 0.23 \text{ m}$$

$$p_1 = \rho g H_i = 13.4 \text{ kN/m}^2$$

$$p_0 = \frac{\rho g H_i}{\cosh(kd)} = 7.3 \text{ kN/m}^2$$

In which:

- $d = 5.5$ m, the local water depth
- $k = \frac{2\pi}{L} = 0.22 \text{ m}^{-1}$, the wave number, with $L = \frac{gT^2}{2\pi} \tanh(kd) = 29$ m (for a transitional water depth)
- $H_i = 1.33$ m, the incoming wave height.

The resulting force is acquired by computing the surface area of the pressure region and multiplying it by the width of the ship (16.2 m). This yields a wave force of **543.2 kN**.

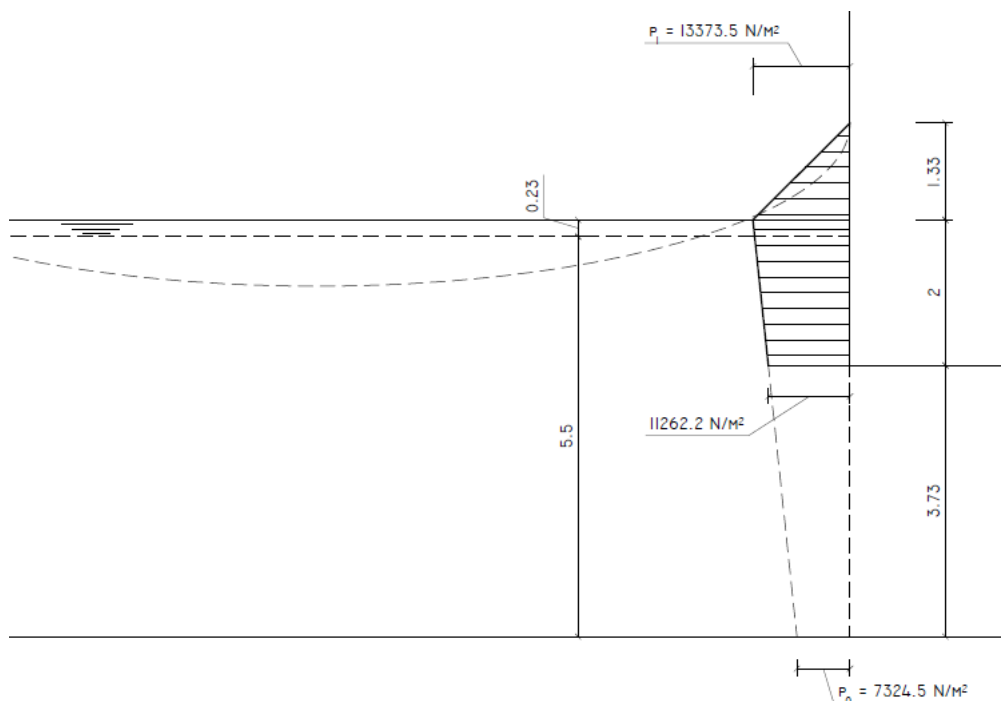


figure P.14 - adapted Sainflou method for a berthed vessel

Current load

According to 'Appendix I: Hydrodynamic analysis – Delft3D-FLOW' no current occurs at the location of the ferry terminal.

Conclusion

Because the wave load is in the direction of the ferry terminal, these forces will be acting on the fender structure and not in the mooring lines and on the bollards. Therefore, only the wind forces perpendicular to the orientation of the vessel are taken in consideration to determine the design forces acting on the bollards. The total force that will act on the quay wall is therefore 76 tons. This force will be divided over four mooring lines and bollards (figure P.15), which will mean an estimated pulling capacity of 19 tons is required for the bollards.

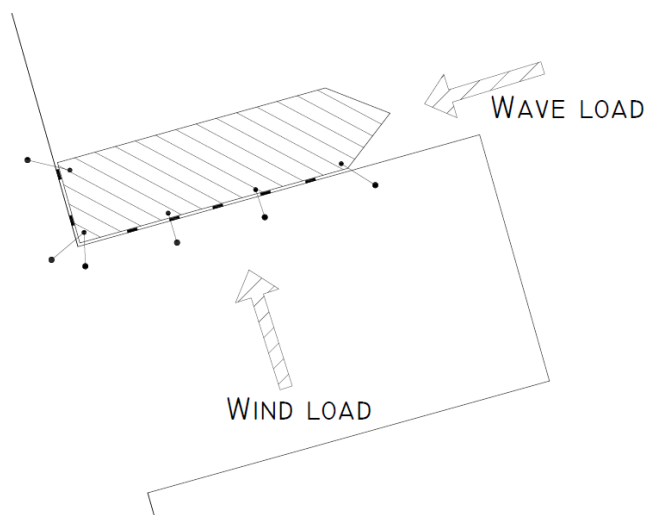


figure P.15 – loads acting on a berthed vessel

Fender selection

According to the above, the selected fender must be able to handle reaction forces of 743 kN and absorb impact energy of 256 kNm. Highest reaction forces will be created at the fenders that support the stern of the vessel.

Impact energy is converted into a reaction force by the fender as follows:

$$E_d = R_m * f * d_m \quad (\text{PIANC, 2002}), \text{ where:}$$

- E_d = design mooring energy [kNm]
- R_m = reaction force [kN]
- f = absorbing factor [-]
- d_m = maximum fender deflection [m]

The product of the energy absorbing factor and the maximum deflection can be interpreted as a spring constant. This characteristic is entirely dependent on the type of fender and thus on the manufacturer. In figure P.16 the spring mass system is depicted to schematize the mooring process. Disregarding damping is assumed safe in a preliminary design and thus all kinetic energy is transformed into potential energy: displacements and forces (Vrijling, et al., 2011). This approach leads to an upper limit of the reaction force.

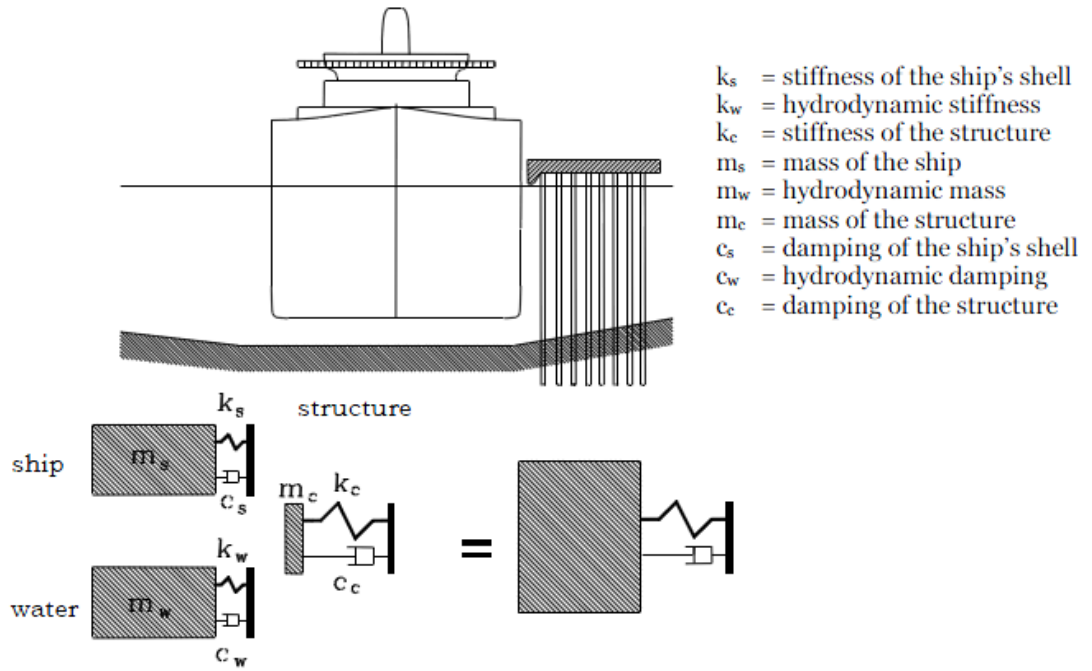


figure P.16 – spring-mass system (Vrijling, et al., 2011)

The relation between both load and energy and the corresponding deflection are given by the curves depicted in figure P.17 and figure P.18 (Longwood, 2012). Different D-shaped fender dimensions can be considered using these figures.

To determine the type of fender, the load of 743 kN has to be converted to the form used in figure P.17. This is done by dividing the load by g and the beam of the vessel, which yields a 'load' of 4.7 tons/m. For the maximum berthing impact of 743 kN, a the deflection is 3.5 centimetres for all given dimensions of the D-shaped fender.

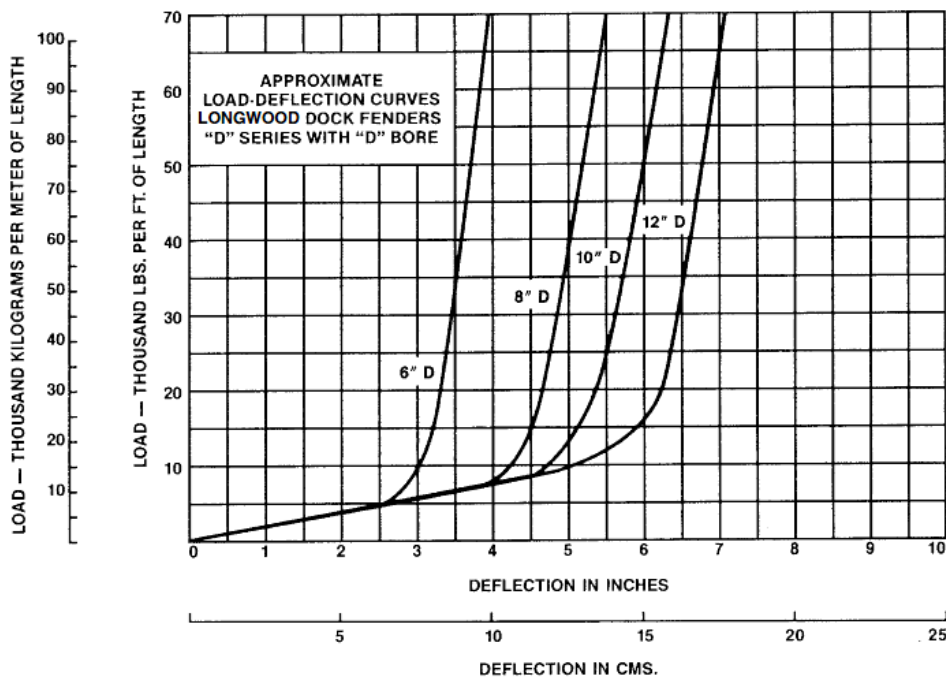


figure P.17 – load deflection curves

For the maximum mooring impact of 256 kNm, converted to 1.6 tons, the 12" type is chosen. For this type the deflection is 16.3 cm. This deflection leads to a reaction force of 1 571 kN. The performance of these larger types could offer better solutions for the fender design.

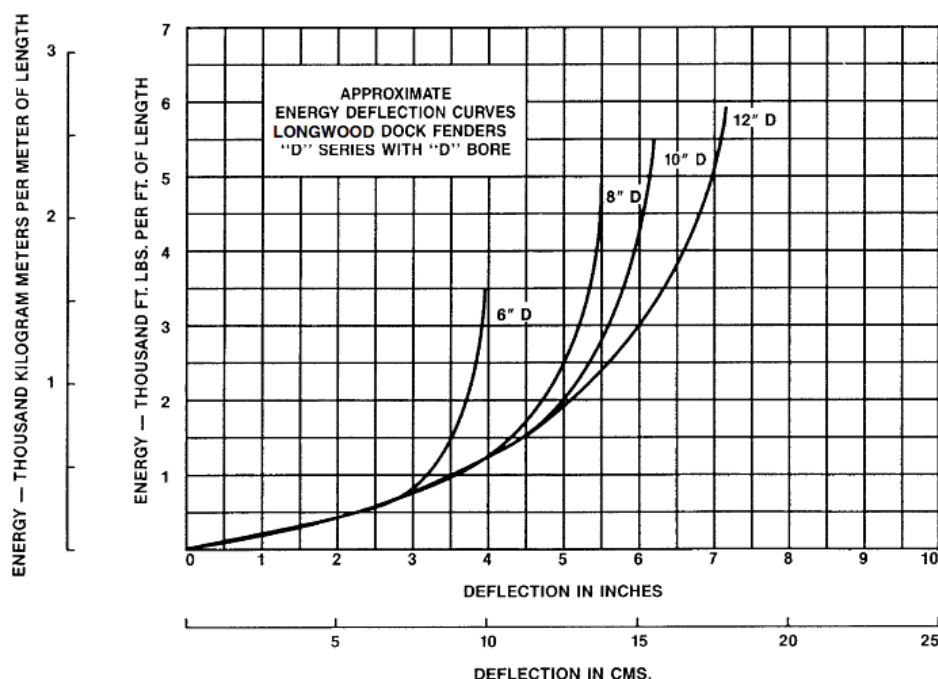


figure P.18 – energy deflection curves

Fender dimensions data for specific types of the D-shaped fender with a D-shaped bore are given in figure P.19.

SIZE		A HEIGHT		B WIDTH		C BORE		APPROX.	
IN	MM	IN	MM	IN	MM	IN	MM	LBS/FT	KG/M
3	76	2 ⁵ / ₈	67	3 ³ / ₈	81	2 ³ / ₈	60x41	2	3
4	102	4	102	4	102	2x2	51x51	5	8
4 ¹ / ₂	114	3 ⁷ / ₈	98	4 ⁷ / ₁₆	113	2 ¹⁵ / ₁₆	75x41	6	9
5	127	5	127	5	127	2	51x51	10	14
6	152	6	152	6	152	3	76x76	12	18
8	203	8	203	8	203	4	102x102	22	33
10	254	10	254	10	254	4	102x102	38	57
12	305	12	305	12	305	6	152x152	49	73
14	356	14	356	14	356	7	178x178	67	100

figure P.19 – D-shaped bore specific data

From the calculations above the 12" type is recommended to be applied. However, it is stated that this decision is based on a preliminary design process containing many uncertainties and assumptions. It is therefore strongly recommended to perform detailed studies in order to reconsider the selection.

Computer programs are usually applied to get more insight in fender behaviour. In these programs a range of input can easily be studied to get insight in the sensitivity of several parameters. In this way a lot of information on the fender behaviour is obtained that will make the decision more reliable. It is also recommended to

perform calculations from a probabilistic point of view to learn about uncertainties, sensitivity and failure probabilities.

Improvement of the design can be achieved by recalculating the exact mass of the vessel. Also, the influence of temperature fluctuations should be investigated.

P.3.11 STRUCTURAL DESIGN OF THE PIER

In this section, a preliminary design will be given for the pier. Because of the rather low water depth in the most south-western part of the Atarés basin and the relatively low forces acting on the pier, a standard type caisson seems a good structure at first glance. Moreover, low costs for the structure combined with relatively easy transportation give this option more advantages. The standard caissons are prefabricated and subsequently transported over water, where they will be immersed on their final location.

Other possible options are the use of L-type walls or sheet pile walls. The latter is not preferred because of the rocky bed material and the use of L-walls is considered more expensive and 'over powered' for this design. Therefore, it can be reasoned that for this case, a standard type caisson seems to be a feasible structure.

Height

The height of the caisson is the first property to determine, as it is directly coupled to the top level of the final structure. There is a limitation to this height because of the usability of the pier. It must be possible for the incoming vessels to (un)load cars at all times, but on the other hand, the pier needs to have a certain height to remain dry. The required height of the caisson to remain dry is a result of the water depth, tidal elevation, wind set-up, sea level rise and the required freeboard.

A typical design condition is during a storm with a return period of once a year with an average wind speed of 21.7 m/s, see also paragraph 'H.4 Wind conditions'. During this storm the ferry terminal is not operational, but it is preferred that the pier itself remains dry. The once per year storm seems a rather low design value. However, the focus is on the usability state of the pier. Flooding of the pier during extreme case scenarios is of less importance, because the failure of the structure is not coupled to flooding of the pier. The pier becomes simply not operational during this extreme case, but during such storms the ferry terminal is not operational anyway. In 'Appendix K: Hydrodynamic analysis – SWAN', it is determined that significant wave heights of 0.71 m occur with a peak period of 2.96 s in the south-western part of the bay during this 'once per year storm'.

Local depth

From figure P.10 it can be seen that the local water depth at the location of the pier is 5 m with respect to MSL. The depth is irregular in this part of the bay and before the caisson can be placed, the soil layer needs to be flattened to be as horizontal as possible.

Maximum tidal elevation

In paragraph 'H.2.3 Tidal analysis', a maximum tidal range of 0.66 m was found. This means an elevation of water of $0.66/2 = \underline{0.33 \text{ m}}$ above still water level.

Wind set-up

The wind set-up in the bay can be calculated with the formula:

$$W = c \frac{u^2}{gd} F$$

in which c is a friction coefficient with a value of $4.0 \cdot 10^{-6}$. From paragraph 'J.2 Determination of internal waves' it was determined that the fetch F in north-eastern direction is approximately 3 730 m with an average depth (d) of 10 m. Using the wind speed (u) of 21.7 m/s, a wind set-up of 0.07 m is found.

Sea level rise

In paragraph 'H.2.2 Sea level rise' it is determined that in 50 years (design lifetime of the ferry terminal), a sea level rise of 0.175 m can be expected.

Freeboard

A freeboard is necessary to reduce overtopping from occurring waves. With the calculation tool in the overtopping manual (EurOtop, 2007), it is possible to determine the overtopping discharge rate. The caisson has been schematised as a vertical wall (figure P.20). The overtopping rate is dependent on the local water depth, wave period, incoming significant wave height and freeboard.

With the values determined above and a chosen freeboard of 0.8 m, the resulting mean overtopping discharge rate of about 9.8 l/s/m has been obtained. With respect to equipment and machinery on the structure, 10 l/s/m is considered a maximum overtopping discharge (Voorendt, et al., 2011). Hence, a freeboard of 0.8 m is adequate for design.

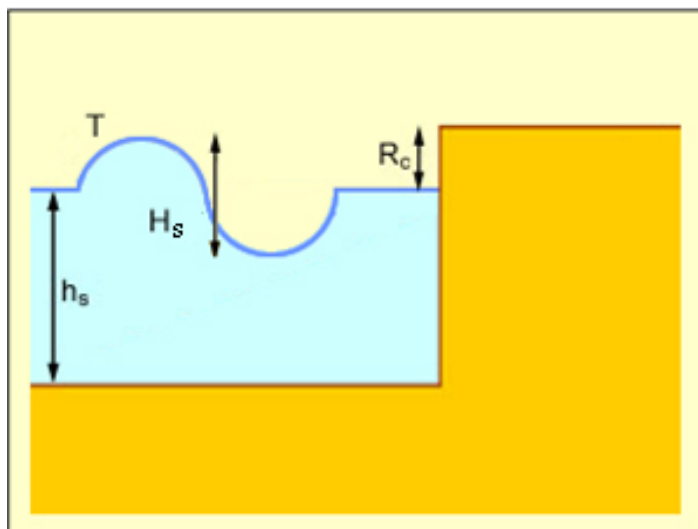


figure P.20 – caisson schematised as a vertical wall

The total height of the structure becomes:

5 m (depth) + 0.33 m (tidal elevation) + 0.07 m (wind set-up) + 0.175 m (sea level rise) + 0.8 m (freeboard) = 6.375 m \approx **6.4 m**.

In this case however, the height of the pier seems to be determined by the usability of the pier. Two classes of ships can use a fixed ramp: 'class A' are ships equipped with ramps which can reach levels from 0.25 to 1.75 m above still water level, and 'class B' ships can reach 1.5 to 3.0 m (PIANC, 1987). The Fast Ropax 6016 is considered to be a 'class A' ship. For a fixed land ramp, the angles as depicted in figure P.21 are recommended. This means that the maximum height of the caisson

should be 1.75 m above low water level. With a low water level of $5 - 0.33 = 4.67$ m, this means that the maximum height of the structure becomes 6.42 m.

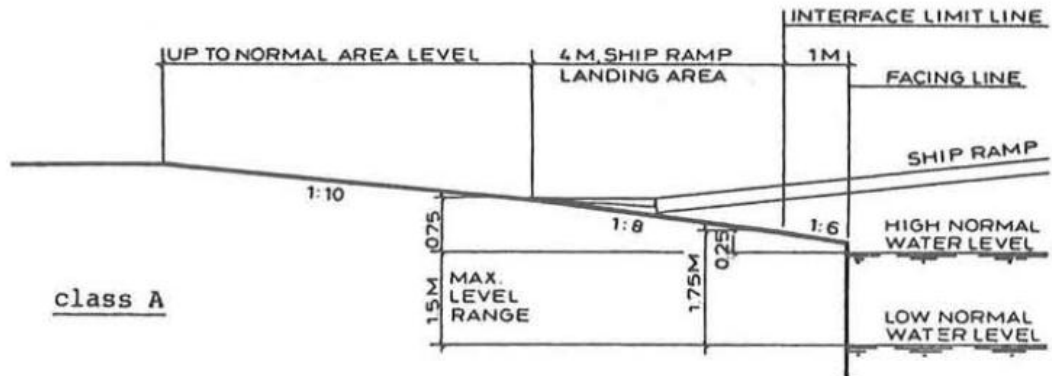


figure P.21 – recommendations for fixed ro/ro ramps (PIANC, 1987)

With the predicted high water level during operation of 5 m depth + 0.33 m tide + 0.175 m sea level rise = 5.51 m, the minimum height of the structure becomes 5.76 m.

A height of the structure at the facing lane of 6.4 m is therefore chosen. This means that, with the angles given in figure P.21, the height of the structure at the landside of the ship ramp landing area will be 7.1 m. The length of the part up to normal area level with a slope of 1:10 will be around 4 m, which means a total height of the caisson of **7.5 m**.

Estimating main dimensions

For the considered type of caissons, the floating phase often appears to be governing for the caisson width. This is because during floatation there should be equilibrium between the buoyant force and the weight of the caisson. Using the previously determined caisson height, the minimum required keel clearance during transportation (1 m), and a yet to be determined length–width ratio, the main dimensions of the caisson can be estimated.

A length–width ratio of approximately 3:1 is a good ratio for navigational purposes (Voorendt, et al., 2011). Therefore, values close to this ratio are preferred. The total length of the pier is 75 m and the width is 46 m. If one assumes to cover this width with 4 caissons, each caisson will be $46/4 = 11.5$ m in width. Also, the length of 75 m will be covered with 2 caissons. The length will be $75/2 = 37.5$ m each. The length to width ratio will then be 3.26:1, which is considered a ‘good’ ratio for navigational purposes. The next step is checking if the actual draught (d) of the caisson is less than the maximum allowable draught of the caisson. The draught of the caisson is limited by the required minimum keel clearance and this implies that the buoyant force should be large enough. This force (F_b) can be determined by computing the under-water volume of the caisson:

$$V_{uw} = b * l * d = 11.5 * 37.5 * d \quad [m^3]$$

The buoyant force can then be calculated by:

$F_b = V_{uw} * \gamma_w = 11.5 * 37.5 * d * 10$ [kN], in which d is the unknown draught parameter.

The maximum allowable draught has to be determined for various situations. In this report, two situations are examined; transportation and positioning.

- The transportation will take place during high water and the minimum water depth on the transportation route is 5.33 m (near the final location). When applying a keel clearance of 1 m, the maximum allowable draught (d) is 4.33 m.
- During positioning, manoeuvres will be more careful, resulting in a keel clearance of 0.5 m. During MSL, the depth is 5 m and the resulting maximum allowable draught is 4.5 m.

To compute the draught of the caisson, the weight of the caisson has to be determined first. This can be done by assuming a certain thickness of walls and bottom slab. A wall thickness t_w of 0.50 m and a bottom thickness of $t_b = 1.00$ m will be assumed. In this case, a roof is not necessary and the weight of the caisson will be:

$$F_w = \{l * b * h - (l - 2t_w) * (b - 2t_w) * (h - t_b)\} * \gamma_c$$

All dimensions are known and by using a γ_c one can obtain the weight of the caisson. The result is $F_w = 18\,581.25$ kN

The force equilibrium holds: $F_w = F_b \rightarrow 18\,581.25 = 11.5 * 37.5 * d * 10$, which results in a draught of 4.31 m. This is less than the maximum allowable draught and these dimensions can be used for further evaluations.

Summarising, one pier consists of 8 caissons of 37.5 x 11.5 x 7.5 (LxBxH) each. The pier will be compounded of 2 caissons to cover the length and 4 caissons to cover the width.

Total weight of caissons

In this section the total weight of the caissons will be calculated when the caissons are fully ballasted with sand. After this, the shear criterion will be checked.

The weight of one caisson is 18.58 mN. This means that the weight of eight caissons is $8 * 18.58 = 148.6$ mN. This is without headwalls, so an additional amount of $8 * (10.5 * 6.5 * 1) = 0.55$ mN needs to be added. The total weight of the eight caissons combined becomes **149.15 mN**.

When assuming that these caissons are fully ballasted with sand, the total amount of sand needed is: $8 * 10.5 * 36.5 * 6.5 = 19\,929$ m³. When using a ρ_{sand} of 2650 kg/m³, a total weight of **518.1 mN** has been found.

There is also a buoyancy force acting on the bottom surface of the caissons. The average water pressure below the caisson is equal to: $\rho * g * d = 1025 * 9.81 * 5 = 50.28$ kN/m². Multiplying this value by the total surface area of the bottom results in: $50.28 * 46 * 75 = 173.5$ mN.

The resulting total weight is then given by: $149.15 + 518.1 - 173.5 = 493.65$ mN.

Total horizontal forces

In section P.3.10, a fender force of 1 571 kN has been determined. This force is 'located' at a level of 1 m above still water level (6 m above the bottom). It is also possible that during mooring of the ferry, the bow thrusters are needed. This high velocity nozzle can result in a significant force acting on the pier. In 'Appendix G: Nautical analysis', a velocity of $u = 41.3$ m/s has been found with a nozzle diameter of 0.75 m. The force that will be exerted on the pier can be calculated with the formula:

$$F = \frac{1}{2} \rho u^2 * A = \frac{1}{2} \rho u^2 * \pi r^2 = 0.5 * 1025 * 41.3^2 * \pi * \left(\frac{0.75}{2}\right)^2 = 386 \text{ kN}$$

This force is acting two metres below water level (3 m above the bottom).

Because there is no water level difference over the caissons, the resulting water pressures can be neglected in this approach. The total horizontal force is then:
 $1\,571 + 386 = \mathbf{1939 \text{ kN}}$.

Moments

The horizontal forces are creating a momentum around the point in the middle of the caisson, located at the bottom of the structure. The fender force of 1 571 kN is acting 6 m above this point. This results in a momentum of $1\,571 * 6 = 9.5 \text{ mNm}$. The horizontal force originating from the bow thrusters is 386 kN and is acting 3 metres above the centre of rotation. This results in a momentum of $386 * 3 = 1.2 \text{ mNm}$. These moments have the same direction (clockwise) and can therefore be added. The resulting moment (clockwise rotation) is **10.7 mNm**.

Shear criterion

The horizontal forces are supported by the friction force created at the interface of the caissons and the sub layer. This friction force is dependent on the vertical force of the structure. The required resultant vertical force must be greater than the horizontal forces divided by the friction factor. For the preliminary design the friction factor is assumed to be 0.5 in the case of a concrete caisson on sand or stone. The shear criterion is tested using:

$$\sum F_v > \frac{\sum F_h}{f} \rightarrow \sum F_v > \frac{2.0 \text{ mN}}{0.5} \rightarrow \sum F_v > 5.34 \text{ mN}$$

The resultant vertical force of the structure is 494 mN, hence the horizontal stability of the structure is guaranteed.

Turn-over criterion

For the stability of these caissons, it is required that the soil should not have to exert tensile stress. The adhesive and cohesive properties of sand are very poor, so this tensile stress cannot be provided by the subsoil. Therefore, it is usually stipulated that the soil stresses necessary for rotational stability may only be compressive. This is the case if the resulting action force intersects the core of the structure. This core is defined as the area extending to 1/6 of the structures total width, (Vrijling, et al., 2011). The criterion becomes more critical if ΣM is maximum and if ΣV is minimum. ΣM must be calculated around the point in the middle and at the bottom of the structure.

$$e_R = \frac{\Sigma M}{\Sigma V} \leq \frac{1}{6} * b \rightarrow \frac{10.7 \text{ mNm}}{494 \text{ mN}} \leq \frac{1}{6} * 46 \rightarrow 0.022 \leq 7.67$$

in which b is the width of the structure.

From this it is clear the stability for turning over is guaranteed as well.

P.4 IMPRESSIONS

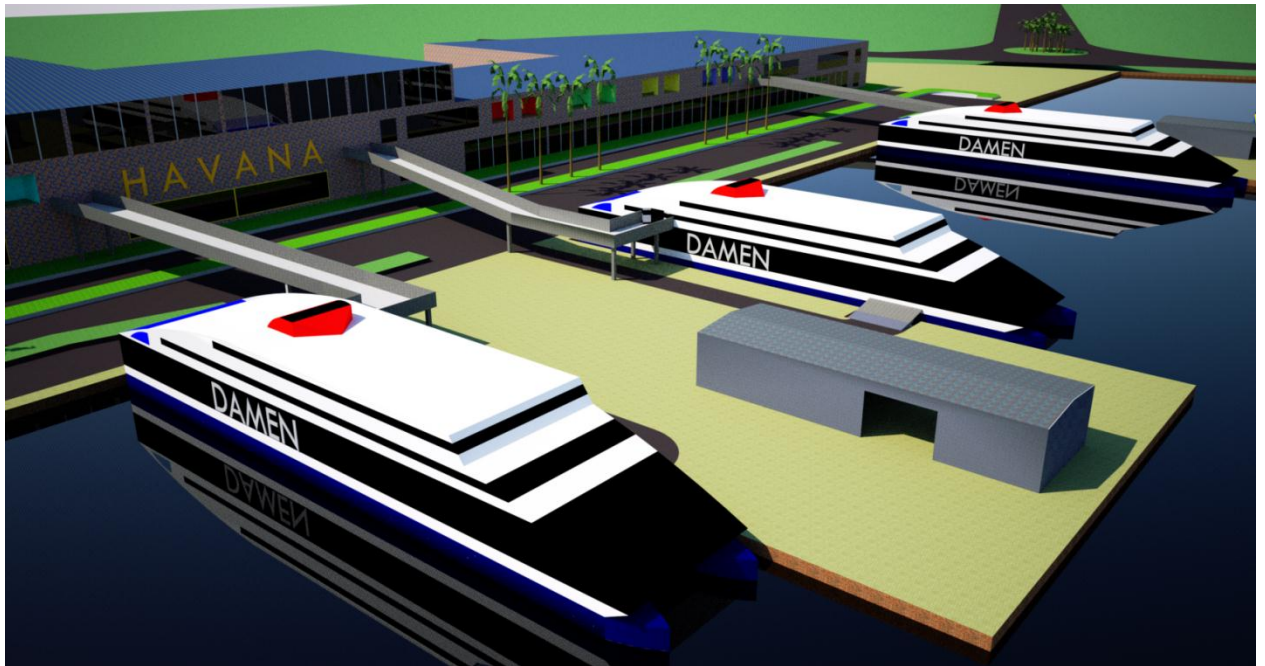


figure P.22 – artist impression ferry terminal (1)



figure P.23 – artist impression ferry terminal (2)

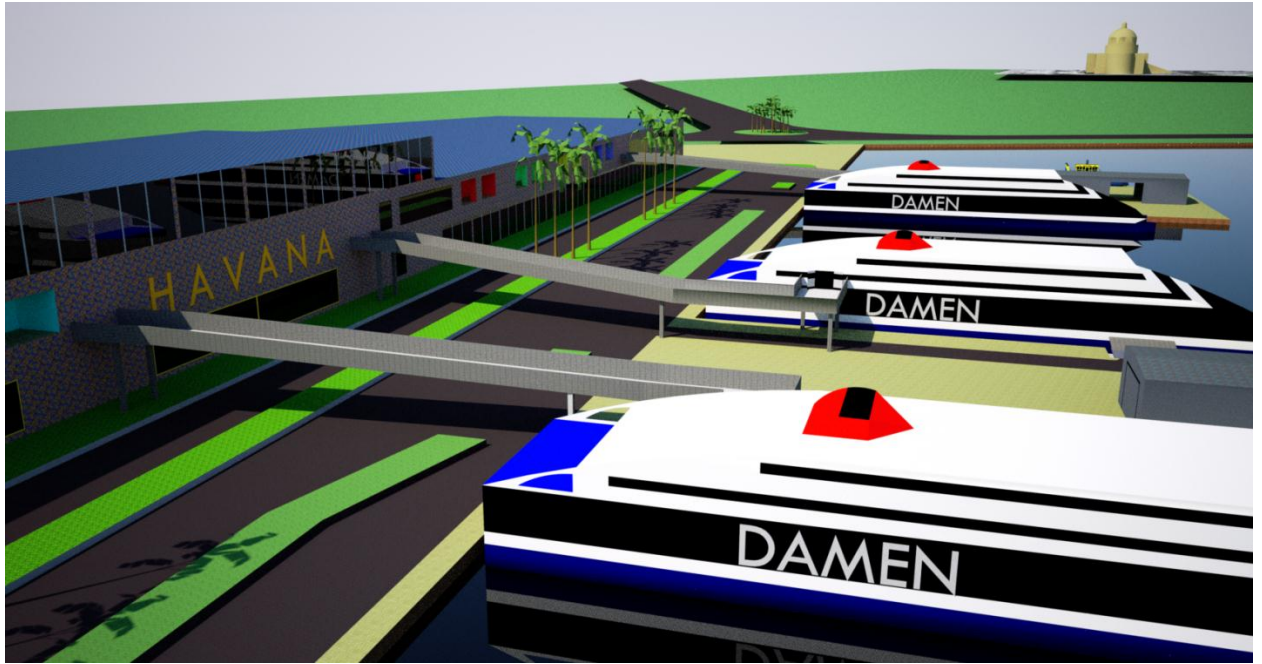


figure P.24 – artist impression ferry terminal (3)

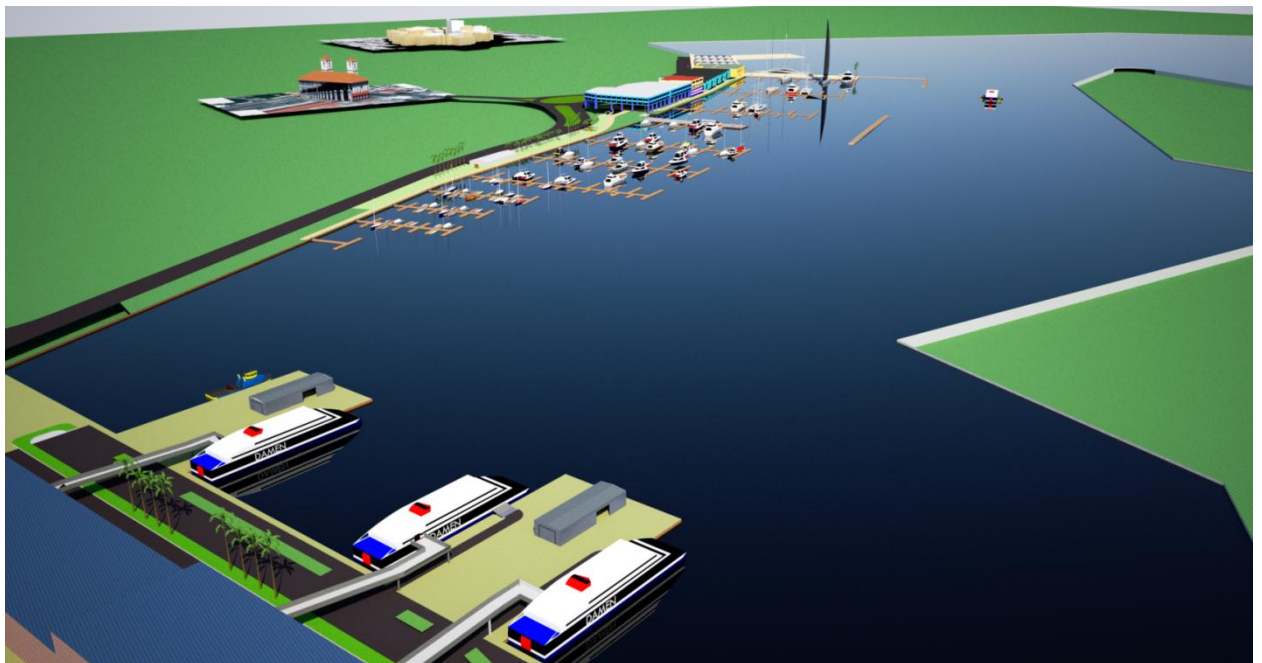


figure P.25 – artist impression ferry terminal (4)

P.5 CONCLUSIONS AND RECOMMENDATIONS

P.5.1 CONCLUSIONS

The ferry terminal will have two mooring places at one pier for the daily connections to Key West and Havana. A second pier will be used to accommodate a third mooring place for the connection with a weekly service to Tampa, Cancun and Nassau. These piers will be connected to the quay that is currently in use by the Terminal Osvaldo Sanchez.

Sufficient space is available on this terminal to construct a two-story terminal building and to accommodate the logistic processes on the terminal.

The nautical infrastructure, as will be discussed in 'Appendix R: Design of nautical infrastructure', will be more than sufficient for the use of ferries. A turning basin with a diameter of 120 m will be located in front of the ferry terminal to make the required turning manoeuvres of the ferries possible.

The ferries will be berthed in a so-called corner berth lay-out with a fixed ramp as a ship to shore method. Multiple caissons with the dimensions of 37.5x11.5x7.5 m³ will be used to construct the piers and the fixed ramp. A supply storage building, marshalling area and an apron will be located on the piers. The berthing direction will be parallel to the direction of the prevailing winds.

The (un)loading of the vehicles will take place via the side ramp of the ferry in order to concentrate the traffic movement on the piers instead of the quay. Arriving vehicles should pass through passport control and custom services before it will be allowed to leave the terminal. The connection to the infrastructural network of the city will be made with the Avenida del Puerto, which will be discussed in 'Appendix Q: Design of the connections to the transport network'.

The terminal building will accommodate all required facilities for departing and arriving customers of the ferry terminal. A forecourt with places for short-term parking and bus and taxi stops will be the connection of the building with the infrastructural network. The design of the lay-out of all on-land facilities is given in 'Appendix W: Technical Drawings, drawing number W8'.

Bollards should be placed in a lowered position in the quay to decrease the hindrance to the traffic on the aprons. These bollards should have a pull capacity of at least 19 tons. Moreover, 12" D-shaped fenders will be required to stop the mooring vessel in a safe and comfortable way and to prevent damage of both the ferry and the quay structure.

P.5.2 RECOMMENDATIONS

The following recommendations are made:

Design of the terminal building

For the specific design of the buildings and overall terminal layout collaboration of engineer and architect is strongly recommended. The interaction between engineer and architect is vital for designing the terminal

Required capacity

A follow-up study is desired in order to gain more knowledge on the demanded sailing frequencies and thus required terminal capacities. By gaining this knowledge a more detailed design for the terminal can be proposed.

Mass of the vessel

The mass of the vessel was assumed by the dimensions given by the producer of the vessel and an estimation of the block coefficient. The exact mass should be investigated before the mooring and berthing forces are examined in more detail.

Approach speed

The approach speed of the ferry at the terminal was conservatively assumed. Experiences with similar vessels and conditions should give more information about the to be expected approach speed.

Fender study

The berthing and mooring forces are a complex combination of wind, wave and collision loads and should be examined in more detail to give a better conclusion about the required fender type.

It is also desired to study more fender types in depth. It is possible that other types offer better solutions.

Pier stability

The stability calculations show that the pier structure can provide sufficient support for mooring. Both the mooring energy impact and the thruster-forces can be absorbed in a safe way. Although the approach to check for stability is very rough, it is recommended to perform a more thorough study on the stability.

Application of caissons

The application of caissons is based on a very rough pre-selection. It is sensible to reconsider this selection. According to the calculations the structure appears to be rather heavy. It is possible a less expensive, more slender design will also fit.

Filling of the caissons

In the design it is assumed that the caissons are completely filled with sand. To provide stability this seems unnecessary. It is therefore possible to house facilities inside the caissons.

Internal stability of the pier

A study must be performed on the internal stability and transfer of forces in the pier elements. The reinforcement of the concrete and the connections of these elements must be calculated.

Appendix Q: DESIGN OF THE CONNECTIONS TO THE TRANSPORT NETWORK

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Q.1 INTRODUCTION

This appendix discusses the design of the connections of the marina and ferry terminal to the network of Havana. In 'Appendix E: Infrastructural analysis' the bottlenecks around the bay are identified. For the most important of these bottlenecks a road layout design has been made. The two most important intersections, Avenida del Puerto – Avenida de Belgica and Avenida del Puerto – Arroyo, coincide with the entrances of the marina, respectively the ferry terminal. Therefore these locations are designed as one. But before they will be discussed, first some general comments are made about the Avenida del Puerto itself. This is the main road around the bay and therefore very important for the distribution of the traffic from and to the marina and ferry terminal. Subsequently, the design variants for the connection of the marina and the ferry terminal are discussed. And finally, these variants are analysed with a Multi Criteria Analysis (MCA).

Q.2 AVENIDA DEL PUERTO

The Avenida del Puerto is an arterial road along the bay side. Its current characteristics are described in 'Appendix E: Infrastructural analysis', as well as the expected problems raised by increasing traffic. The adaption of the port facilities with the master plan Tourist Port Havana will have major consequences for the traffic on this road. Therefore it needs adaption to these developments in order to maximize the accessibility of the new facilities and minimize congestion in the area.

The Avenida del Puerto will entirely be arranged as a distributor road with a maximum speed of 50 km/h. This means that the road has a flow function on the road sections and a distribution function at the intersections. The number of connecting roads is minimized to the essential links, leaving out connections with minor grid roads. The traffic at these connections has to be rearranged to the Avenida del Puerto via other minor roads, minimizing the merging traffic on the main road and maximizing the capacity.

With the implementation of Tourist Port Havana the pedestrian flows will increase substantially. These flows will move along the bay side, into Habana Vieja and towards the Capitolio. These flows have to be accommodated on three meter wide pedestrian walkways on both sides of the Avenida del Puerto. The road itself will consist of at least two lanes in both directions along the entire Avenida del Puerto to ensure consistency in the capacity. This means that the section in front of the Sierra Meastra will be adapted. More detail on this section can be found in paragraph Q.2.2.

The current tradition of stopping cars, picking up passengers all along the road must be controlled to several locations where a pickup lane is situated. These short pickup lanes are implemented along the entire Avenida del Puerto to ensure a continuous flow on the two through lanes. Furthermore parking spaces will be situated on the sides of the road. Current parking in the central separator is banned for safety reasons as they generate unnecessary crossing of pedestrians.

Q.2.1 LINING AND SIGNAGE

The entire Avenida del Puerto will be fitted with extensive lining and signage to increase clarity and safety on the road. The maximum speed will be indicated regularly to keep a uniform speed on the road. This is increasingly important with the great diversity in vehicle characteristics on the Avenida del Puerto and in Havana in general as discussed in 'Appendix E: Infrastructural analysis'

Directions are indicated on both the road itself as on signs alongside the road. Furthermore the public transport lanes, pedestrian crossings and parking areas will be clearly indicated with both lining and signage.

It is of great importance that the lining and signage are implemented consistently and continually. This improves the safety on the road because of the increased predictability, as explained in paragraph 'E.5.2 Sustainable safety'. It is advised to implement the same lining and signage system in the entire city and not just in the project area. This will enlarge the benefits of increasing predictability.

Q.2.2 SIERRA MAESTRA TERMINAL

As described in 'Appendix L: Boundary conditions and design requirements', the section of the Avenida del Puerto at the Sierra Meastra terminal needs to satisfy special requirements. This part of the Avenida del Puerto has to deal with large pedestrian flows as it is situated between the cruise terminal Sierra Meastra and the tourist attraction Plaza San Francisco de Assis. More details about this location can be found in 'Appendix A: General Perspective of Tourist Port Havana' and 'Appendix C: Analysis of the surrounding area'.

The road layout will be changed from one lane to two lanes per direction and additionally a public transport lane per direction in the wider part of this road section. This lane will be dedicated to busses and taxis stopping to pick up or to drop off passengers. In between the two directions a central separator provides room for green areas and pedestrians halfway crossing the Avenida del Puerto. Trees along the road make sure tourists arriving with a cruise get a good first impression of Havana when getting off the boat. One large pedestrian crossing will transfer the main part of pedestrians from the terminal frontcourt to the Plaza.

Tourist facilities as money exchange, food stands and tourist information are situated on the city side of the road alongside the Plaza, next to the church. Bollards along the Plaza protect the pedestrians on the Plaza from the traffic on the Avenida del Puerto, indicating the end of the square.

Q.2.3 INTERSECTION WITH JESUS LOPEZ

The current intersection between the Avenida del Puerto and Jesus Lopez is a very unclear junction without clear lining and signage and with a dangerous crossing of the railway track. On the other side of the railway track the intersection between Jesus Lopez and Fabrica is located, creating a strong linkage between these junctions. More details on this intersection can be found in 'Appendix E: Infrastructural analysis'

The difficulty on this intersection is not the traffic flow, which is relatively small. The main problem is the traffic management. The only current management at this intersection is a bell ringing when a train approaches.

This problem is solved with a traffic management system, containing traffic lights that are coupled to those on the intersection between Jesus Lopez and Fabrica. Another application in this system is the blocking back prevention on Jesus Lopez. This makes sure that if the waiting traffic on Jesus Lopez reaches its capacity, the lights turn green for the traffic from Jesus Lopez. Because the waiting capacity on

Jesus Lopez is only about 30 cars, the greentimes of the two intersections have to be synchronized in order to avoid this situation.

This application of blocking back prevention can be overruled by another one. The railway track is included in this system, putting the lights on red for traffic crossing the rails and lowering the gates when a train approaches the intersection. This automatically implies a red light for the traffic moving from Fabrica onto Jesus Lopez towards the Avenida del Puerto.

With this traffic management system the safety is improved substantially but this at the expense of capacity for this link. This decrease in capacity is compensated with an extra lane for traffic waiting to turn left from Jesus Lopez onto Avenida del Puerto.

In addition to the traffic management, the layout changes as well. The possibility to move from Fabrica, left onto Jesus Lopez is currently not available. This movement is added to create the possibility to reach the ferry terminal from the northern section of Fabrica, improving the accessibility of the ferry terminal. By adding this movement a complete junction with all possible movements is created. This has effect on the traffic management as well, as combined green times have to be rearranged.

Q.3 MULTI CRITERIA ANALYSIS (MCA)

In order to analyse the different variants a Multi Criteria Analysis (MCA) is done. By using different criteria, ranked in importance with their own weight factor, the value of all variants is determined. First the design criteria are discussed and then the determination of the weight factors is shown. With these criteria and their weight factors both the marina as the ferry terminal is analysed and valued.

Q.3.1 DESIGN CRITERIA

The following eight will be used for the evaluation of the variants for both the marina connection as the ferry terminal connection.

Robustness

The robustness of the connection of the port facilities depends on the available routes from and to their location. If more routes are available then the accessibility logically increases. The robustness of the connection to the network is higher with more options as the port facilities are not dependent on a single access route.

Capacity

The capacity of the network around the port facilities, both the road segments as the junctions, should be able to handle the peak hour flows sufficiently in order to avoid congestion in this area, i.e. sufficient capacity should be available. Otherwise, traffic build up in front of the port facilities could block the entrance of the ferry terminal and the marina. But more important, the accessibility of the entire area will drop due to the congestion. This should definitely be avoided. Preferably the peak hour flow of 2060 can be handled without problems, but when this does cause problems with the current capacity, the adding of extra lanes as a capacity increase is not the only solution. Adding capacity to a road also attracts more traffic and therefore it might be better to use other measures. These measures could consist of the distribution of traffic over different routes or the implementation of one-way streets.

Clarity

The connections to the network should be clear to all traffic participators. In this way visitors of the port facilities can easily find their destination and reach it without hesitation. This can be achieved by a logical set up of the road layout and clear signing.

Safety

The safety of the road network is dependent on the road itself, the drivers and the vehicles. The road layout can have a big influence on the behaviour of the driver. It is important to adjust the road layout to the road users and vehicles using it. This way of looking at safety is called the Safe System Approach (SWOV, 2006). In this area there will be many Cuban drivers, used to the Cuban traffic, but also tourist, unfamiliar with the Cuban driving style, will be present in traffic. This causes diverse groups of road users, who should both be guided to their destination safely. Pedestrians deserve extra attention when it comes to safety as they are very vulnerable.

Flexibility

The flexibility of the design consists of two factors. The first is the possibility to adjust the design to new developments. For example, the addition of extra lanes, a bus stop or parking spaces could become desirable in the future. The second is the

flexibility in the planning of the construction. In the current situation, the required capacity is lower than the design capacity. It is however not easy to predict when this design capacity will be needed. The advantage of flexibility is for a great part an economic one. The current financial means in Cuba are not sufficient to adjust a larger part of the network at once. With a high flexibility, a part of the adjustments can be done later, depending on the developments. So a part of the investments will be postponed as well.

Hindrance during construction

The hindrance during construction can be very severe when important through roads are unavailable for long time. This could cause large disruptions in the surrounding network as drivers need to search for other routes. To minimize this hindrance, alternative routes should be available during construction. Another way to reduce hindrance is the use of the current infrastructure so less new connections and road segments have to be constructed.

Public transport

Public transport is an important traffic mode for transport from and to the port facilities. Both the marina and the ferry terminal need to be connected to the public transport network.

Complexity

The complexity of the solution naturally plays an important role in the decision. This component covers the complexity of implementation and the costs derived from this complexity. Since the connection of the marina and ferry terminal primarily has to satisfy the demands, the costs are implemented in the MCA instead of using a cost-benefit analysis. This method is also preferred because the costs, as well as the benefits, are hard to determine in this stage. Instead, the anticipated complexity per component is translated to a complexity valuation per variant, similar to the valuation of the other criteria.

Only the costs for the solution itself are taken into account, this means that costs for renovation of the current infrastructure is not. These costs are considered to be necessary without this project and are therefore not included.

Q.3.2 WEIGH FACTORS

These criteria are compared to each other in order to determine the importance of each individual criterion. When the criterion in a row is considered to be more important than the criterion in the column, it will receive a '1', while the less important criterion will receive a '0'. When a criterion has received no points, the total score of 1 will be assigned, while the total score of the other criteria will be doubled. Afterwards, the total points will determine the weigh factor of a criterion. The results are given in table Q.1. It is stressed that the comparison is made with the eyes and preferences of the client and not of the customer.

table Q.1 – determination of weight factors

	Robustness	Capacity	Clarity	Safety	Flexibility	Hindrance during construction	Public transport	Complexity	Total	Weight factor
Robustness	-	0	1	1	0	1	1	1	14	0.25
Capacity	1	-	1	1	0	1	1	1	10	0.18
Clarity	0	0	-	0	0	0	0	0	1	0.02
Safety	0	0	1	-	0	1	1	1	8	0.14
Flexibility	1	1	1	1	-	1	1	1	12	0.21
Hindrance during construction	0	0	1	0	0	-	1	0	4	0.07
Public transport	0	0	1	0	0	0	-	0	2	0.04
Complexity	0	0	1	0	0	1	1	-	6	0.11
Total									57	1.00

The criteria and their weight factors are listed in order of importance in table Q.2. Robustness is the most important criterion because the traffic flows will increase drastically in the coming years. This growth enlarges the chance for congestion and it is not ruled out that congestion will occur in the project area. Therefore alternative routes are essential for the network. Flexibility is another vital criterion due to the large uncertainty in the port developments.

table Q.2 – criteria and their weight factors

Criteria	Weight factor
Robustness	0.25
Flexibility	0.21
Capacity	0.18
Safety	0.14
Complexity	0.11
Hindrance during construction	0.07
Public transport	0.04
Clarity	0.02

Q.4 CONNECTION FERRY

The connection of the ferry terminal has to be a ground level solution, as elevated road segments do not suit in the inner city of Havana, nor are they fit for the distributor road type. The old city centre has a colonial image, which could be spoiled when elevated roads are implemented. Elevated road segments also leave out some connections, limiting the distribution function at intersections. In addition, the construction of elevated connections is very expensive compared to ground level solutions. Therefore the extra capacity of elevated connections is not searched for in this design.

The design space of the ferry terminal connection to the network of Havana is limited by the railway track on the city side and by the ferry terminal building on the bay side. The current road layout is two lanes per direction along the north-south part of the Avenida del Puerto. More info on the surroundings can be found in 'Appendix C: Analysis of the surrounding area' and 'Appendix E: Infrastructural analysis'.

At the intersection with Arroyo the road towards Habana Vieja changes to three lanes towards Habana Vieja and two lanes towards Regla. This is in contradiction to the flow patterns at this intersection as the flow from Havana Vieja is significantly larger than the flow towards Havana Vieja; 1 865 respectively 1 080 VE in the peak hour. The expected flows in the year 2060 will be at least doubled, i.e. 3 158 VE from Habana Vieja in the peak hour, creating a capacity problem at this location. A possible solution is the road parallel to the Avenida del Puerto, Fabrica, which has unused capacity left in this direction.

The traffic generated by the Ferry terminal is about 210 vehicles in the peak hour, when a ferry arrives or departs. More information on the generated traffic can be found in 'Appendix E: Infrastructural analysis'. The ferry terminal has to be connected to the road network without causing congestion, both on the main road as on the terminal itself. It has to be accessible via public transport and by car. A connection to the walking routes of Tourist Port Havana is preferable, but not a requisite as it is the most remote part of the master plan.

Q.4.1 VARIANT 1: DIRECT CONNECTION

Variant 1 consists of a direct connection to the Avenida del Puerto from the forecourt of the ferry terminal. This is the most simple, and economic, solution for the connection to the road network. Entrance and exit of the ferry terminal are located at both ends of the forecourt. A central reservation is applied in front of the terminal building, between the lanes in different directions. Here traffic arriving from the direction of Habana Vieja can position before crossing the road and entering the ferry terminal. This way the ferry terminal is accessible via both directions of the Avenida del Puerto. This road segment is connected to Arroyo and Jesus Lopez, providing decent a distribution function.

By minimizing the new infrastructure that has to be build, costs are minimized and the hindrance during construction is limited as well. The only new road parts that have to be created are in front of the ferry terminal building, consisting of the connection to the forecourt and a central reservation. To achieve this, the lanes in the direction of Habana Vieja are shifted towards the ferry terminal in order to

create space for the central reservation. This way the traffic towards Habana Vieja has to be alerted for cars on the central reservation, waiting to cross. The central reservation has to be clearly marked to create a safe situation. A bus stop is created on the city side of the road, in front of the terminal forecourt. The crossing pedestrians can use the same central reservation used by the cars for security in crossing.

The connection with Arroyo remains the same, only gates are installed to increase safety for crossing traffic at the railway track. This way safety increases without high implementation costs. This does mean that there is merging traffic at this location, but the traffic from Arroyo is only a minor flow.

Q.4.2 VARIANT 2.1: DRIVE THROUGH

Variant 2.1 consists of a drive through along the Avenida del Puerto from Jesus Lopez to Arroyo. This way the ferry terminal is only accessible from the south, at the intersection with Jesus Lopez. This decreases the accessibility as only one route leads to the ferry terminal. Nevertheless, this route is dedicated to the ferry terminal. From the intersection between the Avenida del Puerto and Jesus Lopez an extra lane is added, indicated to lead to the ferry terminal. At 100 meters from the intersection, this lane will diverge from the main road, leading to the parking area and the forecourt of the ferry terminal. The lanes continues in front of the forecourt and departing traffic can enter here before the lane converts to the main road and is connected to the Avenida del Puerto again, about 200 meters from the intersection with Arroyo. Here the Avenida del Puerto continues towards Arroyo with two lanes.

Because of the splitting and joining of this drive through lane the crossing traffic on the Avenida del Puerto is prevented. Nevertheless, merging traffic still occurs at both ends of the drive through. To minimize the effect of this merging traffic on the flow capacity, the drive through has to be indicated before arriving at the intersection between Jesus Lopez and the Avenida del Puerto. This implies that the directions here have to be indicated when leaving Fabrica onto Jesus Lopez and a way back on the Avenida del Puerto. Traffic from Habana Vieja has to be lead from the Avenida del Puerto onto Arroyo and Fabrica to reach the ferry terminal. This is only a minor detour and the capacity of both Arroyo and Fabrica is sufficient to guarantee a smooth through flow. But this detour does cross the railway line twice, increasing the chance of delay by trains.

The intersection between the Avenida del Puerto and Arroyo will be adapted to a junction managed with traffic lights and railway gates, similar to the intersection with Jesus Lopez. A free right from the Avenida del Puerto onto Arroyo provides enough capacity for this flow as the road layout between Arroyo and Avenida de Belgica is changed from 2x3 lanes to 3x2 lanes. This way the capacity is adapted to the flow patterns.

The capacity of the network is increased with this solution, but this increase is limited by the capacity of the intersection with Arroyo. The hindrance during construction is limited as the road can be used almost the entire construction period.

Q.4.3 VARIANT 2.2: DRIVE THROUGH WITH EXTRA LANE

This sub-variant of the drive through has an added lane at the intersection between the Avenida del Puerto and Arroyo. The drive through remains the same, meaning the only way to enter the ferry terminal is the via the intersection between Avenida del Puerto and Jesus Lopez. The extra lane increases the limiting capacity of this junction. Now three lanes enter the intersection from the south, instead of two. This also minimizes the merging traffic at the exit of the ferry terminal as traffic can continue on the drive through lane. Only traffic going onto Arroyo still has to merge to the left lane. This flow consists of the traffic with a destination south of the terminal. This flow travels via the Avenida del Puerto, via Arroyo onto Fabrica, but this flow is significantly smaller than the flow towards Habana Vieja. At the intersection, one lane turns left onto Arroyo, while the other two lanes continue straight on the Avenida del Puerto. There the road layout is changes from 2x3 to 3x2 lanes, just as in the other sub-variant.

This extra lane is only a small adaption of the drive through variant, but it has major consequences for the capacity of the network. At the bottleneck, the intersection between Avenida del Puerto and Arroyo, capacity is increased. This raises the capacity of the road segment behind it. The addition of an extra lane does bring extra costs and hindrance as more asphalt has to be placed and the intersection has to undergo more changes.

Q.4.4 VARIANT 2.3: ROUNDABOUT

This is another sub-variant of the drive through variant. Here the connection of the Avenida del Puerto and Arroyo is converted into a roundabout. The drive through and the connection at Jesus Lopez remains the same as in the previous sub-variant.

The roundabout is put together with the roundabout on the other side of the railway track, connecting Arroyo and Fabrica. This way one major roundabout is created, connecting the Avenida del Puerto to both Arroyo and Fabrica. The roundabout is managed with traffic lights. This 'traffic plaza' creates a very high capacity with three lanes in all directions plus an extra lane for free rights from the Avenida del Puerto towards Habana Vieja and from Arroyo onto Fabrica. This way the intersection is able to handle the peak flow of 7 024 VE per hour in the best possible way. This flow would come down to about one car every two seconds on all four lanes.

The major problem of this solution, however, is the interference of the railway track. The roundabout crosses the railway track twice as the rails go through the centre of the roundabout. When a train approaches the intersection, this will block almost all traffic on the roundabout, creating major block backs in all directions. This variant is also the most expensive one, as a large part of infrastructure has to be added and many parts have to be adapted.

Therefore this variant seems only feasible when the ground level railway track is either moved to the elevated railway track or into the ground. This requires significant more investments, which are not included in this project.

Q.4.5 MCA ON THE FERRY TERMINAL CONNECTION

The results from the MCA for the ferry terminal are shown in table Q.3. Variant 2.2, the drive through with extra lane, has the highest value according to the MCA, just above variant 2.1, the drive through without extra lane. Variants 1 and 2.3, the direct connection and the roundabout respectively, score notably lower. It is notable that all variants score the same on the criterion public transport, as they do not differ here.

table Q.3 – values MCA connection ferry terminal

criteria	factor	variant 1		variant 2.1		variant 2.2		variant 2.3	
		score	value	score	value	score	value	score	value
Robustness	0.25	4	0.98	3	0.74	4	0.98	4	0.98
Capacity	0.18	1	0.18	2	0.35	5	0.88	3	0.53
Clarity	0.02	4	0.07	5	0.09	5	0.09	2	0.04
Safety	0.14	1	0.14	4	0.56	4	0.56	5	0.70
Flexibility	0.21	4	0.84	4	0.84	3	0.63	2	0.42
Hindrance during construction	0.07	4	0.28	4	0.28	2	0.14	1	0.07
Public transport	0.04	3	0.12	3	0.12	3	0.12	3	0.12
complexity	0.11	5	0.53	4	0.42	1	0.11	1	0.11
total	1.00	26	3.1	29	3.4	27	3.5	21	2.9

Drive through with extra lane

The variant Drive through with extra lane gets its high value mainly because the high capacity that is created. With the dedicated access lane for the ferry terminal both capacity and accessibility increase substantially. The results in higher costs and hindrance during construction, but that does not weigh in to the more important criteria accessibility and capacity. table Q.3 also indicates that if these criteria are not weighed to importance, this variant does not have the highest score. From this it can be concluded that if the criteria costs and hindrance are considered more important, this changes the outcome of this MCA.

Drive through without extra lane

The variant Drive through without extra lane scores just below the variant Drive through with extra lane. The difference between the two is the lower capacity without the extra lane. To leave the extra lane increases flexibility and decreases costs and hindrance during construction. But as said above, these factors do not weigh up against the criteria Accessibility and Capacity. When the valuation of criteria might change in the future, this variant can be a decent alternative.

Direct connection

The variant 'Direct connection' reaches a lower value due to the lack of safety and capacity. As the ferry terminal will generate much traffic in a peak hour, the merging traffic on the Avenida del Puerto causes congestion with a blocked entrance of the ferry terminal as result. It is the cheapest solution, that could also be implemented as a primary phase in the planning, before expanding to a solution with higher capacity.

Roundabout

The variant 'Roundabout' has the lowest value in this MCA because of the interference of the railway track in the roundabout. The costs for this variant are high as much of the current infrastructure is changed. This also decreases the flexibility of this solution and the advantage of a high capacity is undone by the two crossings of the railway track for all traffic from Habana Vieja towards Regla. This flow is by far the biggest in the project area and it is undesirable to lead this flow over the railway track twice.

Q.5 CONNECTION MARINA

The connection of the marina will be a ground level connection, for the same reasons as for the ferry terminal. The connecting is limited in space by the marina itself on the bay side and the railway track and station on the city side. In front of the main building of the marina the ruins of the old city wall form another obstacle for the connection. The remnants of the La Coubre disaster on the current central separator are preferred to stay at their current location, but if necessary they could be moved to a nearby location. Furthermore it is preferred to preserve all buildings on the city side of the Avenida del Puerto as the demolition of buildings is a very expensive and time consuming factor, besides the fact that it will raise opposition for the plans. More information on opposition can be found in 'Appendix B: Stakeholder analysis'.

The roundabout connecting the Avenida de Belgica onto the Avenida del Puerto is currently the most dangerous location in traffic in the surroundings of the project area. This safety problem has to be resolved in order to create a valuable connection of the marina to the network. More details on the safety of this location can be found in 'Appendix E: Infrastructural analysis'.

In the same appendix the current road layout is discussed. This layout currently consists of 2x2 lanes on the Avenida de Belgica and on the Avenida del Puerto, two lanes going onto the Avenida del Puerto towards Regla and three lanes from Regla connecting to the roundabout

The traffic generated here is not quantified in the analysis, as there is no data available, but it is assumed to be of similar size as at the intersection between Arroyo and Avenida del Puerto. The traffic generated by the marina consists of only a small flow of passenger cars. More important are the connections for pedestrians and supply of the marina. Furthermore the marina has to be accessible by public transport to move tourists around the city.

The design of the connection is characterized by the limited space available for new infrastructure. This could especially be a problem for the required parking spaces at the marina. More requirements for the connection can be found in 'Appendix L: Boundary conditions and design requirements'.

Q.5.1 VARIANT 1: DIRECT CONNECTION

This solution consists of a direct connection of the marina onto the Avenida del Puerto at La Coubre portal. This comes down to the development of the existing connection to a more spacious entrance of the marina. The space for this entrance will be inside the current facilities, behind the portal. Here space is created for supply trucks as well as a few parking spots. The available space is limited, because the turning area for supply trucks requires a lot of space.

This option is the simplest solution for the connection of the marina to the network. It requires the least cost and minimizes the hindrance during construction as only small adaptations have to be made to the current infrastructure.

The marina is accessible from both directions of the Avenida del Puerto. The traffic from the direction of Regla can enter the marina directly from the Avenida del Puerto with a right turn and the traffic from the roundabout can enter using a

central reservation in between the lanes in different directions while waiting to enter.

The connection with public transport will be provided at the bus station of La Coubre, directly on the other side of the road. The generated pedestrian flow is guided to the marina with a zebra crossing over the Avenida del Puerto.

Additional parking places are situated in front of the restaurant and at the bus station to meet the requirement of 50 parking spaces. These parking spaces can be implemented in phases, according to the development of demand.

The layout of the roundabout remains the same in this variant, only the connection of the minor grid road leading onto the roundabout is rerouted onto the Avenida de Belgica. This solves just a part of the safety problem at this location, but it is the cheapest way to increase safety.

This variant is very flexible as it is always possible to change the current layout of the connection in the future but the investments in this solution will then be of little value.

Q.5.2 VARIANT 1.2: CONNECTION AT BUS STATION

This variant connects the marina at the western end of the bus station, 250 meters from the La Coubre portal. In order to create this connection, the road layout at this location has to be adapted. The direction of the middle lane changes into the direction of Regla, creating three lanes in this direction and two towards Habana Vieja. A central reservation provides the crossing traffic space to line up while waiting to enter the marina. The three continuing lanes go around this central reservation, which therefore has to be clearly marked. The same entrance will be used for both visitors and supply of the marina. From the entrance a single lane will lead to the exit, located at the La Coubre portal. From this lane supply trucks can head on to the supply pier where the provision takes place.

Public transport will be operated from the La Coubre bus station. The pedestrian flows will be transported to the marina via a tunnel under the Avenida del Puerto. This solution is substantially more expensive but it provides a safe crossing for the large pedestrian flow to the bus station and city side of the road.

The roundabout is adapted so the driving lines are less straight. This forces drivers to slow down at the intersection, improving safety. Also unnecessary connections of minor grid roads are rerouted to minimize merging traffic.

This connection of the marina requires more costs as more road segments are adapted. The changes on the roundabout are also included as costs for the connection of the marina. The flexibility of this solution is relatively low as many irreversible changes have to be done at once.

Q.5.3 VARIANT 2.1: ROUNDABOUT

The Roundabout variant connects the marina directly to the roundabout, creating a four-armed roundabout when the connections from minor roads are rerouted. From the roundabout the access lane of the marina leads to the parking building where two floors provide the required parking spaces. The other end of this parking building connects to the main walkway along the bay.

By adding another arm to the roundabout the merging traffic will increase. Even though the flows from and to the marina are small, this could cause problems on the roundabout itself, blocking traffic in all directions. Therefore the flows are managed with traffic lights during peak flows. The addition of traffic lights could be phased later, when the traffic volume increases.

The supply of the marina will have its own entrance at the La Coubre portal. It is only accessible from the direction of Regla, limiting the accessibility. This is not a problem for supply trucks, which are able to adapt their route before departure. The main advantage of this limitation is the removal of merging traffic just after the roundabout. This way spilling back because of waiting supply trucks is impossible.

The connection with public transport is provided with bus stops just after the roundabout in front of the restaurant, 150 meters from the entrance, and at the La Coubre bus station. A pedestrian tunnel between the entrance of the marina, the centre of the roundabout and the city side of the road, between the bus station and the train station, provides a safe walking path from the bay side in the direction of the Capitolio. This solution is an expensive one because of the length of this tunnel, but it extends the walking route along the bay towards other touristic attractions like the old city wall, the central train station and the Capitolio.

The flexibility of this solution is relatively low as most solutions are irreversible without high extra investments. For the connection the roundabout has to be immediately adapted, only the traffic management system can be added later.

Q.5.4 VARIANT 2.2: TURBO ROUNDABOUT

The variant Turbo roundabout is a sub-variant of the regular roundabout. The marina is still connected to the roundabout directly and the pedestrian tunnel and supply entrance also remain the same. Conversely, the layout of the roundabout changes drastically. The Turbo roundabout is a Dutch invention by Fortuijn, who designed several versions of safe, high capacity roundabouts. The solution used here is a combination of two of those versions. The main form is derived from the so called 'knucklebone roundabout'. A realization of this type of roundabout in the Netherlands is shown in figure Q.1. It is commonly used as a on and off ramp distributor at highways.

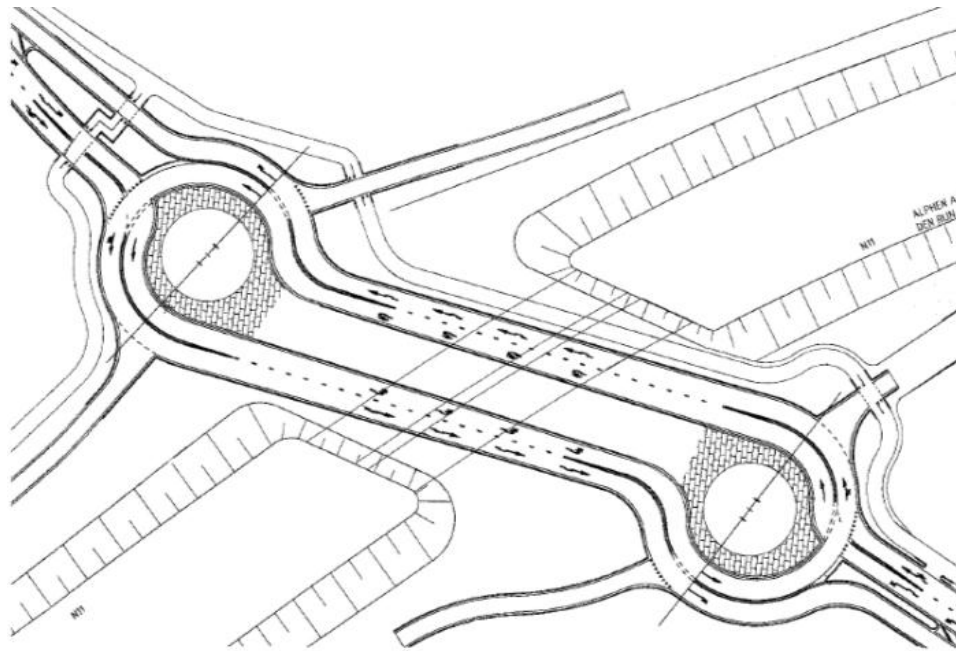


figure Q.1 – 'The knucklebone roundabout' (Fortuijn, 2012)

The two roundabout elements at both ends in this solution will be designed with a higher capacity, similar to the Star roundabout shown in figure Q.2. Only the arms of the entrance, at the La Coubre portal, and the exit, at the parking building, are one-way instead of two. The problem of the Star roundabout normally is the low share of capacity for turning left (when originating from the right in the picture), but this is not a problem in this case as flow towards the marina will only be a small part

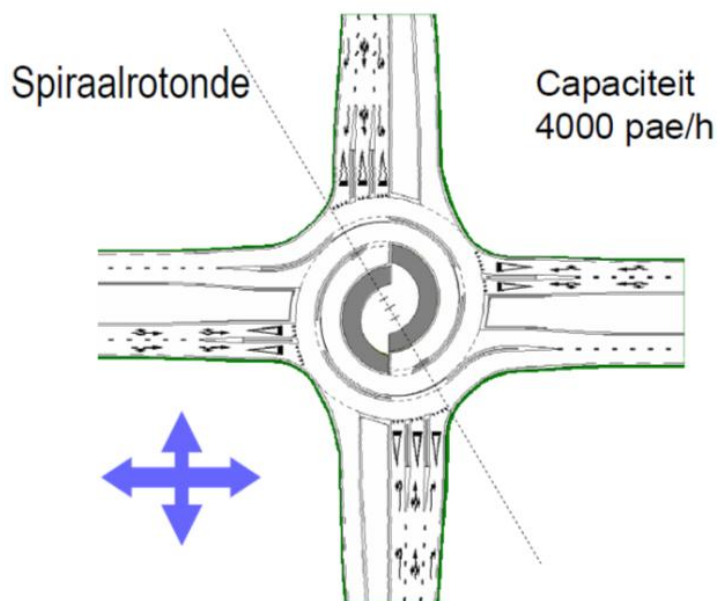


figure Q.2 – spiral roundabout (Fortuijn, 2012)

To reach the parking building, one lane for cars and supply trucks is available around the main building.

This type of roundabout is safer than a regular roundabout as the number of conflict points is minimized and drivers are forced to keep at low speeds. Even with lower speeds the capacity remains very high. The capacity will be around the 4 000 VE of the Spiral roundabout from figure Q.2. This is significantly more than the capacity of a regular two lane roundabout, with capacity between 2 100 and 2 400 VE/h. (CROW, 1998)

With this layout of the roundabout the available space in front of the main building could be used as taxi stand. This results in extra merging traffic on the roundabout, contrary to the starting principles of this design. Therefore the taxi stand is located at La Coubre bus station, together with the bus stop. The space in front of the main building is instead used for the pedestrian walkway and green, adding to the green inside the roundabout.

This solution is by far the most expensive solution because of the pedestrian tunnel and a whole new set up of the roundabout. Furthermore the flexibility is low as it can only be implemented as a whole. This automatically means that the hindrance during construction is high as the roundabout will be unavailable during a substantial part of the construction.

Q.5.5 MCA ON THE CONNECTION OF THE MARINA

The results of the MCA for the marina are shown in table Q.4. The variant Turbo roundabout scores the highest value by far with a 3.6. But it is also notable that the unweight scores off all variants are almost equal, with the variant Connection at bus station just on top with 26 points.

table Q.4 – values MCA connection marina

criteria	factor	variant 1.1		variant 1.2		variant 2.1		variant 2.2	
		score	value	score	value	score	value	score	value
Robustness	0.25	3	0.74	4	0.98	3	0.74	5	1.23
Capacity	0.18	1	0.18	3	0.53	3	0.53	5	0.88
Clarity	0.02	3	0.05	4	0.07	2	0.04	3	0.05
Safety	0.14	1	0.14	2	0.28	4	0.56	5	0.70
Flexibility	0.21	4	0.84	3	0.63	2	0.42	2	0.42
Hindrance during construction	0.07	5	0.35	3	0.21	4	0.28	2	0.14
Public transport	0.04	3	0.11	4	0.14	2	0.07	2	0.07
complexity	0.11	5	0.53	3	0.32	4	0.42	1	0.11
total	1.00	25	2.9	26	3.2	24	3.1	25	3.6

Variant Turbo roundabout

The variant Turbo roundabout scores the highest value because of its high scores on three important criteria; Accessibility, Capacity and Safety. On other criteria the scores are less impressive. The costs and hindrance for this variant are relatively high and the flexibility is low. These criteria are considered less important and cannot nullify the excellent scores on the mentioned criteria.

Variant connection at bus station

This variant is a good alternative when there is a budgetary problem for the variant Turbo roundabout. It scores high on Accessibility, Clarity and Public transport as it has a simple set up, directly across the bus station.

Variant Roundabout

The variant roundabout is another decent option but it scores substantially lower on accessibility and capacity than the Turbo roundabout variant. It does have less costs and hindrance during construction but it is equally inflexible as it can only be implemented as a whole, making future changes difficult and expensive.

Variant Direct connection

This variant is by far the most economical variant, but the value created with these investments barely meet the requirements. It is advised to invest more in the infrastructure to increase the value of the marina.

Q.6 CONCLUSIONS

This paragraph lists the conclusions of this appendix on the design of the connections for both marina and ferry terminal. First the general conclusions on the Avenida del Puerto road are discussed, followed by the conclusions on the designs for the ferry terminal and the marina.

Q.6.1 AVENIDA DEL PUERTO

The overall layout of the Avenida del Puerto will remain roughly the same. The road will consist of two lanes per direction, except for some road segments with additional public transport lanes or pick up areas. The maximum speed is 50 km/h to ensure a uniform speed on the road, smoothening the flow.

Parking spaces are moved from the centre of the road to the side of the road to minimize crossing pedestrians and merging cars driving on and off parking spaces from the most left lane.

Pedestrian crossings are implemented at intersections to control the crossing of pedestrians towards safer zebra crossings.

The lining has to be redone extensively, creating a uniform system of recognizable guidance on the road, together with the signs on the side of the road.

The road section at Sierra Maestra changes completely with the relocation of parking onto the pier. The road is expanded from one to two lanes per direction, plus a public transport lane on both sides for 100 meters to pick up and drop of tourists. A large pedestrian crossing is implemented at the Plaza San Francisco de Assis, after the pedestrian crossing in Lisbon. Tourist facilities are located alongside to the Plaza, next to the church.

Q.6.2 FERRY TERMINAL

The best option for the ferry terminal according to the MCA is the variant Drive through with extra lane. This variant combines a drive through as access lane for the terminal with the expansion of the Avenida del Puerto at the intersection with Arroyo. This intersection will be managed with traffic lights and railway gates to increase safety without a major capacity drop.

A more economical alternative is the variant Drive through without the extra lane. This lowers the costs of the connection, but at the same time capacity decreases at the intersection between the Avenida del Puerto and Arroyo, with consequences for the road sections behind it.

Q.6.3 MARINA

The best option for the connection of the marina according to the MCA is the variant Turbo roundabout. Even though this variant has high costs and hindrance during construction, it meets the requirements the best by far. Implementing this solution means a substantial increase of the value of the marina in the means of accessibility.

The variants 'Connection at La Coubre bus station' and 'Roundabout' could be more economical alternatives for the connection of the marina. With a connection at la Coubre bus station the public transport is available just across the street and the flexibility for adaptations to future changes is higher. Connecting the marina directly on the roundabout reduces costs and especially hindrance during construction.

Appendix R: DESIGN OF NAUTICAL INFRASTRUCTURE

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R.1 INTRODUCTION

A port requires a well-designed nautical infrastructure in order to receive visiting vessels in a safe and comfortable way. The dimensions of the approach and entrance channel, together with the turning basin, depend on the dimensions of the design vessel and natural conditions such as water depth and wind and wave conditions. The alignment and the required width of the approach and entrance channel are discussed first in this appendix, after which the infrastructure inside the bay is designed. Subsequently, utility services such as tug assistance, buoy marking and anchorage areas will be dealt with. The eventual design of the nautical infrastructure can be found in 'Appendix W: Technical Drawings', drawing number W9. The separate components are treated individually in this appendix.

Because an increase in the number and variety of vessels is expected in the future, traffic intensity will increase to a point where mitigating measures are required. The problem of increasing traffic intensity and a plausible solution are given in this appendix as well.

R.2 APPROACH CHANNEL

Vessels can enter the port of Havana by an approach channel that eventually changes over into the entrance channel and the interior manoeuvring areas in the Bay of Havana.

R.2.1 ALIGNMENT OF THE APPROACH CHANNEL

The approach channel is preferably aligned with the prevailing wind and current direction aligned with the channel to minimize the cross currents. It is therefore desirable to design the entrance to the harbour according to the prevailing wind and wave direction in the area. The Bay of Havana is however a natural bay with an entrance channel directed more or less perpendicular to the prevailing wind direction. These beam waves and winds lead to a decrease in the navigability and thus safety and should be prevented as much as possible. It seems therefore advisable to change the direction of the approach channel to the wave direction. However, bends and turns in the approach channel should also be prevented close to the entrance of the port. A balance should therefore be found between the direction of the channel and the location of the bend.

The required width of the approach channel can be calculated in the way as described in 'Appendix G: Nautical analysis'. The maximum width of the entrance channel is determined by the dimensions of the natural bay and is 220 m. Because of the rapid decrease of the water depth, it is not necessary to dredge an approach channel as it is safe to sail at any location. The approach channel can therefore have any possible width without much extra costs. It is however recommended to design an approach channel that let vessels sail into the bay in an orderly way. Since a uniform width along the approach channel enhances the navigability, the approach channel will be designed with a width limited by the natural entrance channel. The alignment of the approach channel is NNE, an orientation of about 15°, so the prevailing wind direction (see paragraph 'H.4 Wind conditions') is along the direction of the channel, see figure R.1.

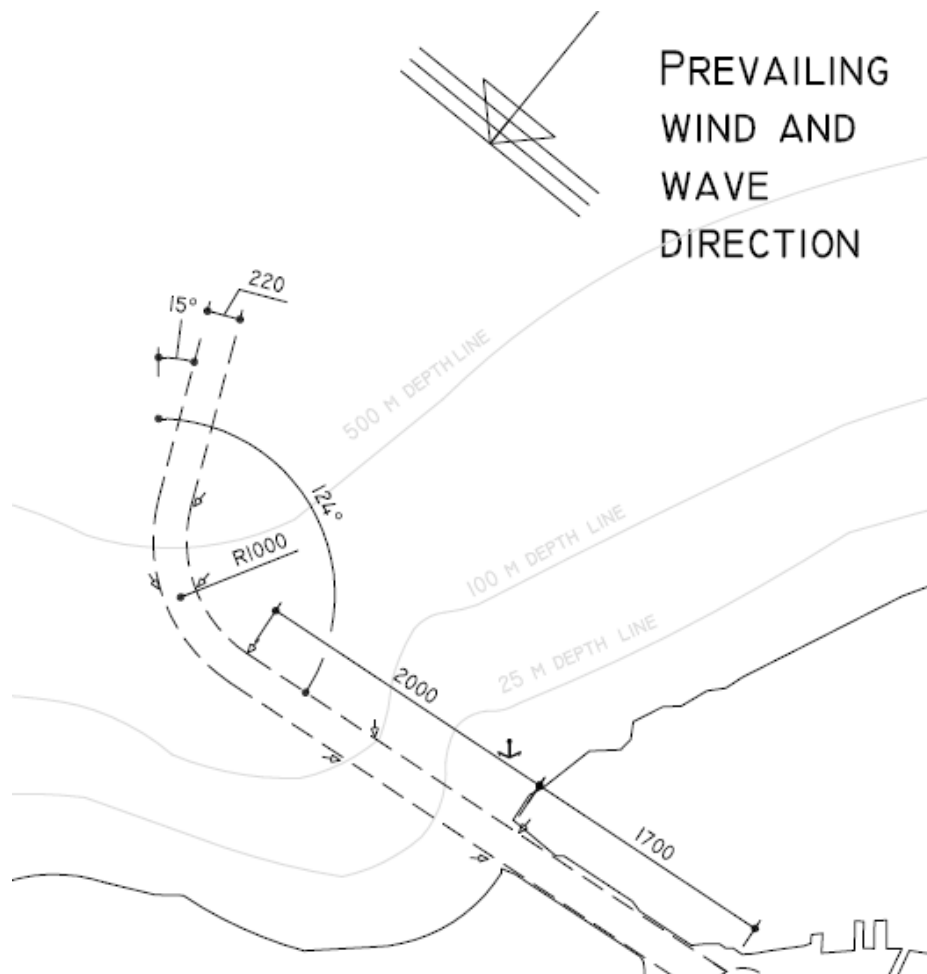


figure R.1 – the alignment of the approach channel

At a distance of 2 km northwest of the entrance to the bay, a bend will be located to change the direction of the approach channel to the direction of the entrance channel. The entrance channel has an orientation of 124° , which means a 71° change of heading. The radius of a bend depends on the manoeuvrability of the ship, which is on its turn dependent on water depth and the rudder angle. During the initial design phase, a rudder angle of 20° is considered a good basis (Ligteringen, 2009). With a depth of about 300 m at the location of the bend, this would mean a depth/draught ratio of near infinity, which means a radius of four times the length of the ship, see figure R.2. The design cruise ship has a length of about 240 m, which means a radius of about 1 km.

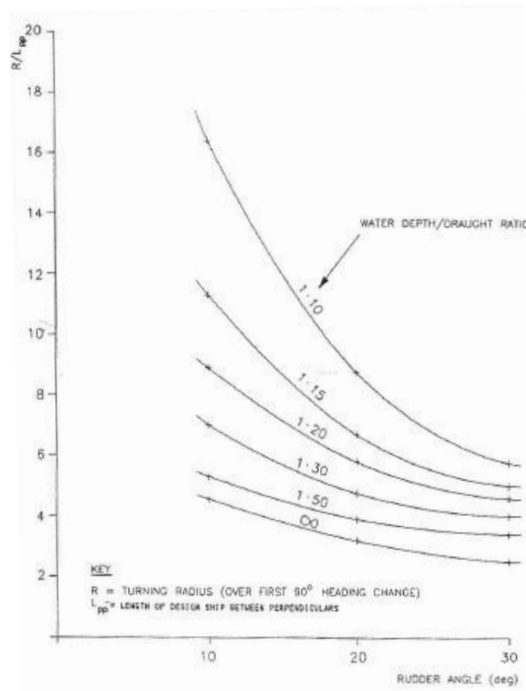


figure R.2 – turning radius in an approach channel (PIANC, 1995)

A vessel ‘sideslips’ as it turns in a bend, creating a path wider than its beam (PIANC, 1995). The width of this swept track depends on the depth/draught ratio and is given in figure R.3. With the ratio of near infinity, this leads to a value of $W_s = 1.8B$. This value of W_s is exactly the same as the value of W_{BM} for ships classified as having a poor manoeuvrability, see ‘table G.3 – increase of the basic manoeuvring lane’. This means that no additional width is required in the bend.

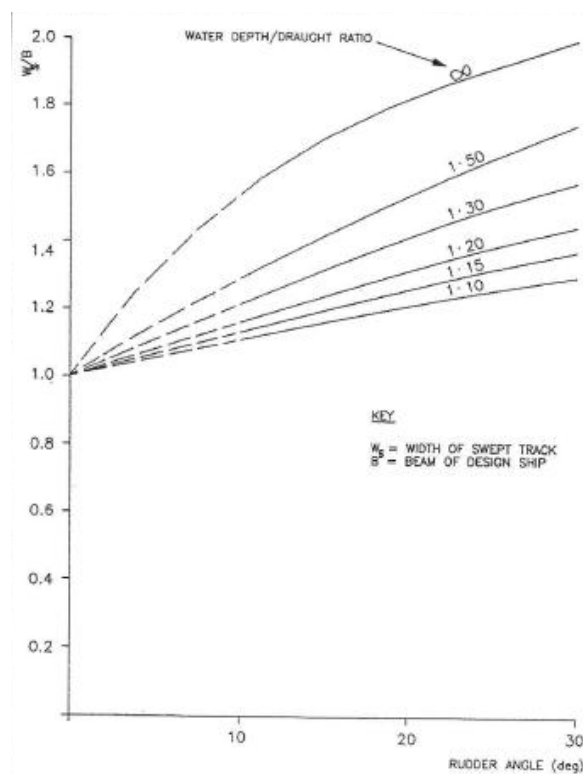


figure R.3 – width of the swept track in a turn (PIANC, 1995)

R.2.2 ENTRANCE CHANNEL

The length of the entrance channel is determined by the time tugs need to make fast. Tugs can make fast with a maximum speed of 6 kn and need typically 8 minutes for this process (PIANC, 1995). The vessel will slow down to a lower sailing speed during this process, preferably 4 kn (Ligteringen, 2009). The distance required for the tugs to make fast is therefore the distance covered with 5 kn during 8 minutes, which is about 1.25 km. An extra distance of $1.5L_s$ is required as stopping length. Given the length of the design vessel of 237 m, this leads to a total distance of the entrance channel of 1.6 km.

The entrance channel ends in a swinging area where the vessel can stop, turn and subsequently sail or be towed to its berth. The minimum diameter of this turning circle is $2L_s$, from which a diameter of about 450 m is followed. For the sake of the location of the turning basin inside the bay, the total length of the entrance channel and the embankment, see figure R.4.

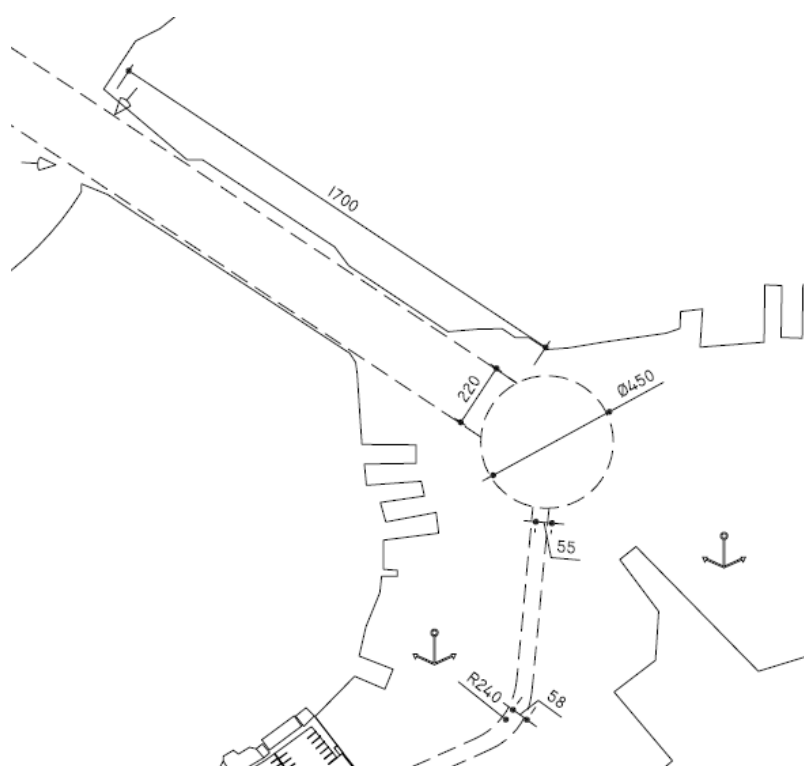


figure R.4 – dimensions of the inner channels and swinging circle

The maximum draught of a vessel allowed to enter the port remains 11.2 m, as described in 'Appendix F: Analysis of existing port infrastructure and facilities' and 'Appendix G: Nautical analysis'.

R.2.3 PORT BASIN AND BERTHING AREA

After the turn in the swinging area, the ferry or yacht will make his way to the Ensenada de Atarés, where its berth is located. The required minimum width of an inner channel, sheltered by waves and currents, depends on the width components as given in 'Appendix G: Nautical analysis', table G.4 - table G.6. Considering a classification of 'moderate manoeuvrability', a width of $3.3B$ is required which corresponds to a width of about 55 m for the Damen Fast Ropax 6016.

The Ensenada de Atarés cannot be reached by sailing in a straight line, so a bend has to be made. With a depth of about 10 m and a draught of 2 m, the depth/draught ratio is still near infinity. From figure R.2, this corresponds to a radius of $4L_s$. The length of the ferry of 60 m leads to a radius of 240 m, see figure R.4. The width component due to the swept track, W_s , is again $1.8B$. From this value, a total required width of $3.6B$ is obtained, 58 m, which is slightly larger than the straight parts of the channel.

The interior channel ends again in a turning basin in front of the berthing area. This turning circle is needed as the ferries have to be moored astern, see Appendix P: Design of the ferry terminal'. With a required diameter of $2L_s = 120$ m, this circle creates no problems as enough clearance is maintained between the turning basin and the embankments and marina, see figure R.5.

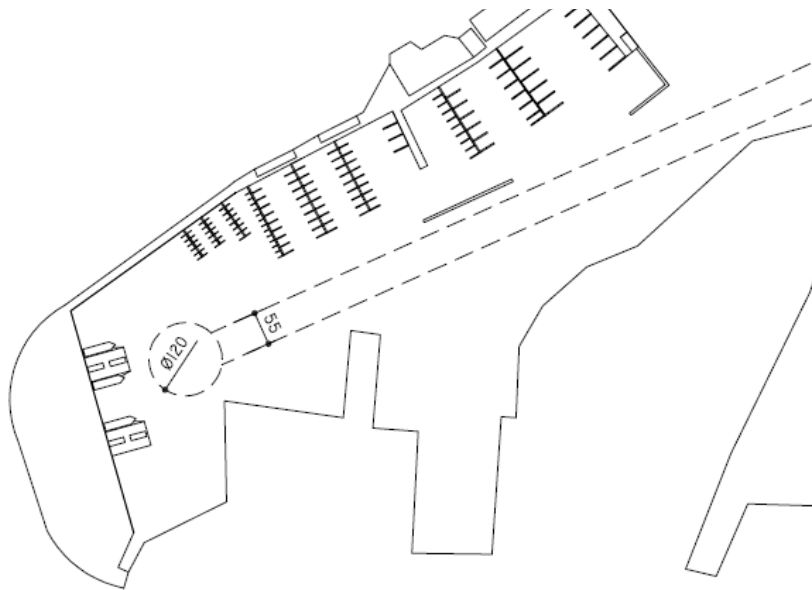


figure R.5 – fairway and turning basin of the ferry

R.3 NAVIGATIONAL UTILITIES

Next to the entrance and approach channel, also utility services as pilots, tugs, anchorages and buoys are required for a safe handling of calling vessels.

R.3.1 ANCHORAGE AREAS

An anchorage area is necessary to give vessels a safe location where they can wait if entrance of the Bay is not allowed by the port authorities. This prohibition of entrance can have multiple causes: another vessel is sailing in the approach channel, a vessel with a higher priority is expected to call or leave the port, the weather conditions have suddenly worsened or an emergency situation has occurred. A possible emergency situation is a collision or motor failure. At least one anchorage area should therefore be located close to the port entrance (Ligteringen, 2009).

The location of an anchorage area at the outer side of the bay is limited by the rapidly increasing water depth. The current used anchorage area, about 250 m north of the Castillo del Morro (see figure R.7), will therefore be retained. This anchorage area is located close to the entrance and has suitable soil conditions.

An anchorage area inside of the bay is desired as well in the case a berth is occupied or when a leaving vessel has to wait on another vessel before entering the 'approach' channel. The current Fondeadero de Casablanca can be used for this purpose. The current main anchorage site, Fondeadero la Tasajera will be relocated slightly to the west and will be used as an anchorage place for waiting yachts. This area will preferably be marked by a buoy to prevent the inexperienced sailors, as yachtsmen are, from lying at anchor in the fairway of the international or regional ferry service, see figure R.6.

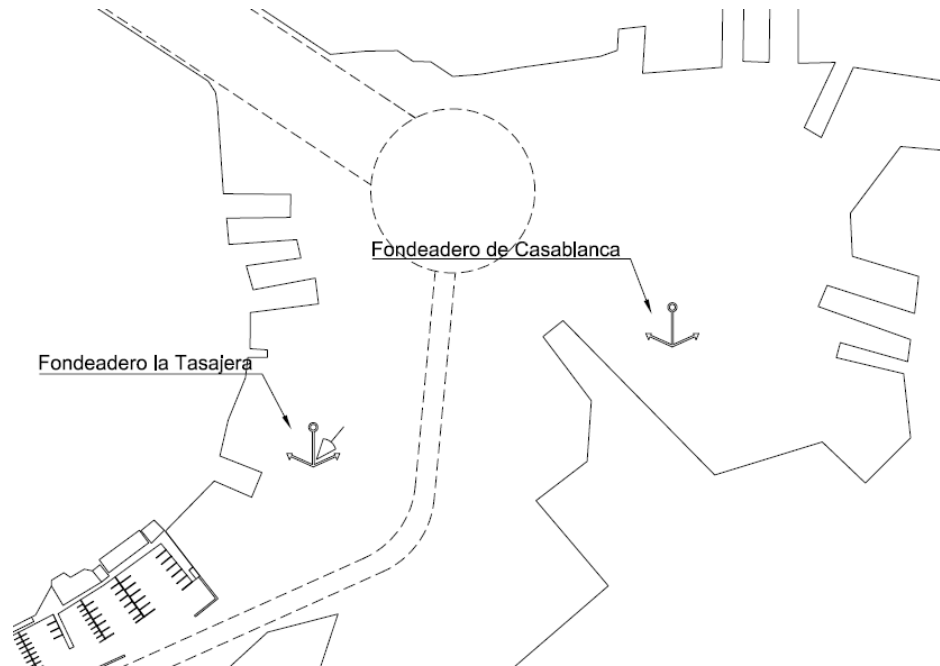


figure R.6 – the two anchorages in the bay

Any anchorage action is prohibited in the entrance channel because of the tunnel.

R.3.2 BUOYS

The alignment of the approach channel should be clearly marked by buoys at both sides of the channel. Without proper marking, a ship-handler can become disorientated, especially in a long bend (PIANC, 1995). There are two ways of indicating a bend in an entrance channel: with buoys at both side of the channel or with a so-called radar-conspicuous mark at the centre of the circle of the bend. This last option is suitable for the conditions for Havana, where the channel has no shallow embankment. It is however a technique that not every sailor is familiar with. Especially yachtsmen will have problems with this technique, so the buoy pair configuration is preferred.

In a one-way channel, the required minimal marks are three buoys at the inside of the bend: one at the apex and one at the entry and exit of the bend. Marks placed at the inside are better visible than at the outside, although a buoy at the outer apex is recommended to simplify the navigation. The best marking is of course with three buoys at the outside of the bend as well, but because the channel does not have a shallow embankment, the basic navigation should suffice.

The width of the entrance channel can be marked by the two buoys currently located at the entrance of the channel.

The minimum distance between two buoys should be about 1 nm (PIANC, 1995). Considering the distance of 2 km between the bend and the entrance channel,

another pair of buoys is required about half way between the entrance and the bend. This leads to the configuration as illustrated in figure R.7.

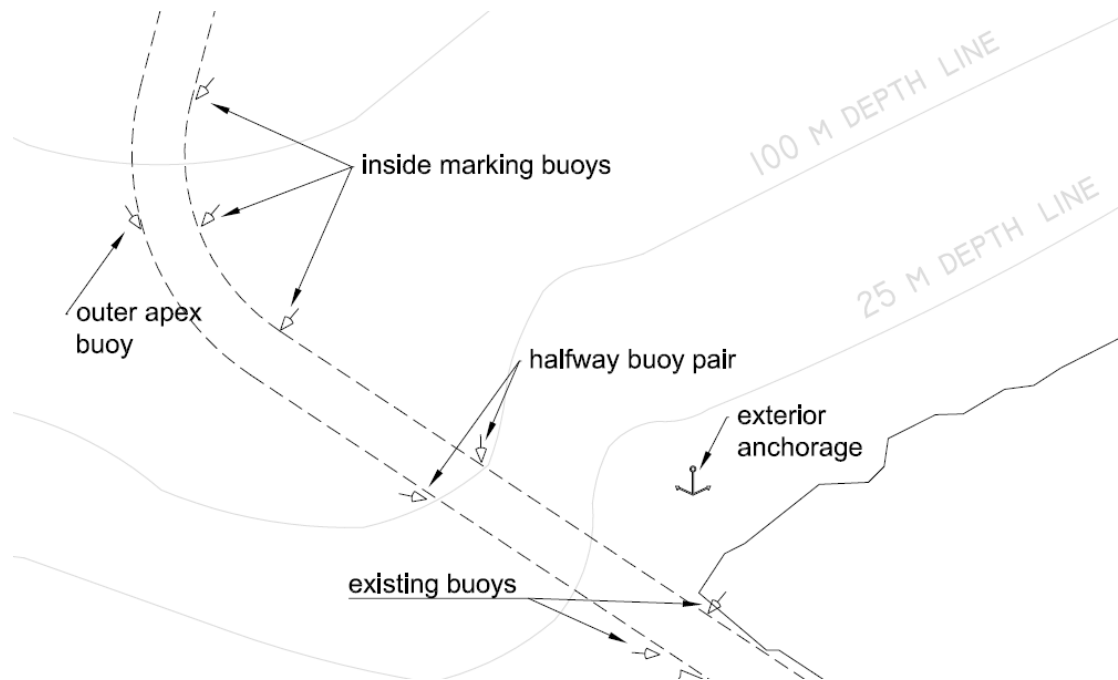


figure R.7 – the buoy configuration of the approach channel

To increase the navigability at night, the buoys should be equipped with lighting and/or radar reflectors.

R.3.3 TOWAGE SERVICE

Large vessels have to be accompanied by tugs when entering the port, as they have little manoeuvrability and long stopping distances. But a towage service may be desired for relatively small vessels as well when difficult circumstances arise, like high wind speeds. Although ferries and cruises have a high manoeuvrability by itself, especially cruise ships may be vulnerable to high wind speeds and may require tug assistance to pass the entrance channel.

The design cruise vessel has dimensions as given in 'Appendix G: Nautical analysis', which means a water displacement of about 50 000 tons. The required bollard pull that the assisting tugs have to deliver can be calculated by (Ligteringen, 2009):

$$T_B = \frac{\nabla}{10^5} 60 + 40$$

with:

T_B = required bollard pull [tons]

∇ = water displacement [tons]

Given the water displacement of a cruise ship, a total bollard pull of 70 ton is required. An example of a tug is the Damen ASD Tug 2810 "Paramaconi", figure G.1, with a bollard pull capacity of 60 ton. This means that two tugs are sufficient: one operating fore and one aft.

R.3.4 PILOT SERVICE

The port of Havana works with a compulsory pilot service for vessels that are calling the port. This will be only limited to cargo, cruise vessels and mega yachts in the

future. Yachts are able to enter the port without pilot assistance as they will experience little problems with their relatively small dimensions. The ferry service will be captained by a sailor with a lot of experience in the Bay, thanks to the frequent connections.

The current legislature will be maintained. This means that a vessel has to announce its arrival 72 hours before the estimated time of arrival and it has to confirm its call one hour before entering the bay. The pilot will enter the vessel about 1 nm before the channel by means of a pilot service boat, see figure R.8.



figure R.8 – Damen Stan Tender 1504

The small service boats, such as tugs and pilot boats, should be berthed at a sheltered area close to the entrance channel. A berthing place at the north east side of the Bay, in Casablanca, is therefore preferred.

R.3.5 TRAFFIC CONTROL TOWER

The traffic control centre should be located at a place close to the entrance channel with a good visibility on the approaching vessels, as well as the bay itself. The current location of the traffic control tower close to the Castillo El Morro is suitable and is recommended to be retained.

R.4 TRAFFIC LIMITATIONS

According to the current legislation, no manoeuvring is allowed in the entrance channel with wind speeds of 6 Bft and higher. However, even with these wind speeds, the entrance channel should have a sufficient width for vessels entering or leaving the port in accordance with the guidelines. Nevertheless, the current legislation has been evolved by practical experience over years, and should therefore be respected by the designer (PIANC, 1995).

It is however recommended to investigate the exact circumstances at which navigating becomes problematic. The ferry connection and a call of a cruise vessel are important and valuable assets of the country and it will therefore be costly if a vessel is not allowed in the bay. Although wind speeds of 6 Bft and higher occur only about 5% a year (see H.4.4 ARGOSS data) and a downtime of 5% is not unacceptably high, it is preferred to decrease the downtime as much as possible. A possible method to investigate this is by means of a manoeuvring simulation program.

Moreover, wind speeds are generally lower in the morning, i.e. between 05.00-12.00 h. (Valle Benero, 2013). The higher wind speeds occur mainly at the end of the day. These observations can be used for traffic management, for instance with the schedule of the ferry service.

R.5 TRAFFIC INTENSITY

As stated before in 'Appendix G: Nautical analysis', little is known about the expected intensity of traffic in the future. Although a prediction about the number of expected vessels in the future lacks, a general design of the traffic control can be made.

R.5.1 EXPECTED ARRIVAL RATE

The arrival rate of cruise ships and ferries can analytically be determined, as they work with tight schedules. An arrival of a yacht and cargo vessel is more random and some assumptions have therefore to be made.

Cruise ships

A port for cruise ships can be either a homeport or a port-of-call. In the first situation, the cruise ship starts and ends its journey at the homeport. The ship has to be supplied for gasoline, food and water for the entire travel. Tourists usually arrive at the homeport by airplane and will stay for more than one night in the port's city. Havana will however probably become a port-of-call, particularly in the early stages of operation of the renovated cruise terminal. A port-of-call is a port at which a cruise is only berthed for one or two days before the next port is called. In general, a cruise ship will arrive at the port-of-call in the morning and will leave after approximately 10 hours (de Jong, 2012). During this period, the passengers visit the city. The cruise vessel will preferably leave the port before dinner, so passengers can enjoy the evening shows on the vessel. As an example, the shipping schedule of Nassau, Bahamas, of July 2009 shows a typical arrival time of 08:00 h and a typical departure time of 18:00 h or, to a lesser degree, 22:00 h (Blue Engineering Ltd., 2008).

From 'Appendix D: Tourism analysis', it follows that the number of cruise passengers visiting Havana is predicted to be between 1.5 and 3 million. With an average capacity of 2 500 passengers for each ship, the number of calls per year is predicted to be between 600 and 1 200. On average, two or three cruise ships per day are expected to be berthed in the port. During the high season of the tourism industry,

this number will be higher. Given the capacity of the renovated cruise terminal of four vessels, the maximum number of cruise ships expected to enter the port on a day is four.

It is therefore assumed that in the limiting situation a total of four cruise ships will enter the bay in the morning and leave in the evening.

Ferry

From the nautical analysis, appendix G, it was concluded that a daily fast ferry connection with Key West and Miami will be assumed. The service with Key West can even be executed twice a day when the demand is high enough. Furthermore, a weekly connection with Tampa, Cancun or Nassau could be feasible.

Considering the sailing times, the travel between Havana and Miami, Tampa, Cancun and Nassau will probably be performed overnight. This means that the ferry will leave the port late in the evening and will enter the port early in the morning. The connection with Key West can be carried out with a departure in the morning and early in the evening. As a result, the arrivals are expected to be late in the morning and late in the evening.

Yachts

Yachts will arrive very irregularly as the travel with a pleasure craft has generally no commercial purposes. This also means that waiting times are not harmful except for the mood of a yachtsman on his holidays. More yachts are to be expected during the yachting season or during a possible yachting event as described in 'Appendix D: Tourism analysis'.

Cargo vessels

The expected arrival rate of cargo vessels depends on the capacity, the service times and the demanded cargo throughput of the port. The service time of a terminal depends on the type of cargo. A general cargo vessel has a service time of multiple days, while the other types of cargo have a service time of preferably less than 24 hours (Ligteringen, 2009). A general cargo vessel has therefore fewer problems with waiting times than bulk carriers or container ships.

The arrival rate of cargo vessels in the future is highly uncertain; therefore no assumptions of arrivals of cargo in the future are made now.

R.5.2 TRAFFIC SCHEDULING

The most plausible method of traffic management seems a traffic scheduling scheme. The vessels calling the Port of Havana will then be divided in the four categories used above: cruises, ferries, yachts and cargo ships. These four classes are each given a window during which they can enter or leave the port. The duration of the windows depends on the expected numbers of vessels that will want to enter or leave the port. A call will therefore have to be applied for at the port authority on time. For ferries, cruises and cargo, this will be of no problem. One can however not assume that a yachtsman will apply for the entrance of the bay days before. The window for yachts will therefore not depend on the number of applications, but rather on the number of expected yachts given the experiences of the port authority about the weather and time of the year.

It is recommended to assign priorities to the different classes in case of a conflicting schedule, for instance when a vessel arrives later than expected. In such a situation, the ship with the higher priority has the right of way over the other vessel, although

the arrival is during the window of the ship with the lower priority. The recommended order of priority is given below:

5. Ferries

Ferries sail according a tight schedule that will be similar every day. Furthermore, the port authority will be working closely and will thus be familiar with the company that owns the ferry connection, which simplifies the making of appointments and increases the reliability. Therefore the ferries are given the highest priority when encountering another vessel.

6. Cruise ships

The cruise industry will be of major importance for the Cuban economy. As Havana will probably be a significant cruise destination, high wages can be asked of the cruise operators. But the port of Havana will have to give some reliability in return, as cruise companies will pass Havana by just as easily if waiting times are excessively high. After all, cruise lines are thriving today without Havana as destination. Cruise line operators have therefore to be treated with care and cruise ships need thus a high priority. Furthermore, if the Port of Havana wants to be a 'tourist port', the cruise activities should become the central activity. The only reason why ferries should be assigned a higher priority is that the schedules of ferries are more reliable and more or less in control of the port authorities.

7. Cargo vessels

Cargo transporting ships will not like waiting times, but can notify the port authorities about its arrival days beforehand. The authorities can anticipate on this call by adjusting the time schedule or, more plausibly, by notifying the captain of the cargo vessel about the exact time window at which entrance is allowed. The captain can then adjust its sailing velocity so its estimated time of arrival fits in the window. Cargo vessels are used to his strategy, as many ports are operating with a tidal window. Moreover, this method reduces fuel costs. It is however still a hidden form of waiting time (Ligteringen, 2009).

8. Yachts

The number of yachts is numerous. Moreover, yachts have unreliable arrival times and have above all a non-commercial nature. They are therefore given the last priority. It is recommended to assign a fixed window to the entrance of yachts which is commonly known along yachtsmen. When necessary, the duration of the window can be adjusted to the yachting season. Multiple yachts can then enter the bay during this window at which commercial shipping is temporary prohibited. Yachtsmen can adjust the estimated time of arrival to this window, or otherwise have to wait until the next window. When a yacht cannot make the window on time, it is also possible to sail on to Marina Hemingway.

A possible schedule during a regular situation and during touristic high season is given in table R.1 and table R.2 respectively. During the touristic high season, four cruise ships have to enter in the morning and leave in the evening. This leads to long windows for cruise ships after which the morning and evening windows of cargo vessels cannot be maintained anymore. After all, a window of around an hour is too short to plan an arrival on. Although cargo ships have a higher priority than yachts, it is decided to sustain to the yachting window around 14:00 h. Consistency is after all important for the window for yachts, as yachtsmen are not easy to be informed

about daily changing window times. It is therefore clear that cargo shipping is only possible at night during touristic high season. Hence, if the Port of Havana decides to focus on tourism, the attractiveness of the port as a destination for cargo purposes decreases significantly.

With the given schedules, a ferry service with Key West as depicted in table R.3 is taken into account, considering the sailing times as given in 'Appendix A: General perspective of Tourist Port Havana'.

table R.1 – an example of a traffic schedule on a normal day

Opening [h]	Closing [h]	Vessel	Remark
6:00	7:30	Ferry	Arrival from overnight trips, departure to Key West
7:30	9:00	Cruise ship	Arrival of cruise ships
9:00	13:00	Cargo	
13:00	15:00	Yachts	
15:00	16:30	Ferry	Arrival and departure to Key West
16:30	17:30	Cargo	Particularly the departure of cargo vessels, as window is too short for arrival
17:30	20:30	Cruise ship	Departure of cruise ships
20:30	21:30	Yachts	For yachts that missed the first window
21:30	23:00	Cargo	
23:00	01:00	Ferry	Departure of overnight trips, arrival from Key West
01:00	06:00	Cargo	

table R.2 – example of a traffic schedule during cruise season

Opening [h]	Closing [h]	Vessel	Remark
6:00	7:30	Ferry	Arrival from overnight trips, departure to Key West
7:30	12:00	Cruise ship	Arrival of cruise ships
12:00	15:00	Yachts	
15:00	16:30	Ferry	Arrival and departure to Key West
16:30	17:30	Cargo	Particularly the departure of cargo vessels, as window is too short for arrival
17:30	22:30	Cruise ship	Departure of cruise ships
22:30	23:00	Yachts	For yachts that missed the first window
23:00	01:00	Ferry	Departure of overnight trips, arrival from Key West
01:00	06:00	Cargo	

table R.3 – timetable for the Havana – Key West ferry service

Time [h]	Action
07:00	Departure from Havana
11.00	Arrival in Key West
11.30	Departure from Key West
15.30	Arrival in Havana
16.00	Departure from Havana
20.00	Arrival in Key West
20.30	Departure from Key West
00.30	Arrival in Havana

The timetables given in table R.2 and table R.3 only give a general example of a day-schedule. It is of course possible to give a cargo ship permission to enter the bay when there is an expected interval of, for instance, 45 minutes between two cruise ships. This possibility should be arranged with a single vessel that is expected around that window, as only one vessel could be given the clearance during such a short interval. It gives however little certainty to the cargo ship, as it has only a few minutes at which it can arrive at the approach channel before the prioritized cruise ship arrives. A possible solution for the cargo vessel is to arrive in advance and stay in anchorage until permission to enter the bay is given by the port authorities. Again, this scenario gives little certainties to the captain of the cargo vessel, but it may be better than no entrance at all.

These uncertainties will be of fewer problems for general cargo vessels than for bulk or container carriers. It seems therefore plausible to limit the trade of particularly bulk goods and containers in Havana and relocate it to other ports in the country, as listed in 'Appendix G: Nautical analysis', paragraph 'G.5 Other ports in the region'. Moreover, as these port basins have a greater depth than the tunnel-limited Bay of Havana, they can receive ships with a larger draught as well.

It is above all clear that communication is very important with the use of traffic scheduling, especially when dealing with inexperienced sailors as yachtsmen. Yachts have therefore to be equipped with a compulsory radio communication system on the right frequency. Besides, the port authority should be ready to intercept vessels in order to maintain safety.

R.6 CONCLUSIONS AND RECOMMENDATIONS

R.6.1 CONCLUSIONS

A marked approach channel is required for the safe and orderly reception of vessels. The natural Bay of Havana is large enough to accommodate the minimum required dimensions of the design vessel. The design of the alignment and dimensions of the nautical infrastructure can be found in 'Appendix W: Technical Drawings, drawing number W9'.

With an increase in the number of different types of vessels, an implementation of traffic management becomes necessary. A plausible solution is the use of time windows. Windows are reserved in the morning and evening for cruise ships and ferries, around 14.00 h for yachts and in between and at night for cargo transporting vessels. The passenger transporting vessels, ferries and cruise ships, will be assigned a higher priority than cargo ships and pleasure craft. During the touristic high season, the time windows of cargo ships will become unreliable and will therefore decrease the attractiveness of the Port of Havana as a destination for cargo vessels as a whole. As a result, cargo activities of especially bulk carriers and container ships should probably be relocated to other ports in the country.

R.6.2 RECOMMENDATIONS

The following recommendations are formulated to further increase the accuracy of the design and the certainty of the conclusions:

Leeway drift

The leeway drift of vessels caused by high cross winds are not taken into account with the determination of the vessel's speed in the approach channel. The wind force on especially cruise ships will be significant, which can result in a higher speed of the vessel that is required to have control of the direction of the ship. An increase in the entrance speed will also increase the required minimum width and length of the approach channel.

Entrance limitations

It is recommended to carry out a simulation model in order to investigate the exact circumstances at which the entrance of a ferry or cruise ship becomes intolerable dangerous. When the current limitation with wind speeds of 6 Bft could become less rigid, the downtime of these vessels will decrease. Moreover, as winds generally grow stronger during the day, it decreases the probability that the cruise ships that entered the bay in the morning are not allowed to leave the harbour which can possibly lead to high compensation costs for cruise line operators.

Increase in dimensions of cruise ships

The proposed capacity of the cruise terminal is relatively low. When increased, larger cruise ships can call the Port of Havana, as has already been recommended in the nautical analysis. This has however implications for the dimensions of the nautical infrastructure, as the current design vessel is the relatively small cruise ship "MS Zaandam". The width of the entrance channel is able to accommodate a cruise ship with a beam of about 54 m, which is sufficient for large vessels such as the Oasis of the Seas with dimensions of 360x47x9.2 m³ (de Jong, 2012). This also increases the required diameter of the turning basin to 720 m.

Timetable of ferry connections

The timetable given in table R.3 is based on the sailing times to Key West as given in 'Appendix A: General perspective of Tourist Port Havana' and is chosen in order to still have an appropriate second arrival time in Havana. Whether this timetable is feasible should be investigated in more detail. A different timetable will probably have influence on the traffic control schedule as well.

Moreover, fast ferries are assumed to be feasible for the connection with Miami and further located destinations because of its high sailing speed. These services are also assumed to be performed as overnight trips. However, such passages are usually carried out by Ropax ferries with passenger cabins, which are absent on the fast ferry. Whether an overnight connection without passenger cabins is feasible has to be researched in more detail.

Expected cargo throughput

The future cargo throughput of the Port of Havana is impossible to predict in this project and should be investigated in more detail. Especially the development of other ports in the country can be of influence; these port authorities should therefore be involved in the process as well.

Other vessels

Only yachts and passenger and cargo transporting vessels are taken into account with the traffic control schedule. Other small vessels such as fishermen's boats and service related vessels, such as round-trip boats and rented sport fishing boats, are not included. The position of these boats in the schedule will have to be determined when more information about the exact numbers is available.

Appendix S: CONSTRUCTION METHODS

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S.1 INTRODUCTION

In this appendix a proposal is presented for the method to construct the marina and ferry terminal. In order to do so, the entire project is divided in components which are considered separately. These components are described in S.3 and the construction methods are clarified in S.4. The building method is mainly dependent on three elements that are considered in this study:

- Labour
- Construction material
- Equipment

The building method is of direct influence on the planning of the project as the required time to construct components depends on the building processes. Therefore, the aim of this analysis is to provide information on what kind of labour, equipment and construction material is required. This information provides a basis to perform the building planning.

S.2 CUBAN BUILDING COMPANIES

In this section an overview is given of several companies that are appropriate for the construction of structures or the supply of building material, equipment and labour. These companies are listed by the material they offer (S.2.1) or their activity (S.2.2), (Cordova, 2013). However, these lists are not exhaustive, only a brief overview is given. In Cuba, it is common that the empowered ministry of construction works organizes a tendering process. Companies are free to tender for the works.

S.2.1 MATERIALS

Available in Havana

In Havana, relatively many factories and construction companies are present that presumably have appropriate qualifications to take part in the project. The list below shows products that can be provided in Havana, between brackets the district, if known, is given.

- Concrete (Guanabacoa)
- Steel (Cotorro)
- Painting (Boyero)
- Glass (La Lisa)
- Asphalt
- Aluminium

Available outside Havana

Below, products provided by companies outside of Havana are listed. Between brackets the providing city or province, if known, is given.

- Wood (Pinar del Rio)
- Rock (Mariel and Cardenas)
- Sand (Artemisa and Havana province)
- Sanitary facilities

It is stressed that in general sophisticated materials are scarce at Cuba. In general, these have to be imported.

S.2.2 ACTIVITIES

- **Hydraulic structures constructors**

‘Obras Maritimas’ and ‘Seramar’ are Cuban contractors that have proven to build hydraulic structures. The latter is currently constructing the Varadero Marina and it is therefore assumed this company has some experience in building marinas.

- **Waterborne equipment**

Damen shipyards is a Dutch company that manufactures seagoing vessels. Damen shipyards provides waterborne equipment that is able to perform hydraulic construction works. This company has an office and shipyard established in Santiago de Cuba. This subsidiary company is owned by both the Cuban government and the Dutch parent company.

- **Labour**

In Cuba sufficient labour is available, e.g. constructing, finishing, decorating, plumbing, tiling and installing equipment and facilities is present.

S.3 SUB-PROCESSES AND COMPONENTS

In this section a description of all project phases is given. The construction of the marina and ferry terminal is discussed separately as they can be considered as sub-projects of the entire Tourist Port Havana project. These sub-projects both consist of components, these are for example: design, acquisition of permits, demolition and construction. These components are divided in sub-components that contain a specific activity, which are listed in table S.1 and table S.2. The completion of all sub-components results in the finish of the project.

S.3.1 MARINA

table S.1 – marina; sub-processes and components

Sequence number	Sub-process	Components
1	Design	
2	Acquisition of permits	
3	Transference of the site	
4	Demolition of the piers	Vaciadero pier Juan Manual Diaz pier
5	Demolition of existing buildings	
6	Preparation of the site	
7	Renovation of buildings and structures for reuse	Juan Manual Diaz 1 building Juan Manual Diaz 2 building de la Coubre pier Aracelio Iglesias pier Existing quay walls
8	Renovation of the utilities	Water supply Electricity supply Sewage system
9	Marina 1 st phase	Piers Floating breakwater Fuel supply Boat launch or trailer ramps Parking and dry berthing area Garbage collecting service Customs services Money exchange Personal care and health facilities 1 st phase Shops 1 st phase
10	Infrastructure	Access roads Walking paths
11	Marina 2 nd phase	Hotel Catering services Yachting club Supermarket Recreational services Personal care and health facilities 2 nd phase Shops 2 nd phase

1. Design

A further design process is required to detail the designs proposed in 'Appendix O: Design of the marina'. This phase of the project is also meant to carry out more sophisticated analyses to improve the assumptions made and reduce uncertainties. An overview of required material and quantities is one of the results of this process.

2. Acquisition of permits

Permits for building are required before starting the construction process. Acquiring these permits may be a difficult process that can have a considerable impact on the progress of the project. An expectation of the time required is hard to estimate, if not impossible, as many unexpected issues may arise. However, it is stressed that buildings in Cuba are owned by the state, which accelerates this process, see also 'Appendix B: Stakeholder analysis'. Furthermore it is sensible to start the process of acquiring permits at an early stage of the project; it is preferred to start the procedures at the same time the design process starts.

3. Transference of the site

Currently, the buildings at site are in use by several companies and enterprises. They must leave before demolishing and construction works can commence. Transference of the site should start after the permits are acquired, see also 'Appendix B: Stakeholder analysis'.

4. Demolition of the piers

The Vaciadero and Juan Manuel Diaz pier are demolished in the design. This phase can only start after the site is transferred.

5. Demolition of existing buildings

The demolition of the first and second floor of the Juan Manuel Diaz no. 1 building and some relatively small other buildings is required. This can commence at the same time the demolishing of the piers is initiated, i.e.: after the site is transferred.

6. Preparation of the site

After the structures which are discussed above are demolished, the site must be prepared for the building phases. Preparations are required to install site huts and portable toilets for construction workers and be able to receive building equipment.

7. Renovation of buildings and structures for reuse

After the site is prepared, the renovation of the La Coubre pier, Arcelio Iglesias pier, Juan Manuel Diaz quay, Juan Manuel Diaz no. 2 building and upper floors of the Juan Manuel Diaz no. 1 building can start. The renovation is required to facilitate new services inside these buildings in a later stage.

8. Renovation of the utilities

The existing water supply, electricity supply and sewage services will be reused. However, they require expansion and improvements.

9. Marina first phase

The first phase of the marina consists of building and/or equipping the structures that are vital for a proper existence of the marina. These are buildings that house: fuel supply, customs services, money exchange service, personal care and health facilities, garbage collection service and shops. Furthermore, vital marina infrastructure is built in this phase, this consists of: boat launches, trailer ramps, a parking area, dry berthing area and the floating breakwater. These construction works can start after the renovation works have been finished. Also, it is clear that in this phase a part of the total amount of (finger) piers must be installed in order to be able to receive tourists.

10. Infrastructure

After the construction works of the first phase of the marina have finished, the infrastructure inside the marina and the infrastructure connecting the marina to the traffic network of Havana is built. The construction of the new infrastructure should not commence earlier in order to prevent damage caused by heavy construction equipment.

11. Marina second phase

The second phase of the construction of the marina is characterized by the installation of the remaining (finger) piers. Furthermore, less essential buildings of the marina are built and/or equipped. These are buildings that house: a hotel, catering services, yachting club, supermarket and recreational services. Also a second group of buildings to house personal care and health and a second group of buildings to house shops is constructed in this phase. The start date of the second phase of the marina is dependent on the development of the demands for more berths.

S.3.2 FERRY

table S.2 - ferry terminal; sub-processes and components

Sequence number	Sub-processes	Components
1	Design	
2	Acquisition of permits	
3	Transference of the site	
4	Demolition of existing buildings	
5	Preparation of the site	
6	Renovation of buildings and structures	Existing quay wall
		Southern building
7	Renovation of current utilities	Water supply
		Electricity supply
		Sewage system
8	Construction of the first pier	Preparation of the bottom
		Construction of caissons
		Filling the caissons
		Completion for use
9	Construction of terminal building	Waiting lounge
		Fuel supply
		Customs services
		Money exchange services
		Catering services
		Shops
		Waste collecting services
		Vehicle ramps
Walking bridges		
10	Construction of traffic infrastructure	Terminal roads
		Parking area
		Access roads
11	Construction of the second pier	Preparation of the bottom
		Construction of caissons
		Filling the caissons
		Completion for use

For sub-process 1, 2, 3, 5 and 7 the same holds as for the marina. Reference is made to S.3.1 for the description of these phases.

4. Demolition of the existing buildings

Many buildings are currently present at the future terminal area. These buildings will not be reused for ferry purposes since they do not meet the requirements for housing ferry terminal facilities. Only the building located at the southern end of the terminal is preserved. All other currently existing buildings are demolished. This phase can commence only after the site is transferred.

6. Renovation of buildings and structures for reuse

After the site is prepared, the Osvaldo quay and the preserved building at the southern end of the terminal area are renovated to be equipped with new services in a later stage.

8. Construction of the first pier

After the Osvaldo quay has been renovated, the construction of the first pier can commence. After construction the terminal provides berths for the ferry vessels.

9. Construction of the terminal building

The construction of the terminal building can start directly after the preparation of the site, simultaneously with the renovation of the Osvaldo quay and the building at the southern end of the terminal area. The terminal building houses the waiting lounge, customs service, money exchange service, catering services and shops. The renovated building at the southern end of the terminal area is equipped with the waste collecting services. Furthermore, in this phase the fuel supply facility, vehicle ramps and walking bridges are installed.

10. Infrastructure

After the construction works of the first pier have finished, the infrastructure inside the ferry terminal and the infrastructure connecting the terminal to the traffic network of Havana can be built. The construction of the new infrastructure should not commence earlier in order to prevent damage caused by heavy construction equipment.

11. Construction of the second pier

The construction of the second pier is performed in the same way as the first pier. The start date of this phase is dependent on the development of the demands for more ferry lines.

S.4 CONSTRUCTION METHOD PER COMPONENT

In this section the construction method per component is explained. The discussion is arranged per sub-project, i.e. marina and ferry terminal.

S.4.1 MARINA

Demolition of the piers

The Vaciadero pier and the Juan Manuel Diaz pier have to be demolished. These structures consist of reinforced concrete floors founded on multiple piles of reinforced concrete. To orderly remove these structures, a waterborne backhoe equipped with demolishing tools and a barge to collect the residues are required. This process can be accelerated by the employment of multiple equipment combinations and crews. After the removal of the floors and piles, the bottom of the basin must be checked for debris.

This debris, if present, must be removed to leave a clean site for the later installation of the (finger) piers. The concrete debris can be reused in the base layer of the constructed roads, which are built later on. The steel debris should be separated as it can be reused by steel companies.

Demolition of existing buildings

The demolition of the first and second floor of the Juan Manuel Diaz no. 1 building requires a lot of caution as the third and fourth floor must be retained in a good condition for reuse. To perform these works, sophisticated demolishing equipment is required; it is possible that this equipment has to be hired from foreign countries. The demolition of several other small buildings around the site requires less caution, as nothing has to be preserved. Also, these buildings are located relatively isolated. Like for the demolition of the piers, the process can be accelerated by applying an enlarged quantity of equipment and working crews.

The debris must be separated by its materials for reuse purposes as is explained for the pier debris. Also the existing buildings may house facilities and materials (e.g. wood, glass and plastics) which can be reused.

Preparation of the site

For the preparation of the site, obstructions like small walls, trees, bumps and holes have to be removed in order to provide unrestricted traffic of equipment and crews around the construction site. It is also possible that a special road for construction equipment is required. Furthermore, this phase is characterized by improving the liveability at site for construction workers: security measures are taken and essential facilities like portable bathrooms are placed.

Renovation of buildings and structures for reuse

The partially demolished Juan Manuel Diaz no. 1 building and the warehouse at the Juan Manuel Diaz no. 2 have to be renovated for reuse. The interior, floors, ceilings and walls have to be rehabilitated for housing the future facilities. In this phase also a new arrangement of the building can be constructed by placing internal walls. Considering the exterior, walls and roofs have to be renovated. Also, replacement of windows and paintwork of the walls is required.

Furthermore, the existing La Coubre quays and Juan Manuel Diaz quays have to be renovated. The quay walls and aprons have to be levelled and reinforced if their strength is insufficient. The quays are moreover prepared for the connection of the piers with the quays. These works will therefore mainly consist of relatively small concrete works performed by small crews and equipment.

Renovation of the utilities

In the reused buildings and over the entire marina area, utility services have to be renovated. An adequate electricity, water and sewage network must be provided in order to house the future facilities. Moreover, the marina requires a water and electricity network that reaches over every pier to provide utilities at every berth. This implies a vast extension of the existing utility networks. The newly built networks have to be connected with the existing networks that are currently renovated as is discussed in 'Appendix Q: Design of the connections to the transport network'.

As the renovation and expansion of networks is relatively extensive, much national labour can be employed. Furthermore, large quantities of pipes and wires are required. Most elements are provided by Cuban companies; only for relatively difficult junctions import may be required.

Marina 1st phase

The characterizing progress of this phase is the installation of the first actual marina facilities. A part of the total amount of marina berths is created by installing piers and finger piers along the existing Juan Manuel Diaz quay. The exact pier configuration is discussed in 'Appendix P: Design of the ferry terminal'. The piers and finger piers consist of floating pontoons attached to each other. The whole is attached to the Juan Manuel Diaz quay and the bottom of the basin. Pontoons occur in a great variety of materials, like: plastics, steel, wood and concrete. The material used is mainly dependent on the availability of materials (at Cuba) and the durability and required maintenance.

Moreover, the floating breakwater is installed; this structure also consists of attachable pontoon elements. During the installation, these pontoons are kept on their final location by working pontoons. From these pontoons, crews can connect the elements of the breakwater to each other and to the Iglesias pier. For the connection of the pontoons to the bottom of the basin, divers are necessary. Furthermore, structures required for launching vessels and the fuel supply station are constructed.

Vital facilities for the existence of the marina are established. All initially required services are installed. This requires a lot of labour (e.g. plumbers, electricians, tillers and installers) and many different building materials. To execute all these processes, special care must be taken for organizing this labour to minimize conflicts. For all executing works, Cuban workmen can be employed.

Infrastructure

The connection of the marina to the existing traffic network is improved by the construction of new roads. The construction of new asphalt layers is performed by the Havana asphalt company. The debris, obtained by the demolition of the piers and buildings, is reused as base material for the construction of the foundation.

Furthermore, the internal traffic system, mainly consisting of walking paths, is constructed in this phase. Also, the connection to the floating boardwalk promenade at the Almacén San José is established. The walkways on the piers and finger piers are equipped with strips to provide sufficient grip. In case of wet surfaces, safe walking can be provided.

Marina 2nd phase

The second phase of the construction of the marina is characterized by the installation of the remaining berths. Like in the first phase, working pontoons with equipment and crews are required to connect the remaining piers and walkways. The La Coubre pier requires finger piers only. Furthermore, less vital structures and facilities of the marina are constructed. Like in the first phase, the establishing of these facilities requires many different kinds of labour and construction material. Like in the first phase a lot of attention must be paid to the organization of the works to minimize conflicts.

S.4.2 FERRY TERMINAL

Demolition of existing buildings

The demolition of the existing buildings can be performed with heavy equipment and extensive crews. These buildings do not have to be preserved, so a quick and dirty (but safe) approach is desired. These buildings mainly consist of steel and concrete elements that can be reused. The concrete elements can be crushed and can in a later stage be applied to the foundation of the roads or the filling of the caissons. The steel elements are brought to the Havana steel factories that re-melt the debris for the manufacturing of new steel elements.

Preparation of the site

After the demolition works, the site has to be cleaned and large debris has to be removed. Obstructions like small walls, trees and heavy irregularities in the roads should also be removed by relatively small equipment and crews. Also special roads for heavy construction equipment may be required.

Renovation of buildings and structures

The most southward located building in the area must be renovated for the installation of the ferry sewage water and garbage collection services. The priority in this renovation is aimed on fitting these services in the building and not on visual attractiveness. This renovation requires small working crews that perform their specific part of the rehabilitation works.

Also, the Osvaldo quay is renovated in this stage of the construction works. The quay wall and apron are required to be in good condition to construct the connection with the piers in a later stage. The extent of this works is hard to predict as the current condition of the quay is not exactly known.

Renovation of current utilities

The existing utility networks around the future terminal area are currently renovated (see also 'Appendix C: Analysis of the surrounding area'). These works are extended to the connecting internal networks of the terminal area. Furthermore, these internal networks require a vast expansion to answer the future demands created by the services and facilities of the terminal building.

Considering the scale of expansion, relatively much material (e.g. pipe systems and wiring) and labour is required. The complexity of this works requires a thorough organization. For sophisticated elements like junctions, import may be required.

Construction of the piers

The construction of the piers is composed of the positioning of eight concrete caissons. These caissons require a levelled bottom to be positioned. The bottom is therefore prepared by the installation of sub-layers and filter layers, consisting of the concrete debris from the demolished buildings and quarry run. As relatively few water motions are present in this part of the basin, it is expected that this material will remain in position during the other construction phases. The caissons are prefabricated at the concrete factory in Guanabacoa, located at the southern waterfront of the Bay of Havana. Taking into account the size of the caissons, it is required to manufacture these caissons in a dry dock that can be filled with water. Subsequently they are transported by waterborne equipment that sails the caissons to their required location along the Osvaldo quay. The caissons are sunk down and installed at their final position. The pier structures are finished by connecting the caissons to each other in order to construct an integral system. The caissons are filled with a mixture of sand, rock and concrete to stabilize the pier structure. The rock consists of quarry run from Cuban quarries or pulverized debris from the demolished building. To finish the piers, the top layer is levelled and the aprons are constructed. The piers are now ready for equipping the required pier facilities.

The two piers are constructed in two separate phases in order to postpone investments. The piers however are identical and the construction processes do not differ. It is stressed that the construction of the second pier is limited by the operational first pier. The construction of the second pier will cause hindrance to the operational first pier. This hindrance must be minimized and the construction works are limited.

Construction of terminal building

The terminal building consists of two or three floors dependent on the exact required space and arrangement of facilities inside the building. This building is constructed in phases; first, the skeleton (consisting of floors, walls and roofs) is constructed. The skeleton will consist mainly of steel, concrete and wood. The exact quantity of these construction materials are not known and is outside the scope of this project. Second, the internal layout is built: the facilities and required services are equipped.

In order to fulfil the construction of this building, relatively much heavy building equipment and relatively few labour is required initially. In the second phase, the required building equipment is more sophisticated and hiring from foreign countries is maybe necessary. Also, required labour increases as many specific construction works like plumbing, tiling, decorating and installing are executed in this second phase. For this works many different construction materials are required. As many special and sophisticated elements are demanded, a lot of import is required. After the completion of these two phases the terminal building is ready for operation.

Also, the sewage water and garbage collecting facilities are installed in the renovated building at the southern end of the terminal area. The storage supply building at the head of the pier is also constructed and equipped with facilities in this construction phase. The fuel supply station is installed inside the building at the head of the pier.

Furthermore, the connections for berthed vessels at a pier are created. The vehicle ramps and walking bridges are steel structures that are relatively sophisticated; it is likely that these structures have to be imported. The assemblage and installation of these structures is performed by local labour from Havana steel factories.

Construction of traffic infrastructure

The ferry terminal requires extensive internal traffic networks and connections (access roads of the terminal) to the surrounding traffic network of Havana. The increase of flow requires improvements to the intersection of roads north of the ferry terminal.

As relatively much asphalt is required, a collaboration of the Havana asphalt company and road constructors will perform these works. The base layer of the roads consists of a mixture of pulverized debris from the demolished building and quarry run from Cuban quarries. It is assumed Havana is able to provide sufficient equipment and labour.

S.5 CONCLUSIONS AND RECOMMENDATIONS

It can be stated that the construction methods of the components explained above are not very detailed, as they are preliminary. During the recommended design phase, improvements on these methods are required. In general this is achieved by refining assumptions and minimizing uncertainties. In order to do so, the recommendations below must be taken into account.

- The required types and quantities of construction material, equipment, products and labour must be investigated. A further division of components is therefore required.
- A more exact estimation of import quantities (construction material, equipment, products and labour) has to be obtained.
- The capacities of Cuban companies and enterprises must be investigated to determine whether assistance from foreign countries is required.
- It is required to determine what specific equipment and tools are required to perform the demolition and construction processes.
- The list of Cuban enterprises is not complete and is based on information that is possibly out of date. An investigation in Cuban factories and companies is required to update and expand this list.
- An investigation is required on the working conditions at the site in order to learn about issues that possibly limit working methods.
- The project planning presented in appendix T provides feedback to improve and tune these construction methods. It is therefore desired to detail the building methods simultaneously with the project planning.

It is stressed that detailed building methods improve the financial (appendix U) and economic (appendix V) evaluations. Furthermore, detailed building methods are required to start tendering and provide thorough construction specifications.

Appendix T: PROJECT PLANNING

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T.1 INTRODUCTION

In this appendix the planning of the project is studied. In order to do so, the project is divided into components, as is explained in 'Appendix S: Construction methods'. Project planning is required since it gives insight into the timescales of the project, but also because there is an interaction with both the building method and the financial analysis.

- The building method per component of the process determines the time required for such a component. Furthermore, the organization of these components in time depends on the building method. For the building method, reference is made to 'Appendix S: Construction methods'
- Project planning provides a basis to perform the financial evaluation. The cash flow studied in the financial evaluation is mainly dependent on the progress of the project. For the financial evaluation, reference is made to 'Appendix U: Financial evaluation'.

The project planning should not be seen as an exact instruction of the required start and end date of the project. Such an exact instruction is simply impossible at this stage of the study. The purpose of project planning in this study is to get insight into the project progress and in order to provide information for the financial analysis and to tune the building method.

Also, it is difficult to give the exact progress of the project as it is dependent on many (foreseen and unforeseen) circumstances. As the nature and impact of these circumstances is unknown, three scenarios for the progress of the project are studied. In chapter T.2 a 'fast', 'moderate' and 'slow' progress of the project processes are discussed. The resulting output according to these scenarios is evaluated in chapter T.3. In appendix X, Gantt charts of the scenarios are given.

T.2 DESCRIPTION OF THE SCENARIOS

In this section three scenarios are considered for the development in time of the project process. The development is mainly dependent on political progress and the progress of building processes. The considered scenarios are based on: a 'slow', a 'moderate' and a 'fast' development in time.

T.2.1 FAST

In this scenario it is assumed both political and building progress is achieved relatively fast. The embargo by the United States is raised promptly and without time consuming difficulties. As a result, the demands for the marina and ferry lines will increase fast and available financial resources increase.

Also, the building processes are performed in a steady way without severe delays. The second phase of the project is therefore executed relatively early after the first phase has ended. The delays and required building time per component are assumed to be short. This scenario therefore gives insight in the lower limit of the total time required to finish the entire project.

T.2.2 MODERATE

In this scenario a moderate progress of both political and building progress is assumed. The raise of the embargo by the United States is executed step by step, taking into account that some time consuming difficulties will arise. Also, the building processes have fluctuating progress. This scenario therefore gives insight in the more or less expected required time for the execution of the entire project.

T.2.3 SLOW

In this scenario it is assumed both political and building progress is achieved relatively slow. The embargo by the United States is continued for a relatively long time. The demand for the marina and especially ferry lines to cities in the United States is as a result low. Also, it is assumed building processes are delayed for relatively long times. The second phase of the project is therefore postponed for a relatively long time. This scenario therefore gives insight in the upper limit of the total time required to execute the entire project.

T.3 SCENARIO OUTPUT

In this section characteristic output of the scenario-dependent plans is presented. The complete plans are depicted in Gantt charts given in appendix X. The start of the project process is set to January 1st, 2014.

T.3.1 FAST

table T.1 – planning characteristics for scenario 'fast'

Characteristic	Point in time / Duration
Start date	01-01-2014
End date	2029
Total duration	15 years
Total duration of construction delays	4 years, 6 months

T.3.2 MODERATE

table T.2 – planning characteristics for scenario 'moderate'

Characteristic	Point in time / Duration
Start date	01-01-2014
End date	2042
Total duration	28 years
Total duration of construction delays	13 years

T.3.3 SLOW

table T.3 – planning characteristics for scenario 'slow'

Characteristic	Point in time / Duration
Start date	01-01-2014
End date	2056
Total duration	42
Total duration of construction delays	28 years, 6 months

T.3.4 ADDITIONAL DELAYS

The demand for the marina and ferry terminal determines the required start date of the project. The lack of demand may also require postponement of the project. This postponement is taken into account as an initial delay.

Also, the start date of the second phase is possibly postponed dependent on the demands for expansion. This postponement is called the 2nd phase delay. The effects of these postponements are given in table T.4 and table T.5 for the marina and ferry terminal respectively.

table T.4 – additional marina delays

Marina Scenario	Initial delay (year)	Marina 2 nd phase delay (year)	Operational (year)	End date (year)
Fast	1	8	2026	2036
Moderate	5	15	2044	2062
Slow	20	30	2068	2104

table T.5 – additional ferry terminal delays

Ferry Scenario	Initial delay (year)	Ferry 2 nd pier delay (year)	Operational (year)	End date (year)
Fast	1	10	2028	2040
Moderate	5	30	2042	2076
Slow	20	50	2067	2126

It is stressed that the end dates presented, are the dates the **total** project is finished; the marina and ferry terminal are operational earlier. The completion of the second project phases is the date the marina and ferry terminal are fully operational.

In table T.6 ranges are presented of the expected end dates of the first and second phase, for both the marina and ferry terminal.

table T.6 – ranges of required time

	First phase		Second phase	
	Lower limit (year)	Upper limit (year)	Lower limit (year)	Upper limit (year)
Marina	2026	2068	2036	2104
Ferry Terminal	2028	2067	2040	2126

T.4 CONCLUSIONS AND RECOMMENDATIONS

The plans presented in this appendix are preliminary and require further detailing. Most improvement is gained by decreasing uncertainties on the times required to perform specific components and the duration of delays. To achieve this, one could:

- Further divide components into elements
- Gain more information on building methods
- Compare the elements to reference cases
- Gain more information about capacities of companies and equipment
- Study the continuity of building processes

The series of components that have their effect on the total required time to execute the project determine the critical path. To reduce the total time required for executing the project one should reduce the times required for the components of the critical path. Furthermore, the critical path can be shortened by reorganizing critical components to be executed simultaneously or by introducing more working shifts. However, this will require an increase of labour and equipment. In order to decide on this, the effect of the measure on finances must be analysed.

In general the time required to perform components can be reduced by:

- Detailing and organizing building methods
- Increasing the continuity of processes
- Increasing the occupancy of equipment
- Installation of an overall project progress control

Furthermore, it is recommended to improve the project planning using the feedback from the financial analysis. It is also recommended to perform these analyses simultaneously as they have a strong interaction. Investments in time determine the total costs of the project. From the financial analysis, it may appear postponing specific components may be profitable. From the financial studies it can be concluded that further phasing the total project is profitable and therefore advisable.

Also, the uncertainty of the expectation on the end date increases as the duration of the project increases. This is a result of the superposition of uncertainties of individual components.

Lastly, the raise of the embargo is the factor with the most influence on the estimation of the total required time to execute the project. An early and smooth raise of the embargo will accelerate the progress of the project.

Appendix U: FINANCIAL EVALUATION

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U.1 INTRODUCTION

This appendix will focus on the financial evaluation of the project. A financial evaluation can be used to measure the feasibility of a project. The evaluation constitutes an inventory of the financial in- and outflows, combined with a construction planning. The combination with a planning allows investors to see whether investing in a marina and a ferry terminal in Havana qualifies as a sound investment.

If the financial evaluation shows that the project has difficulties generating a positive return on investment, it can be concluded that the project requires additional external funding in the form of subsidies. Whether the project qualifies for subsidies is investigated in 'Appendix V: Economic evaluation'.

The main inputs for a financial evaluation are the costs of a project. It is general practice to estimate these costs based on a detailed design. The more detailed a design is, the more accurate the estimation of costs becomes. In this case, the design is not detailed enough to make a cost estimation based on exact volumes, i.e. volumes of the basic construction materials such as concrete, steel, wood etc.

Therefore, the estimation of costs is done on the basis of general unit costs. As there are not sufficient references of similar Cuban projects available, foreign references have been used where possible. This leads to the problem of dealing in foreign currencies, which in the case of Cuba can have large consequences for the financials of a project. Because the majority of cost information sources are foreign, it has been decided to construct the financial evaluation as if it were not a Cuban project, but a European or American project. This assumption has led to the use of the Euro as the main currency in this evaluation. The combination of a foreign currency and foreign cost information sources leads to a *high* uncertainty regarding construction costs. Another important basic assumption in the financial evaluation is that the cash in- and outflows are concentrated at the end of each year.

As the future situation of Cuba regarding the embargo is difficult to predict, it is recommended to apply the same scenarios as are set out in 'Appendix T: Project planning' for the financial evaluation. In this evaluation only the scenario 'fast' is used, due to the fact that it can be considered a positive scenario, but also due to time restrictions for this project. It is expected that the conclusions and recommendations done in this evaluation are also generally applicable to the other two scenarios.

The first step in the financial evaluation is the accounting of the cash in- and outflows, which is done in chapter U.2. Following the accounting of the cash flows is the coupling of the cash flows to the construction planning, done in paragraph U.3.1. If cash flows are coupled to the construction planning, it is possible to calculate the net present value of the project, as is done in paragraph U.3.2. The net present value calculation is the starting point for a refinement of the construction and financial planning. The effects of adjusting these variables are investigated in the sensitivity analysis, chapter U.4. The financial evaluation concludes in chapter U.7, in which conclusions and recommendations about the financial aspects of the project are given.

U.2 CASH FLOWS

U.2.1 CASH OUTFLOWS

The main cash outflows can be related to the phases in the lifetime of the project. Where possible, outflows have been divided in material costs (including equipment) and labour costs. The main cash outflows are²⁶:

1. Design (K)
2. Construction (K)
3. Operations (C)
4. Maintenance (C)
5. Demolition/rest value (K)
6. Interest charges (I)
7. Repayments (Rep)

Design and construction

In table U.1 and table U.2 the lists of estimated costs per component are given. For the marina there are ten main components, for the ferry there are thirteen. Where possible, subcomponents have been divided in specifics, in order to make a more accurate cost estimation. For each subcomponent, the costs have been estimated using unit costs. The unit costs are mainly derived from reference projects, but also from general unit cost lists and Cuban construction cost books (PRECONS, 1998). Where no reference was available, the costs have been estimated using the other costs as reference values.

Each unit value is a complete representation of construction costs, which include materials, equipment and labour. To gain insight into the effects of labour for a follow up study, the labour costs have been determined as a percentage of the total construction costs.

Operations

Operations start after the construction of the marina is finished, in year 12. It is estimated that during the operation, the split between labour and operation (e.g. electricity bills) is 20-80%.

The total operation costs per year, when the first phase of the marina is finished, are estimated to be € 500 000,-. Later, when the ferry is operational, these costs rise to € 1 000 000,-. When the 2nd phases of the marina and ferry are ready for operation, the costs rise again to a total of € 1 500 000,-.

Maintenance

In the same way as operational costs fluctuate over time, so do maintenance costs. It is reasoned that in the first years, maintenance costs are low, as not much maintenance is needed. In year 11, maintenance starts, costing practically nothing and rising slowly to a maximum of € 500 000,- for the 1st phase of the marina. Every time a new component (marina or ferry) is finished, there is a rise in the maintenance cost curve. In the 29th year, the curve is flat at a value of € 1 500 000,-.

²⁶ K = Investment in fixed and working capital C = Operating costs I = Interest charges Rep = Repayments

Demolition/rest value

When considering project costs, usually a price is taken into account for demolition costs at the end of a projects lifetime. In this case, the lifetime is 50 years, but some phases of the project start much later in time then the first phases. For this reason, instead of demolishing the structure, a rest value is used. The rest value can be defined as:

$$\text{Rest value} = \text{investments} * \frac{\text{lifetime} - \text{accounted years}}{\text{lifetime}}$$

This means that after a certain period (50 years from year zero in this case), the project continues to generate profits, giving the project a certain value at this time. From this value the demolition costs are subtracted; the costs for demolition are estimated at € 4 500 000,-.

Interest charges

Interest charges are the costs of loaning money. Each year a percentage of interest over the total outstanding sum of loaned money is paid.

Repayments

When the project starts generating revenue, it is possible to make repayments. This will lower the interest charges on the loan, as the loan will decrease.

table U.1 - list of estimated costs per component for the marina

Component	Subcomponent	Specifics	Construction and labour				Labour						
			Material	Unit	Unit costs	Quantity	Costs	% const.	Unit	Unit costs	Quantity	Costs	
Marina													
1	Design	-	-	-	-	-	-	-	#	500000	1	500000	
2	Transference	-	-	m2	30	55000	1650000	-	-	-	-	-	-
3	Demolition of the piers												
	Vaciadero	95*8*2	-	-	-	-	-	-	m3	76.37	1520	116082.4	
	Juan Manuel Diaz	150*40*2	-	-	-	-	-	-	m3	76.37	12000	916440	
4	Demolition of existing buildings	120*20*5	-	-	-	-	-	-	m3	43.42	12000	521040	
5	Preparation of the site	-	-	m2	8	55000	440000	0.3 %	-	-	-	132000	
6	Renovation of facilities for reuse												
	Juan Manuel Diaz 1	-	-	m2	50	11000	550000	0.3 %	-	-	-	165000	
	Juan Manuel Diaz 2	-	-	m2	50	7700	385000	0.3 %	-	-	-	115500	
	La Coubre Pier	-	-	m2	50	5000	250000	0.3 %	-	-	-	75000	
	Existing quay walls	-	-	m	200	1250	250000	0.3 %	-	-	-	75000	
	Iglesias pier	-	-	-	-	-	250000	0.3 %	-	-	-	75000	
7	Renovation of the utilities												
	Water supply	-	-	#	30000	1	30000	0.4 %	-	-	-	12000	
	Electricity supply	-	-	#	30000	1	30000	0.4 %	-	-	-	12000	
	Sewage system	-	-	#	30000	1	30000	0.4 %	-	-	-	12000	
8	Marina phase 1												
	Piers (3)												
		Floating dock	-	m2	3600	3.42	12312	0.2 %	-	-	-	2462.4	
		Dock hardware	-	#	10000	3	30000	0.2 %	-	-	-	6000	
		Dock anchoring	-	#	5000	9	45000	0.3 %	-	-	-	13500	
		Electricals	-	#	10000	1	10000	0.4 %	-	-	-	4000	
		Fire protection	-	#	1200	9	10800	0.2 %	-	-	-	2160	
		Gates	-	#	500	3	1500	0.2 %	-	-	-	300	
		Floating Breakwater	-	m	23	5000	115000	0.3 %	-	-	-	34500	
		Fuel supply	-	#	35644	1	35644	0.3 %	-	-	-	10693.2	
		Boat launch or trailer ramps	-	#	15000	1	15000	0.2 %	-	-	-	3000	
		Parking and dry berthing areas	-	m2	10	2000	20000	0.2 %	-	-	-	4000	
		Garbage collecting service	-	#	60000	1	60000	0.4 %	-	-	-	24000	
		Customs services	-	m2	500	150	75000	0.3 %	-	-	-	22500	
		Money exchange	-	m2	200	100	20000	0.3 %	-	-	-	6000	
		Personal care and health	-	m2	200	200	40000	0.4 %	-	-	-	16000	
		Shops	-	m2	1250	250	312500	0.4 %	-	-	-	125000	
9	Infrastructure												
	Roads	-	-	m2	15.83	1750	27702.5	0.3 %	-	-	-	8310.75	
	Walking paths	-	-	m2	5	500	2500	0.4 %	-	-	-	1000	
10	Marina phase 2												
	Piers (4)												
		Floating dock	-	m2	4800	3.42	16416	0.2 %	-	-	-	3283.2	
		Dock hardware	-	#	10000	4	40000	0.2 %	-	-	-	8000	
		Dock anchoring	-	#	5000	12	60000	0.3 %	-	-	-	18000	
		Electricals	-	#	13000	1	13000	0.4 %	-	-	-	5200	
		Fire protection	-	#	1200	12	14400	0.2 %	-	-	-	2880	
		Gates	-	#	500	4	2000	0.2 %	-	-	-	400	
		Hotel	-	m2	1000	5000	5000000	0.1 %	-	-	-	500000	
		Catering service	-	m2	1250	500	625000	0.1 %	-	-	-	62500	
		Yachting club	-	m2	1250	300	375000	0.1 %	-	-	-	37500	
		Supermarket	-	m2	1250	300	375000	0.2 %	-	-	-	75000	
		Recreational services	-	m2	1250	2500	3125000	0.1 %	-	-	-	312500	
		Personal care and health	-	m2	200	200	40000	0.4 %	-	-	-	16000	
		Shops	-	m2	1250	250	312500	0.2 %	-	-	-	62500	

table U.2 - list of estimated costs per component for the ferry

	Component	Subcomponent	Specifics	Construction and labour					Labour					
				Material	Unit	Unit costs	Quantity	Costs	% const.	Unit	Unit costs	Quantity	Costs	
Ferry														
1	Design		-	-	-	-	-	-	-	#	750000	1	750000	
2	Transference		-	-	m2	30	60000	1800000	-	-	-	-	-	-
3	Demolition of buildings		-	-	-	-	-	-	-	m2	30	30000	900000	
4	Preparation of the site		-	-	m2	8	60000	480000	0.3 %	-	-	-	144000	
5	Renovation of facilities for reuse													
		Quay wall	-	-	m	200	500	100000	0.3 %	-	-	-	30000	
		Building	-	-	m2	50	1500	75000	0.4 %	-	-	-	30000	
6	Renovation of current utilities													
		Water supply	-	-	#	30000	1	30000	0.4 %	-	-	-	12000	
		Electricity supply	-	-	#	30000	1	30000	0.4 %	-	-	-	12000	
		Sewage system	-	-	#	30000	1	30000	0.4 %	-	-	-	12000	
7	Construction of the first pier													
		Preparation of the bottom	-	-	m2	4800	5	24000	0.5 %	-	-	-	12000	
		Construction of caissons	-	-	Concrete	m3	200	5966	1193200	0.4 %	-	-	477280	
		Filling the caissons	-	-	Sand	m3	0.28	19929	5580.12	0.1 %	-	-	558.012	
		Completion for use	-	-	m2	5	3450	17250	0.3 %	-	-	-	5175	
		Fenders	-	-	m	100	236	23600	0.2 %	-	-	-	4720	
8	Construction of terminal building													
		Waiting lounge	-	-	m2	30000	750	22500000	0.2 %	-	-	-	4500000	
		Fuel supply	-	-	#	35000	2	70000	0.3 %	-	-	-	21000	
		Customs services	-	-	m2	500	150	75000	0.3 %	-	-	-	22500	
		Money exchange services	-	-	m2	200	150	30000	0.3 %	-	-	-	9000	
		Catering services	-	-	m2	1250	500	625000	0.1 %	-	-	-	62500	
		Shops	-	-	m2	1250	500	625000	0.2 %	-	-	-	125000	
9	Waste collecting services													
			-	-	#	60000	2	120000	0.3 %	-	-	-	36000	
10	Vehicle ramps													
			-	-	#	100000	4	400000	0.2 %	-	-	-	80000	
11	Walking bridges													
			-	-	#	7000	4	28000	0.4 %	-	-	-	11200	
12	Construction of traffic infrastructure													
		Terminal roads	-	-	m2	15.83	20000	316600	0.3 %	-	-	-	94980	
		Parking area	-	-	m2	15.83	12500	197875	0.4 %	-	-	-	79150	
		Access roads	-	-	m2	15.83	1750	27702.5	0.3 %	-	-	-	8310.75	
13	Construction of the second pier													
		Preparation of the bottom	-	-	m2	4800	5	24000	0.5 %	-	-	-	12000	
		Construction of caissons	-	-	Concrete	m3	200	5966	1193200	0.4 %	-	-	477280	
		Filling the caissons	-	-	Sand	m3	0.28	19929	5580.12	0.1 %	-	-	558.012	
		Completion for use	-	-	m2	5	3450	17250	0.3 %	-	-	-	5175	
		Fenders	-	-	m	100	236	23600	0.2 %	-	-	-	4720	

U.2.2 CASH INFLOWS

Regular cash inflows start when the construction is finished and the operation of either the marina or the ferry commences. Other sources of inflow are at the start of the project, when financing is sought in the form of loans or subsidies. For this project they are²⁷:

1. Marina occupants (permanent and temporary clients) (R)
2. Ferry companies (R)
3. Side-line companies (R)
4. Loans (B)
5. Subsidies (S)

Marina occupants (permanent and temporary clients)

The marina will be composed of berths for temporary clients (visitors) and permanent clients (berth for a whole year). The split for this division is assumed to be 90-10%, as it is likely that the most part of the users will be tourists that want to stay only some days in Havana.

The 1st phase of the marina is operational in the 12th year. In the beginning it will not be operating at its maximum capacity. Therefore, it is assumed that the occupancy rate in the first year of operation is 10%, gradually increasing by 5% each year. In the ninth year of operation, the 2nd phase of the marina is opened, creating a dip in the occupancy rate to 30%. The occupancy rate is expected to reach a maximum of 50% averaged over the year, because of seasonal variations and the relatively large size of the marina.

It is customary to charge a berthing fee per length of the vessel. In the design of the marina there is space reserved for a wide variety of vessels. For simplicity a uniform fee is assumed of € 75,- per vessel per day. In reality, larger yachts would pay more, smaller yachts would pay less.

For the permanent berths a different rate is used. Permanent clients are assumed to be of Cuban origin and would pay a yearly fee. This fee is assumed to be € 2 000,-, the other parameters regarding occupancy are similar for permanent clients.

Ferry companies

The ferry terminal will be operated the way an airport is generally operated. That means that general terminal operations are done by the owner of the terminal facilities, and that ferry companies pay a 'rent' for occupying the berths along the pier. This rent is derived from the expected profits a ferry company would make per trip. It is assumed that € 6 000,- of these profits is a reasonable asking price for each time a vessel berths in Havana.

In the beginning there will be two daily departures from Havana (to Key West and Miami). When the 2nd terminal is operational, this will increase to three departures.

Side-line companies

The side-line companies will be subcontracted to different companies for each side-line activity. These companies will pay rent for the use of the available area for their enterprises. The first side-line operations start at the finish of the 1st phase of the Marina (year 12); which has 250 m² available floor space for 'shops'. In year 15 the ferry terminal is operational, providing 8 850 m² floor space to a variety of side-line companies. At this time also the parking area is operational, adding 12 500 m². In year 21 the 2nd phase of the marina is finished, which provides much more floor

²⁷ R = Current sales B = Borrowing S = Subsidies

space to side-line companies (8 850 m²). For each square meter a rent is assumed of € 50,-.

Loans

Loans are needed to finance the project in the beginning of its lifetime, to finance investments when no revenue is generated.

Subsidies

When there is a general benefit to society or the economy, a governmental organisation may decide to subsidize the project. They will not request interest charges, as they can see the project as an investment on a higher level, by generating labour or environmental benefits.

U.3 TIME ASPECT – DISCOUNTING THE CASH FLOWS

Future cash flows can be discounted to the present using the time value of money. There are two methods available to measure the profitability of a project: the net present value (NPV) and the internal rate of return (IRR).

The planning from the 'fast' scenario is used, as set out in 'Appendix T: Project planning'

U.3.1 CASH FLOWS COMBINED WITH PLANNING – WITHOUT DISCOUNTING

Cash flows without financing costs

The first step is to combine the time aspect with the cash flows (figure U.1). In blue the outflows are visualized, the four blue peaks represent the investment costs for the phases of the marina and ferry. The red peak at the end represents the rest value.

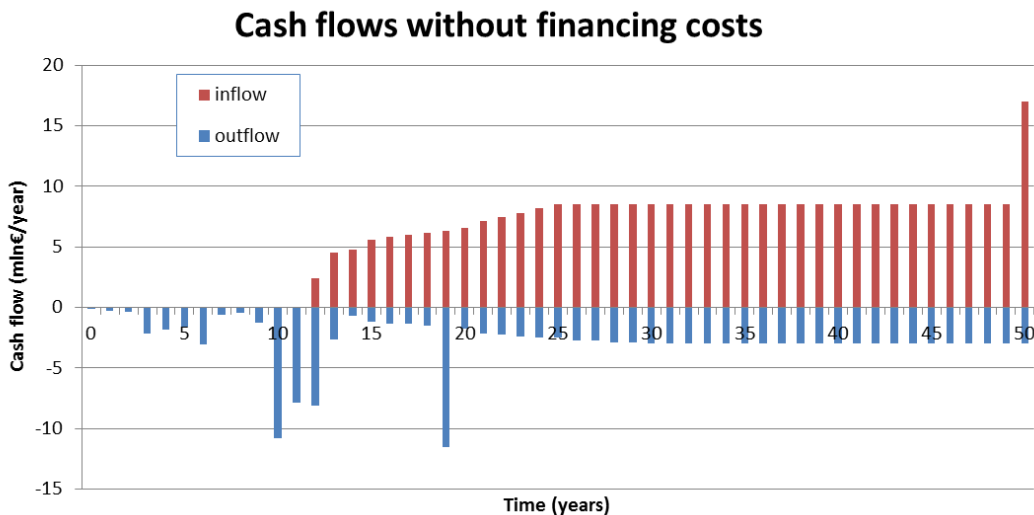


figure U.1 - non discounted cash flows per year

To visualize if the project needs external financing, the cumulative cash flow can be used (figure U.2). This is a tool to see whether at any point in time there is a negative cash balance. It is obvious that as long as there is no revenue, external financing is needed to pay for investments (construction). From the figure it can be seen that this external financing should amount to about € 35 million.

What is also visible in the cumulative cash flow is that the timing of the 2nd phase is unfortunate, as there is not a positive cash balance at that point.

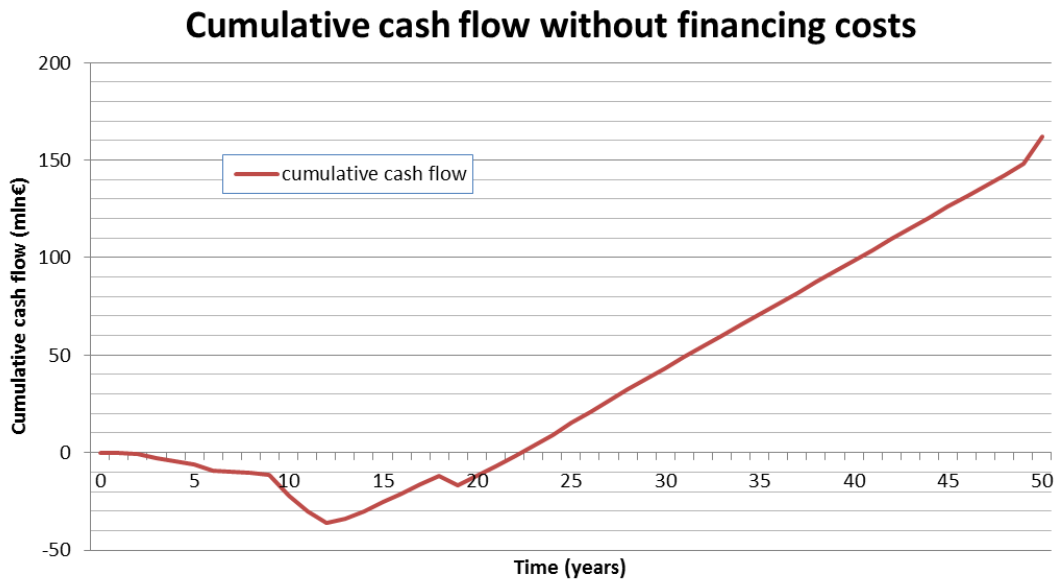


figure U.2 - non discounted cumulative cash flows per year

Cash flows with financing costs

The cash flows with financing costs as in- and outflows are visualized in figure U.3. What is noticeable is the big inflow of € 35 million at the start of the project, and the big outflow in year 34. This big outflow is a repayment of the loan, for simplicity done in one year. The loan itself consists of all the money needed for the design of the project, the construction and the operation and maintenance in the first years. On top of these costs, an extra 10% will be borrowed in order to stay clear of liquidity problems when unexpected costs have to be made. If the regular outflows are subjected to a closer inspection, it can be seen that they are € 2 million a year higher than without financing costs. This is how the interest charges have effect on the cash balance.

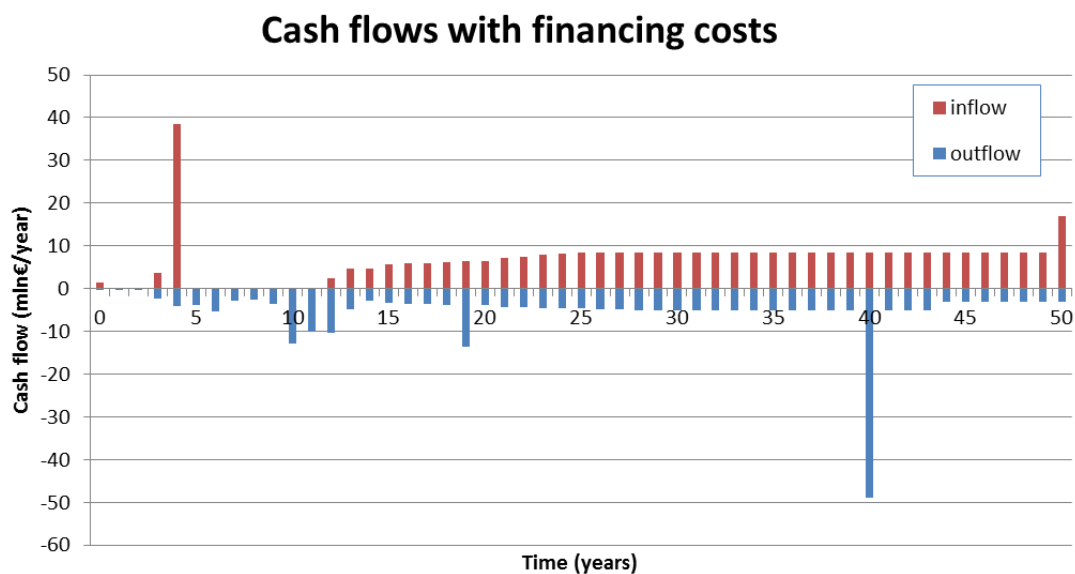


figure U.3 - non discounted cash flows with financing costs

The effect of the loan of € 35 million and the consequences of the interest charges can best be seen in the cumulative cash flow (figure U.4). The figure reveals that in spite of the loan, the cash balance still takes on negative values. This can be attributed to the relatively high interest charges.

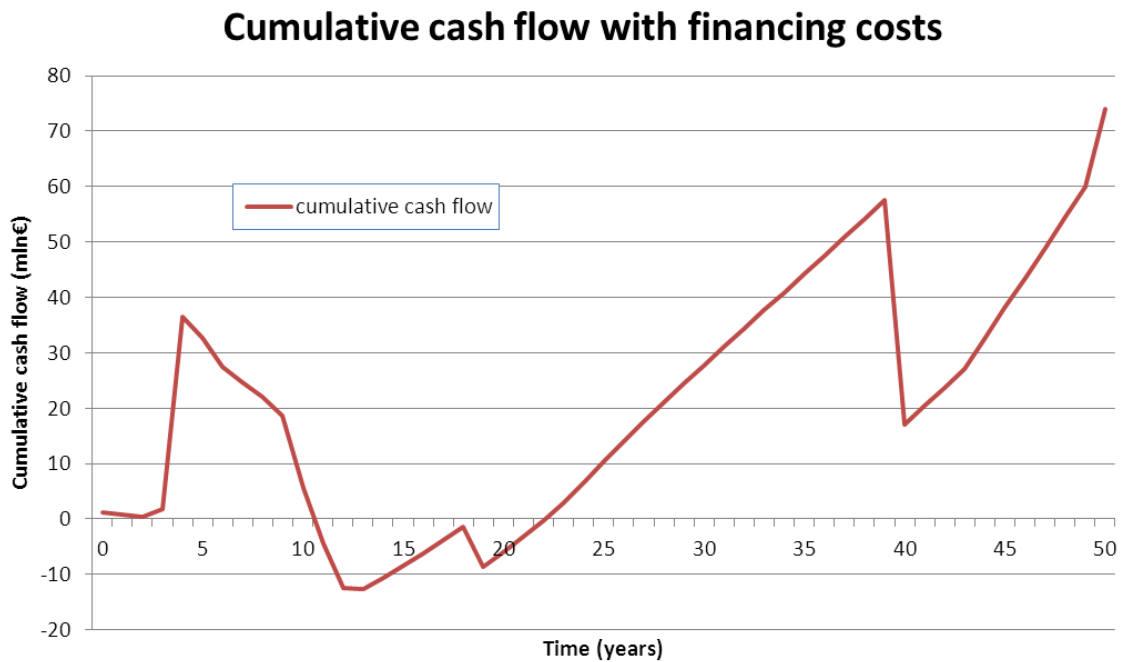


figure U.4 - non discounted cumulative cash flow with financing costs

U.3.2 NET PRESENT VALUES

The net present value is acquired by discounting the costs with a certain discount rate, using the following principle:

$$NPV = \sum_{t=0}^T \frac{X_t}{(1+i)^t} = \frac{X_0}{1} + \frac{X_1}{1+i} + \frac{X_2}{(1+i)^2} + \dots + \frac{X_T}{(1+i)^T}$$

For the discount rate (i) a common value of 5% is used, which is a low value for a preliminary investigation into the finances of a project.

Net present value without financing costs

The curve of the NPV without financing costs takes on a normal shape, creating positive value 27 years after the start of the project (figure U.5). After this point, it can be stated that the investment has been worthwhile.

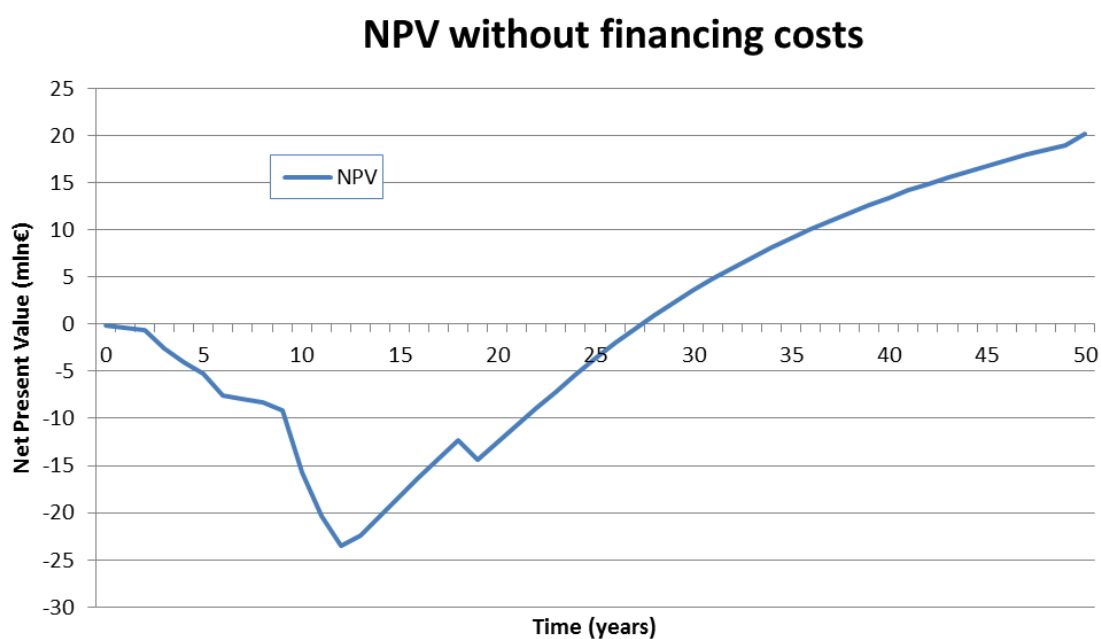


figure U.5 - net present value without financing costs

Net present value with financing costs²⁸

If the NPV of the project with financing costs is calculated, it shows that during the considered lifetime of 50 years, the project can not generate a positive net present value (figure U.6).

An important conclusion to draw from this figure is that, under the current circumstances, the project is not viable. This means that unless the circumstances surrounding financing, project costs, project planning and project design do not change, it is not worthwhile to invest.

It is also important to note that while the NPV curve is approaching zero, the current external financing is not sufficient to generate a positive cash balance during the construction phase. In other words, a higher investment is needed, generating higher interest charges, which cause an even longer time for the NPV to reach zero.

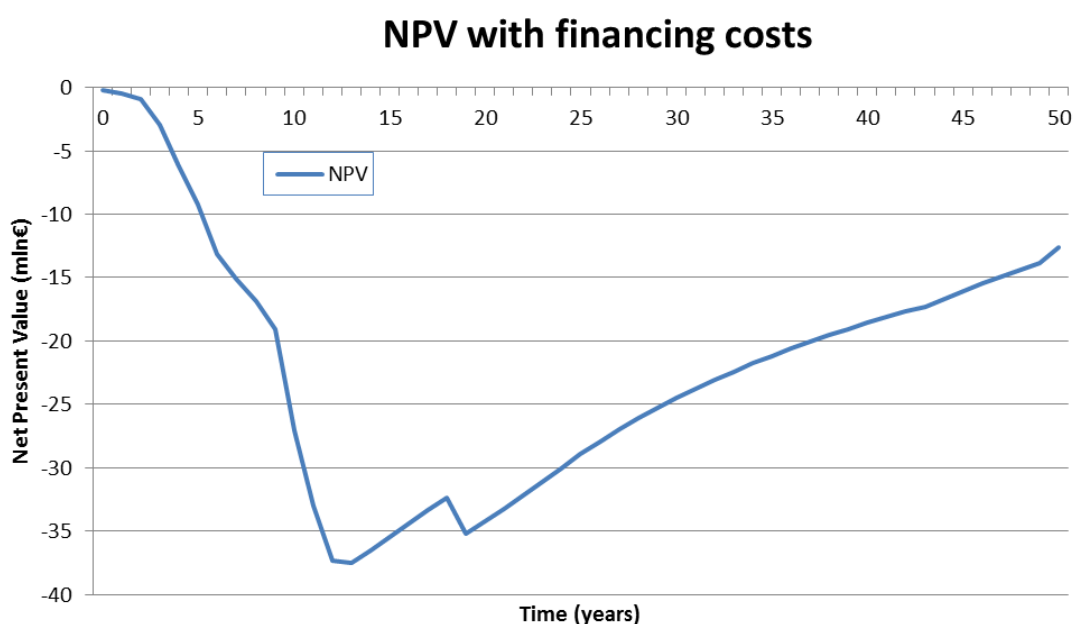


figure U.6 - net present value with financing costs

U.3.3 INTERNAL RATE OF RETURN

The second method to measure profitability is the internal rate of return (IRR) of a project, using a reverse of the NPV method, as follows:

$$\sum_{t=0}^T \frac{X_t}{(1+i)^t} = NPV = 0$$

But as the NPV method has demonstrated, during the considered lifetime of the project, there is no internal rate of return possible under the current circumstances.

²⁸ In the NPV calculation the income peak of the loan is not added, only interest charges due to the loan are added.

U.4 SENSITIVITY ANALYSIS

In this chapter, different variables will be treated to optimise the cash flow of the project. In each case only one considered variable will be changed, the others will remain constant to see the effect of this particular variable.

U.4.1 REFERENCE CASE

In the reference case a negative cash flow is present between approximately 11 years and 22 years after initiating the project, despite the initial loans. The minimum value is about € -12.4 million. A more detailed explanation can be found in U.3.1.

Cumulative cash flow with financing costs

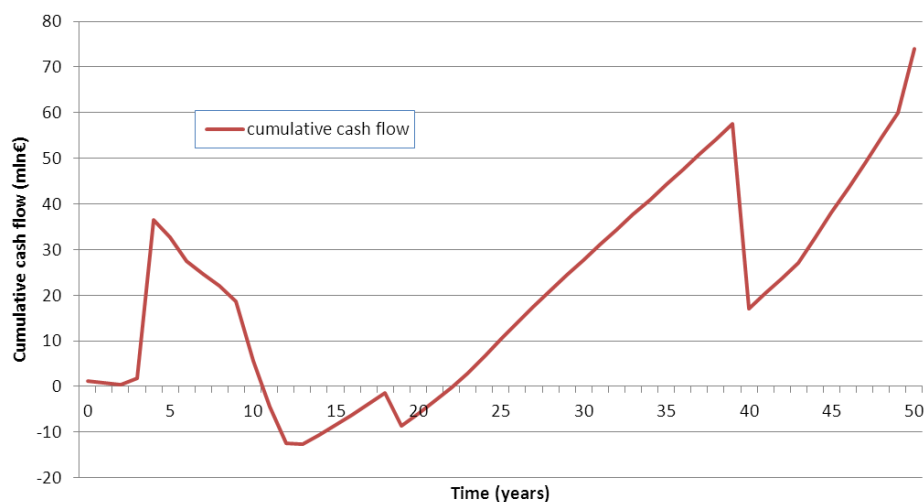


figure U.7 - reference scenario

U.4.2 HIGHER INITIAL LOANS

A possibility for decreasing the negative cash flow is to receive a higher initial loan (if possible). However, the interest values will be significantly higher so the business should create sufficient revenues to repay this interest. With an initial loan of 85 million euros the cash flow remains positive, but this solution proves not to be viable since the business is not generating enough cash to repay the high interests.

Cumulative cash flow with financing costs

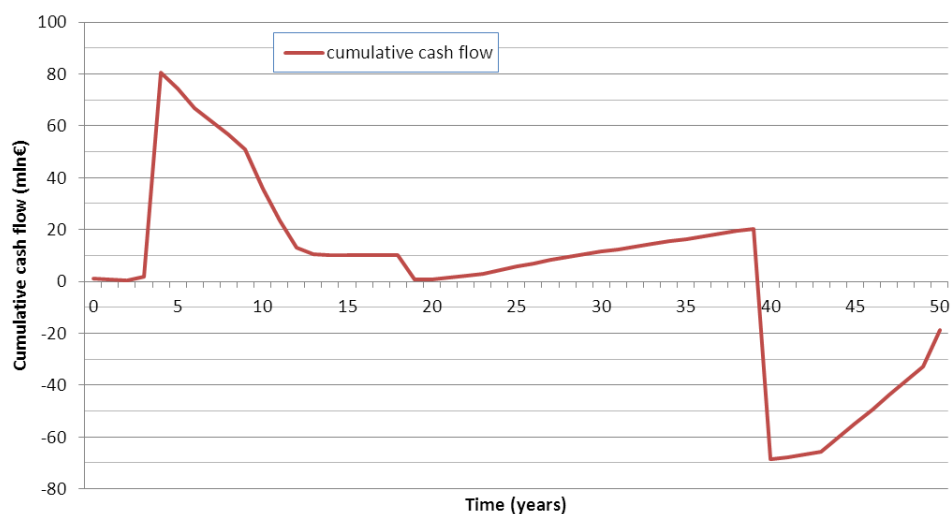


figure U.8 – cumulative cash flow for higher initial loan

U.4.3 EARLIER REVENUES

In the reference case, the marina and ferry terminal open after 12 years, so the first revenues can be seen after 13 years. This is due to the design and building of these facilities. In this scenario, one assumes that the marina and ferry terminal open some period earlier due to a decrease in building time or design time.

If the marina and ferry terminal open 2 years earlier than initially is expected, the negative cash flow decreases significantly. Also, one assumes that the side-line companies open 2 years earlier and that more of these companies open at once. It proves to be the case that earlier revenues are wanted. The cumulative negative cash flow will reduce and phase 2 of the project can be paid with equity capital.

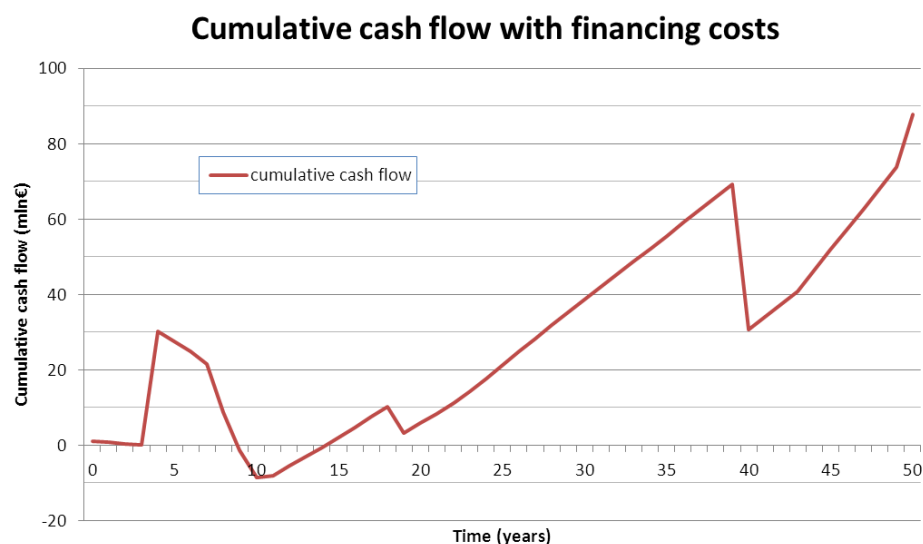


figure U.9 - cumulative cash flow for earlier revenues

U.4.4 HIGHER REVENUES

In this scenario there will be searched to obtain more revenue within the company. It must be stated that this is a hypothetical scenario and that some of these assumptions may not be possible. It is for instance possible to increase the rental prices for the temporary berths from 75 euro to 150 euro per night. Also, the ferry revenues are increased from 2 to 2.5 million euro in the first year and from 4 to 5 million euro in the remaining years. The results can be seen in figure U.10. It can be seen that higher revenues are an important factor for the entire business. The negative cash flow decreases significantly and also here, phase 2 can be financed with equity capital. Furthermore, substantially higher cash flow is present in later stages of the project. It can be reasoned that with such revenues, a higher initial loan may be possible.

Again, some of these measures are not realistic. This is just to show which measures can provide a viable project.

Cumulative cash flow with financing costs

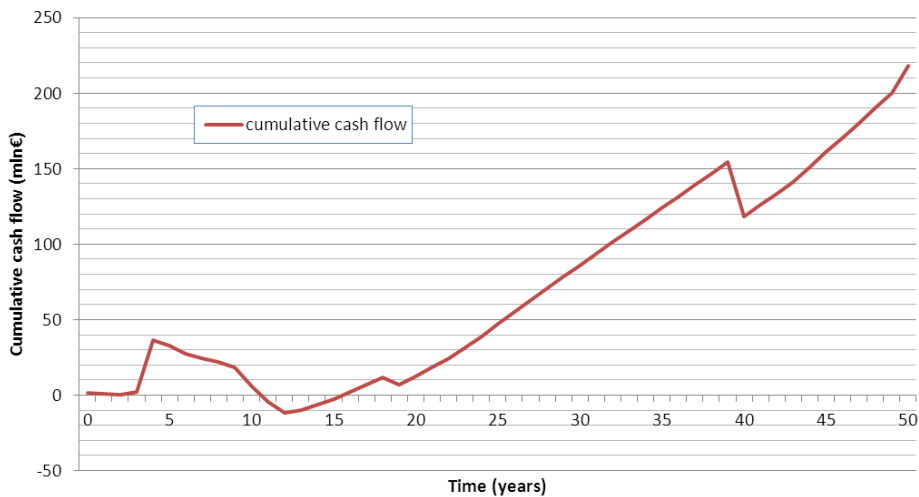


figure U.10 - cumulative cash flow higher revenues

U.4.5 PHASE 2 EARLIER OR LATER

These 2 scenarios will be investigated to see if it is viable to begin earlier or later with the expansion of the marina and ferry terminal.

Phase 2 earlier

In this case, construction begins five years earlier than in the reference case. Phase 2 holds that the walkways of the marina will be expanded and that the second pier of the ferry terminal will be constructed. In this case, revenues are acquired earlier in the project, but building costs are also advanced back in time. In this case, an assumption has been made about the occupancy rate. This is assumed higher (20 % instead of 10%) in the beginning so that earlier expanding can be justified.

The results can be seen in figure U.11, but they don't prove to be satisfactory. A higher negative cash flow can be seen and no equity is available for the expansion. Advancing of phase 2 does not give a viable solution.

Cumulative cash flow with financing costs

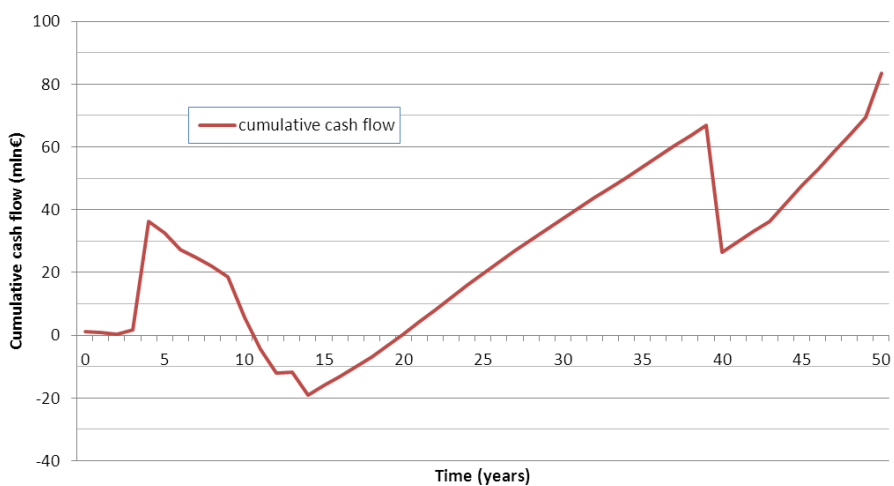


figure U.11 - cumulative cash flow for phase 2 earlier in time

Phase 2 later

The same will be done as in ‘Phase 2 earlier’, but now the construction of phase 2 will be postponed 5 years. Also the occupancy rate will be adapted to fit this scenario; at the start the occupancy rate is 10 % and rises 5 % per year to stop at a constant 50 %. With respect to the reference case, this seems to be an appropriate scenario. Although the negative cash flow is not reduced, the business has enough time to acquire a positive cash flow when the construction (= costs) of phase 2 starts. This can be financed with equity capital.

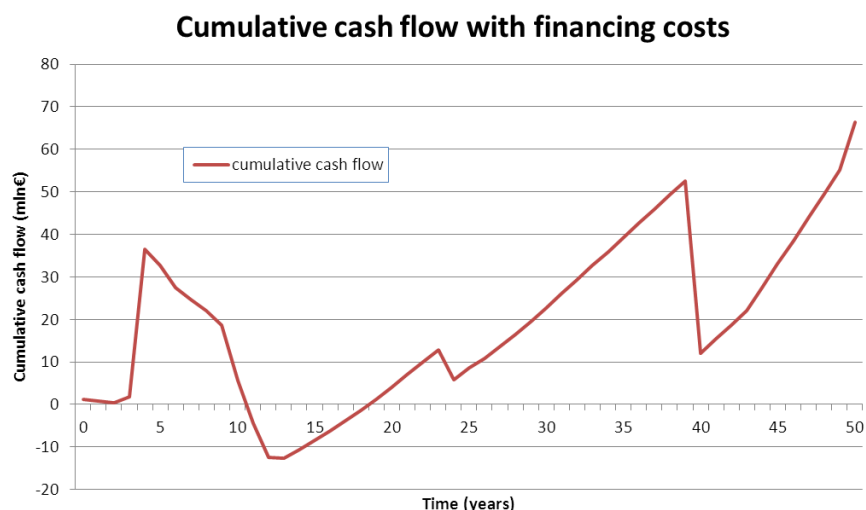


figure U.12 - cumulative cash flow for phase 2 later in time

U.4.6 SPREADING OF THE CONSTRUCTION LOAN

In the reference case, money will be rent for construction at once. This will be done after 5 years. It is useful to find out if spreading of this loan is an appropriate solution to reduce the negative cash flow. Therefore, the exact amount of money will be rented *each year* to minimize the interests. It is stated that the same amount of money will be lent as in the reference case. The result can be seen in figure U.13. The figure proves that this solution is very appropriate since it minimizes the outgoing cash flow significantly. There is still some negative cash flow present, but this can be attributed to the interest rate. A slightly higher rent should solve this problem. This is probably the scenario with the highest influence on the viability of the project.

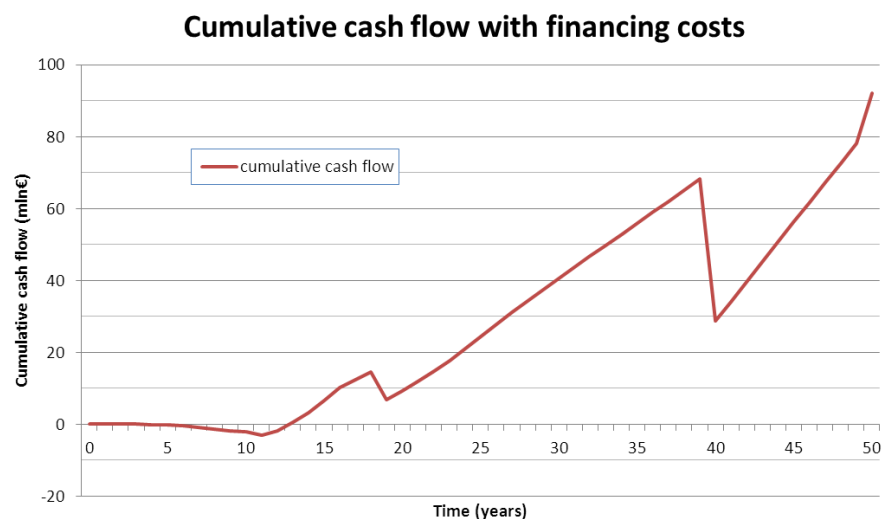


figure U.13 - - cumulative cash flow when spreading the construction loan

U.5 ADAPTED CASH FLOW

The simplification of taking out the loan at once at the start of the project appears to have great consequences on the viability of the project. As concluded in the sensitivity analysis, spreading the loan will drastically decrease the interest charges during the first years of the project. Therefore an adaption is made to the original cash flow analysis. This adaption consists of spreading the loan according to the years the money is needed. This is visible in figure U.14 as the negative peaks are balanced by the inflows of the loans.

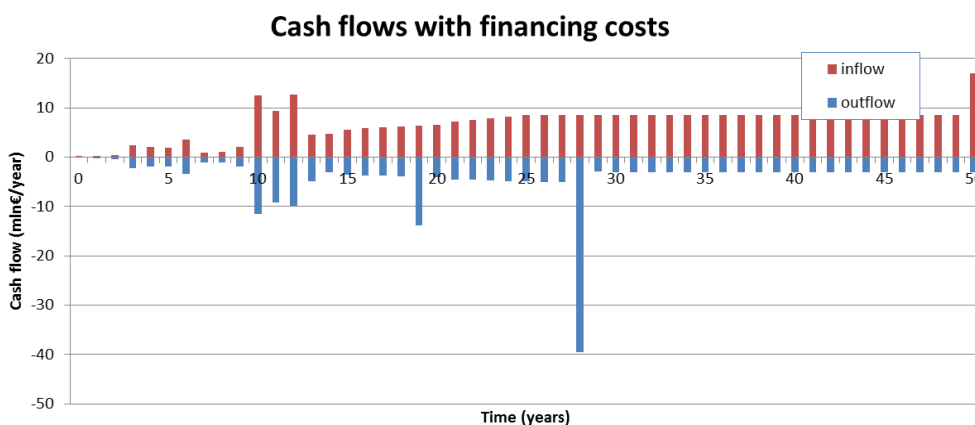


figure U.14 - Cash flows of the adapted cash flow

This results in a viable project with a positive cash balance during the entire project, as shown in figure U.15. The loan can be repaid at once in year 28 of the project with € 800 000 capital left. This could of course also be done spreaded over several years to save more money on interest charges. The cumulative cash flow would then stay just above zero, to maintain liquidity, until all loans are paid back.

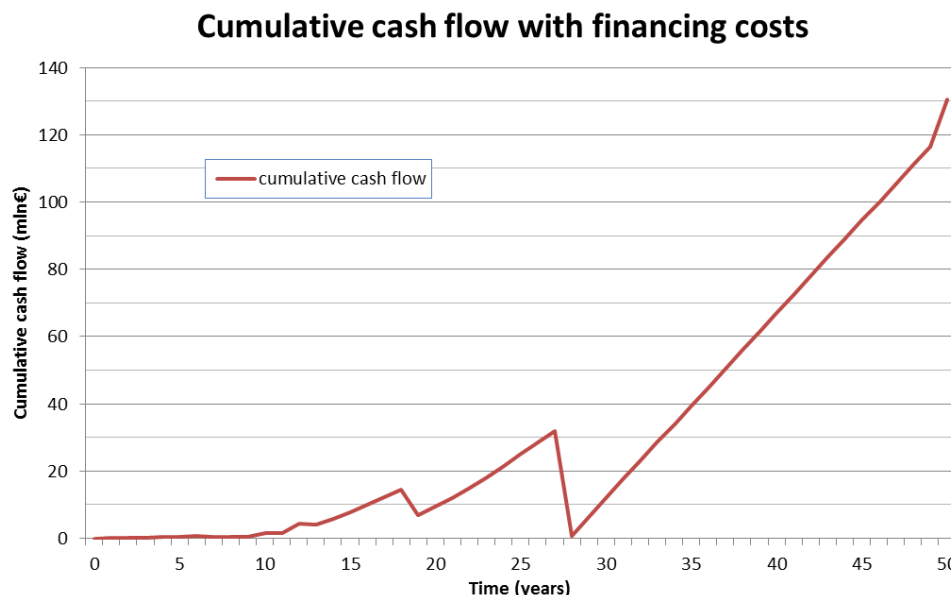


figure U.15 - Cumulative cash flow of the adapted cash flow

The NPV of the project with adapted cash flow remains fairly negative. It does not reach zero until year 46 of the project. This period is very long, even for a public

project run by the government. With the assumptions about the costs, income and planning of the project, it becomes clear that it will not be a good investment from financial point of view. However, the assumptions are made with a lot of uncertainties which could have had either a positive or a negative influence on the required investments. For instance, the assumed unit costs could be taken too high compared to the real costs in Cuba. On the other hand, the uncertainties about the planning and expected demand could also lead to higher costs (or lower income) than in the assumed case.

NPV with financing costs

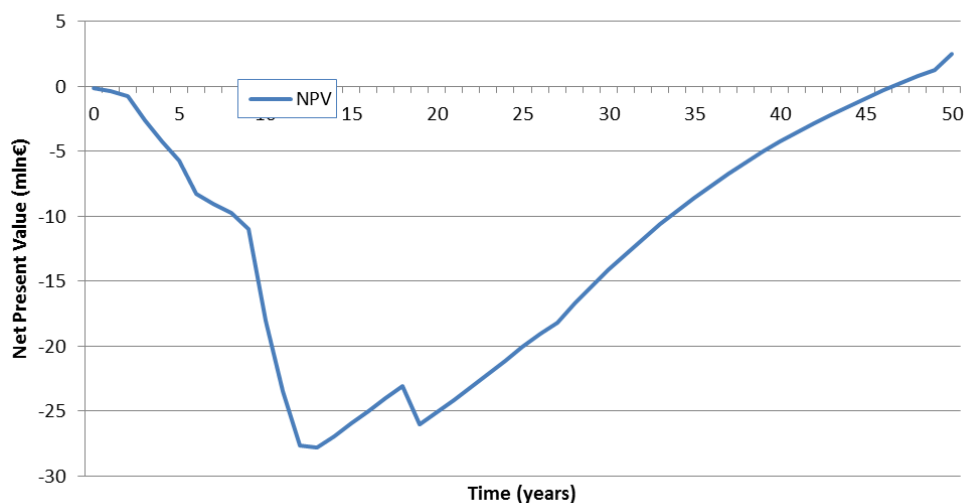


figure U.16 - NPV of the adapted cash flow

U.6 COST RECOVERY

In order to check if the project has enough revenue generation two methods of cost-recovery analysis are applied. First the pay-back period is determined, second the unit cost method is applied. These methods are described below.

U.6.1 PAY-BACK PERIOD

The pay-back period is a parameter which expresses the potential of the project for cost recovery, (Verhaeghe, 2012). It is most commonly used for commercial project in order to determine the time needed to recover the initial investments, but it can also be applied on public projects. For commercial projects a pay-back period of some years implies a viable project, for public projects a much longer period is acceptable.

From figure U.15 the pay-back period for this project can be read to be 28 years. This is a long, but acceptable payback period for a public project like this. The result is obtained with a total loan of € 36.7 million and an interest rate of 5%.

U.6.2 UNIT COSTS

The unit cost method determines the price that should be charged for the product or service created by the project in order to make the NPV zero. This comes down to the minimal costs per unit to reach break-even for feasibility of the project.

With this method the unit costs for a single berth in the marina are computed, as well as the costs for a ferry operator to berth in the ferry terminal.

The unit cost can be computed by equating the present value of the expenditures and the present value of the revenues generated by selling the output at unknown price P , (Verhaeghe, 2012). This would make the NPV at the end of the accounted period zero. In formula;

$$\frac{K1}{(1+i)} + \frac{K2}{(1+i)^2} + \dots + \frac{Kt}{(1+i)^t} = P * \left(\frac{Q4}{(1+i)^4} + \frac{Q5}{(1+i)^4} + \dots + \frac{Qt}{(1+i)^t} \right)$$

With:

Kt = investment costs in year t

Qt = quantity of products or services sold in year t

P = Price of a single product or service

i = discount rate

The number of tourists using the facilities (Qt) is assumed to be the same as in the financial evaluation in appendix U. Furthermore the same discount rate (i) of 5% is applied. These assumptions are fairly important in this method as they have great influence on the results. The costs (Kt) as determined in the same appendix are used. From this the price can be computed by rewriting the formula above to:

$$P = \frac{\left(\frac{Q4}{(1+i)^4} + \frac{Q5}{(1+i)^4} + \dots + \frac{Qt}{(1+i)^t} \right)}{\left(\frac{K1}{(1+i)} + \frac{K2}{(1+i)^2} + \dots + \frac{Kt}{(1+i)^t} \right)}$$

Marina

The costs that are included are the costs of the marina for design, construction, operation and maintenance, the surrounding functions as well as the financing costs. The value for a single berth is then calculated to be € 49 000 per year or € 140 euro per day. This is the average price of all berths in the marina in order to obtain a NPV of zero in year 50 of the project. The revenues from the side-line companies around the marina are not included in this unit cost. When the costs of these surrounding functions are left out of the equation the value for a berth becomes € 46 000, or € 130 per day. These values are significantly higher than the values determined in the financial analysis, i.e. € 75 per day.

This value is subject to many uncertainties but it indicates that the prices for berthing should be higher than the initial values. It also shows that the side-line companies play an important role in the profitability of the marina.

Ferry

The costs that are included are similar to the costs of the marina; they include the costs of the ferry terminal for design, construction, operation and maintenance, the surrounding functions as well as the financing costs.

The costs for one ferry to berth in the terminal are computed to be € 6 250 per berthing. This value is obtained with three ferries per day visiting the ferry terminal. When a fourth line is implemented in year 23 of the project and the number of ferries visiting Havana increases from three to four per day, the price for a berth drops to € 5 325.

U.7 CONCLUSIONS AND RECOMMENDATIONS

U.7.1 CONCLUSIONS

The main conclusion from a financial point of view is that with the current assumptions, the project cannot be qualified as a good investment. This is mainly due to the high costs in the first years and the relatively low revenues that can be created after completion.

The initial financial and construction planning do not allow for a viable project. The sensitivity analysis has shown that it is highly important to match the loan as closely to the expenditures as possible. It has also shown that earlier and higher revenues can accommodate higher loans in the beginning.

Adapting the loan to the expenditures does create a viable project. Without higher revenues however, there is not a high enough present value curve to qualify the investment as 'good'. Adding revenue by means of sideline companies can create a steeper net present value curve, although it should be investigated whether this option is realistic. Another option is the reduction of construction costs, which might be possible considering that this financial evaluation is from the point of view of a foreign project.

The qualification of a good investment in this case is not applicable for the reasons stated above. It is probable that other projects are imaginable that create higher returns on investment. These projects do not have to be very different than the evaluated project. It is possible that a marina and/or ferry terminal in some other form, for instance another location or capacity, can be qualified as a 'good' investment.

In the case of a governmentally run project, it might be the case that the considered project is more attractive. This is because there are other effects not directly linked to the project that can enhance its value. These effects are investigated in 'Appendix V: Economic evaluation'.

An important note to place on this conclusion is the high uncertainty regarding the inputs for the evaluation. In the following paragraph recommendations are given to decrease this uncertainty.

U.7.2 RECOMMENDATIONS

Cash in- and outflows

It can be stated that the main input for the financial evaluation is the construction costs. As is explained in this appendix, there is a large uncertainty regarding the estimation of these construction costs.

To this uncertainty are two underlying components. The first component is a general uncertainty regarding the values used for the unit costs. This uncertainty can be decreased if more and different sources are used as a reference. It is advisable to use Cuban reference sources to determine the cash flows; the recent construction of a marina in Varadero would be a good reference.

The second component to the uncertainty is the influence of the difference in Cuban and foreign resources. Quantifying the differences in Cuban and foreign resources requires a financial analysis in a dual currency system, as certain construction components are to be imported.

Market analysis

The financial analysis has shown that while the main pillars of revenue seem the marina and ferry by themselves, it are actually the side-line activities that can greatly add to the revenue streams. It is recommended to do a market analysis to clarify whether there is enough demand for the side-line activities.

Construction planning and financial planning

The loan is dependent on the construction planning, as it is generally advisable to loan as late and as little as possible, the construction planning has influence on the financial planning. It is recommended to fine-tune the construction planning as much as possible, to plan non-critical construction works later than is the case in the current planning.

Construction and exploitation phases

In the current planning a distinction is made between the first phase and second phase (for both marina and ferry). It is recommended to investigate the possibilities of a more spread out phasing of the construction and subsequent exploitation. It is advisable to fine-tune the phasing to market demand for the provided services. This way, investments can be postponed until the time they are required.

Project 'Tourist Port Havana'

The calculations given above are made with the assumption that the marina and ferry terminal are operating independent of the project 'Tourist Port Havana'. This is however not the case, as the ferry terminal and marina are both components of this master plan. Revenue made from other components of the master plan, such as the cruise terminal, can be (partly) used to cover the costs of the ferry terminal and marina. In this way, the required height of the loan will be lower, which will decrease the interest costs significantly.

Appendix V: ECONOMIC EVALUATION

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V.1 INTRODUCTION

In an economic evaluation, effects are defined as those effects to the economy which can be attributed to a particular project and which would not have occurred in a comparable situation without that project, (Verhaeghe, 2012). The main point of view for an economic evaluation is that effects that are not directly attributable to the balance sheet of the project are accounted for. These effects are not directly of consequence to the management of the project, but they can have an indirect effect on the project.

The goal of the economic evaluation is to quantify these indirect and external effects on the project and to investigate if the project has a larger impact on society and the environment. If the project appears to be beneficial to not only the management of the project, it can be argued that a governmental investment is justifiable.

In chapters V.2, V.3 and V.4 the direct, indirect and external effects are discussed. These chapters are followed by a new net present value curve which incorporates the mentioned economic effects (V.5). In chapter V.6 the conclusions and recommendations are given.

V.2 DIRECT EFFECTS

Direct effects are those effects that are physically linked to the project. The direct effects are confined to the in-and outflows of the project, and have been evaluated in the financial evaluation, appendix U.

In the case of a public-sector project, the benefits or drawbacks are entirely for society. In the case of a private-sector project, society can only benefit through taxation, as after-tax profits go to the project owners (Verhaeghe, 2012).

Effects other than direct effects are divided in indirect effects and external effects. These effects are taken into account in an economic evaluation as they represent a benefit or drawback to society that is not reflected in the financial evaluation.

V.3 INDIRECT EFFECTS

Indirect effects are the effects of a project on other industries. Indirect effects can either be forward linkages or backward linkages. Forward linkages refer to the effects on industries that are the users of the project's output, backward linkages to the effects on industries which supply the project's inputs (Verhaeghe, 2012).

Three main indirect effects are discerned, the effects on labour, on the value of land and the local economy.

Labour

The effect on labour is both a forward and backward linkage. The project will create a demand for labour, which is beneficial to society, but since it is a long-term project can cause higher labour prices in the future. For this evaluation it is assumed that labour prices do not rise during the length of the project.

The discount factor for labour in the economic evaluation is assumed to be 20%, as local labour is expected to be considerably cheaper.

Value of land

The improvement of infrastructure has its positive influence on the other projects of Tourist Port Havana. A better infrastructure also leads to higher prices of land, which is beneficial to the region in general. As incorporating the effects of a rise in land prices requires a more exact approach to evaluating, these effects are neglected in this evaluation.

Local economy

In the financial evaluation it is argued that tourists spend money on sideline activities, but they will also spend money outside the project area. Spending outside the project is beneficial to the local economy and therefore constitutes as an indirect effect.

It is assumed that 5% of daily tourist expenditures are outside the project scope, but still flow into the local economy. A cruise ship visitor spends by estimation about € 100,- a day in a port of call (De Jong, 2012). In the economic evaluation this has been added for marina visitors, accounting for the occupancy rate and number of berths.

V.4 EXTERNAL EFFECTS

External effects are defined as effects from the project which constitute a benefit or costs to society but which are not reflected in the project expenditures or revenues. In this project there are two external effects that can be taken into account:

Congestion

The first is the cost to society in the form of congestion. The marina and ferry will attract more traffic than in a status quo situation, which can have a negative influence on the region. But it is also expected that the region benefits from the renovation of existing road infrastructure because times of local transport decrease due to the removal of traffic bottlenecks. It is assumed that the benefits regarding congestion outweigh the drawbacks.

To incorporate congestion into the evaluation the value of time is considered. From 'Appendix E: Infrastructural analysis' it follows that in year 15 there are 3 600 vehicles during the peak hour. An estimation of a delay of 15 minutes per vehicle results in a combined delay of 900 hours per rush hour, or 1800 hours per day. An estimation of the value of time of € 3,- per hour is used to compute the losses per day, which amount to € 5 400,-. If by a rough estimation there are 300 of these days in a year, the congestion would cause losses of € 1 620 000,- a year.

The improvement of road infrastructure would prevent these losses, but as is stated before, the project also causes more traffic. Therefore, a rough estimate of half the losses is prevented by the road improvements, or € 810 000,-. This is added to the evaluation from year 15.

Environment

The other external effect is the costs to the environment in the form of pollution. The marina and ferry will cause an increase in the use of natural resources, traffic and cause more emissions in the Havana area due to the vessels.

The effect on the environment is added as percentage of the construction and operation and maintenance costs. A value of 10% is assumed to be reasonable.

V.5 NET PRESENT VALUE

In figure V.1 the curve of the net present value, when economic effects are considered, is presented. The curve is the result of an adaptation of the final scenario as is presented in 'Appendix U: Financial evaluation'. The scenario is adapted to incorporate as much indirect and external effects as possible. The result is a positive NPV for 'society'.

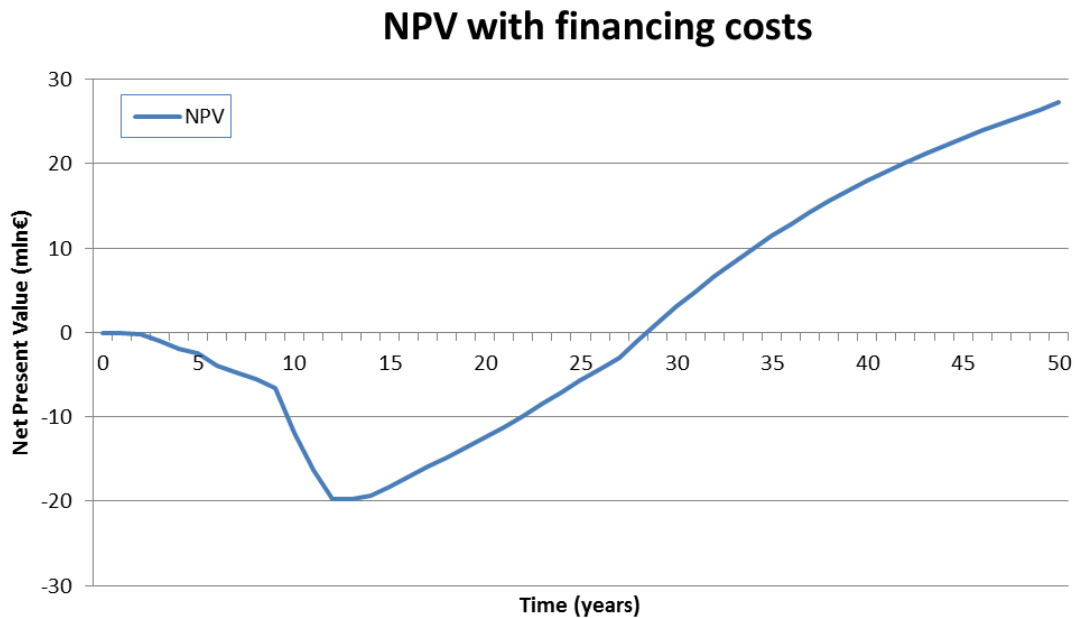


figure V.1 - net present value with economic effects taken into account

V.6 CONCLUSIONS AND RECOMMENDATIONS

The fact that there is a positive net present value for society justifies an application for a subsidy. From the point of view of a governmental organisation such a subsidy is warranted considering the current NPV curve. It is however necessary to mention that the time to get to a NPV of zero is quite long, as is generally the case for projects undertaken by governments. It is also such that the eventual NPV in 50 years is not very high compared to the investments.

Another important note to mention is that the NPV has been calculated with a relatively cheap interest rate, which might not be the case at all. Especially when foreign funds have to be loaned by the Cuban government a much higher interest rate is to be expected.

Discount rates

It is recommended to study what the actual realistic discount rates are, both to incorporate the indirect and external effects and to calculate a more accurate net present value.

Value of land

The effect of an increase in the value of land is not taken into account in this evaluation. The area where the ferry terminal and marina are allocated is currently one of the less attractive areas of Havana. That is why the effect is quite likely to have an influence in the area, and it is advisable to incorporate this in a more detailed study.

Increase of visitors

The presence of a marina and a ferry terminal will increase the overall attractiveness of Havana. It is therefore to be expected that an additional number of tourists will visit the country because of these facilities. These 'extra' tourists will make expenditures in the country that can be added to the economic value of the project. The exact number of these visitors is however not known; it is with the current information impossible to state whether the tourists which will arrive by ferry would have visited Havana without ferry as well. It is recommended to investigate the expected increase of visitors of the country because of the presence of a ferry terminal and marina.

Added value of a marina

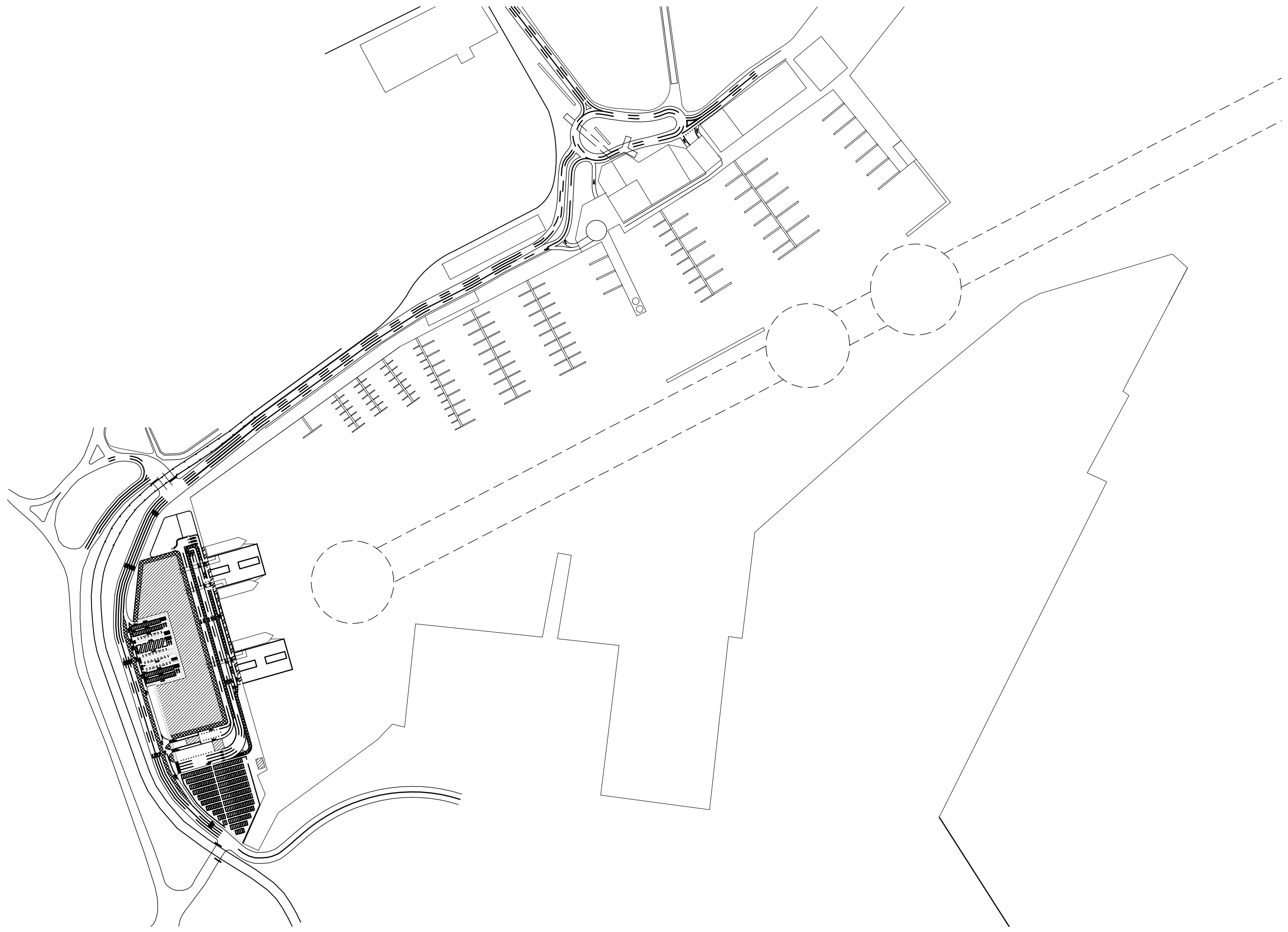
A presence of a marina instead of a commercial waterfront is considered to be an asset of a city (De Jong, 2012) and adds therefore value to Havana. This emotional value is however not easily converted into a financial value. A further research is recommended to convert this value which can be included in the economic analysis.

Influence on commercial activities

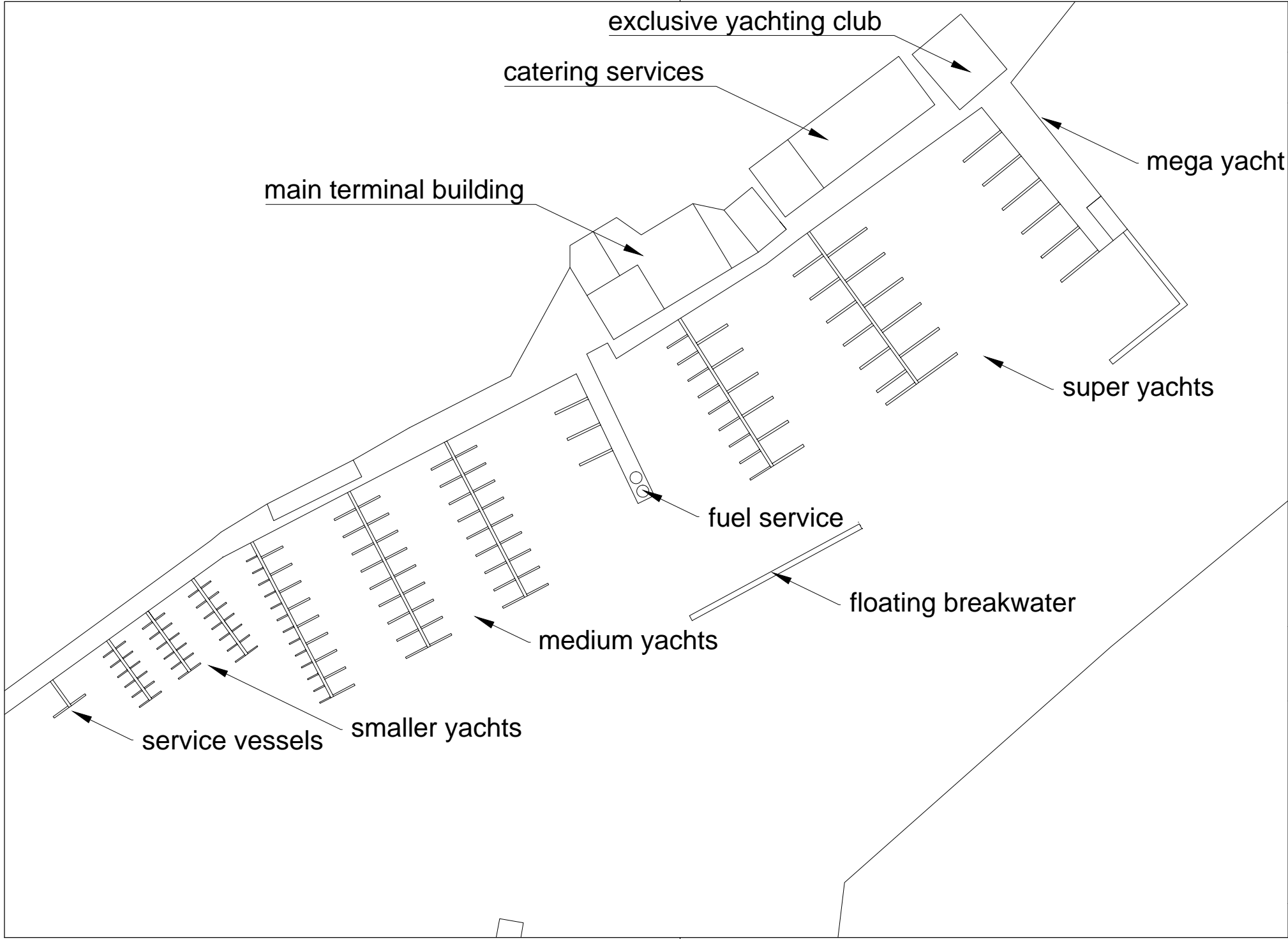
As was concluded in the appendix nautical design, the project Tourist Port Havana will have a negative influence on the commercial shipping trade in the Bay of Havana. This will probably cause a relocation of the cargo terminal to other ports in the country. Whether this will also causes economic costs to Cuba, and how much, has to be investigated in more detail.

Appendix W: TECHNICAL DRAWINGS

Drawing no	Title
01	Design overview of the project area
02	Marina La Coubre
03	Marina – floating breakwater
04	Marina – detail eastern part
05	Marina – detail Espigón La Coubre
06	Marina – detail western part
07	Marina – connections
08	Havana International Ferry terminal
09	Nautical design
10	Havana International Ferry Terminal - detail



Draw no	01	Project group	Tourist Port Havana	Date	04/05/13	Subject	Design overview of the project area	Format	A3	Scale	1:5000
								Unit			



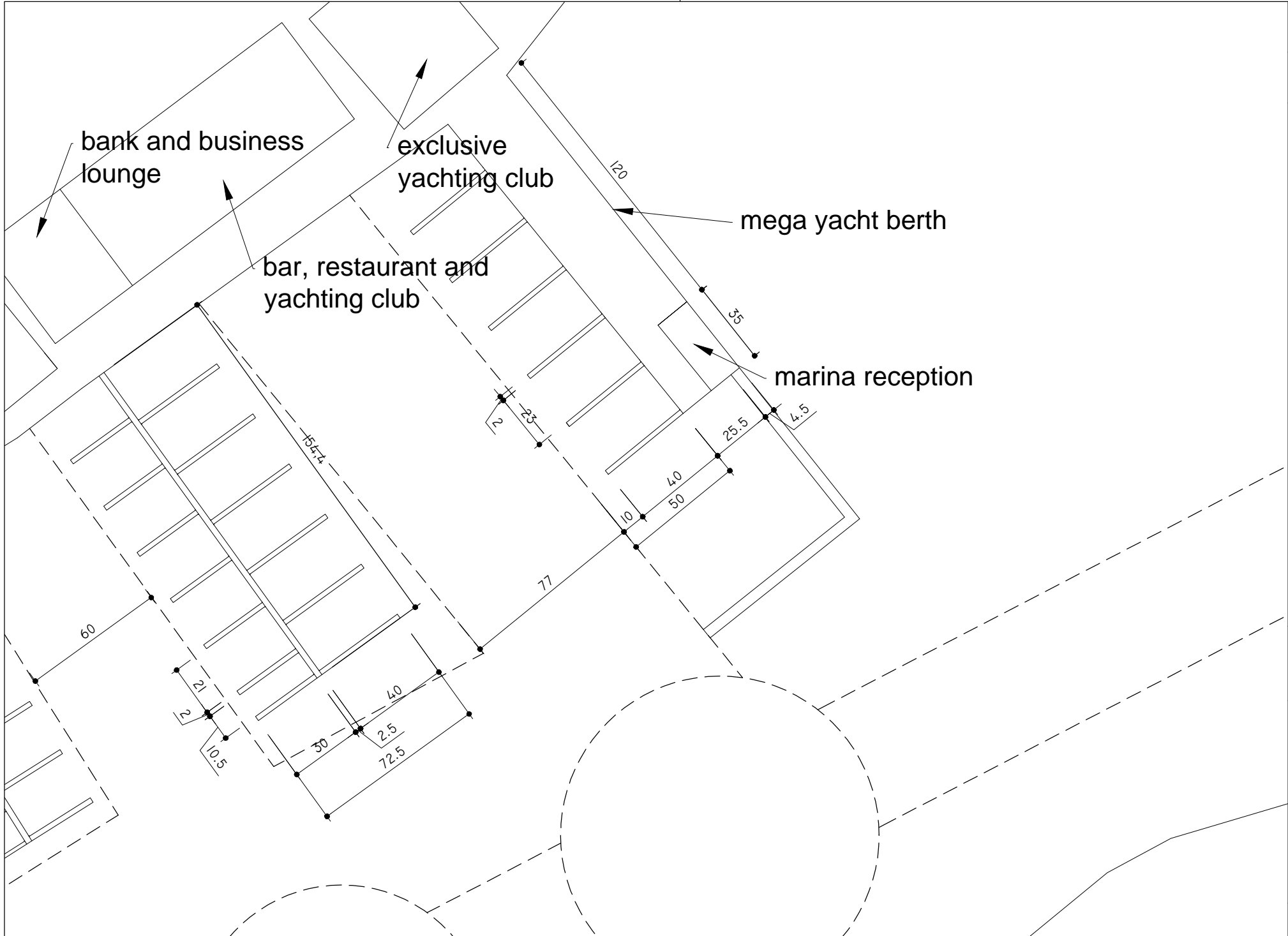
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	Project group
Tourist Port Havana	
Date	04/05/13
Subject	
Marina La Coubre	
Format	A4
Scale	1:4000
Unit	m



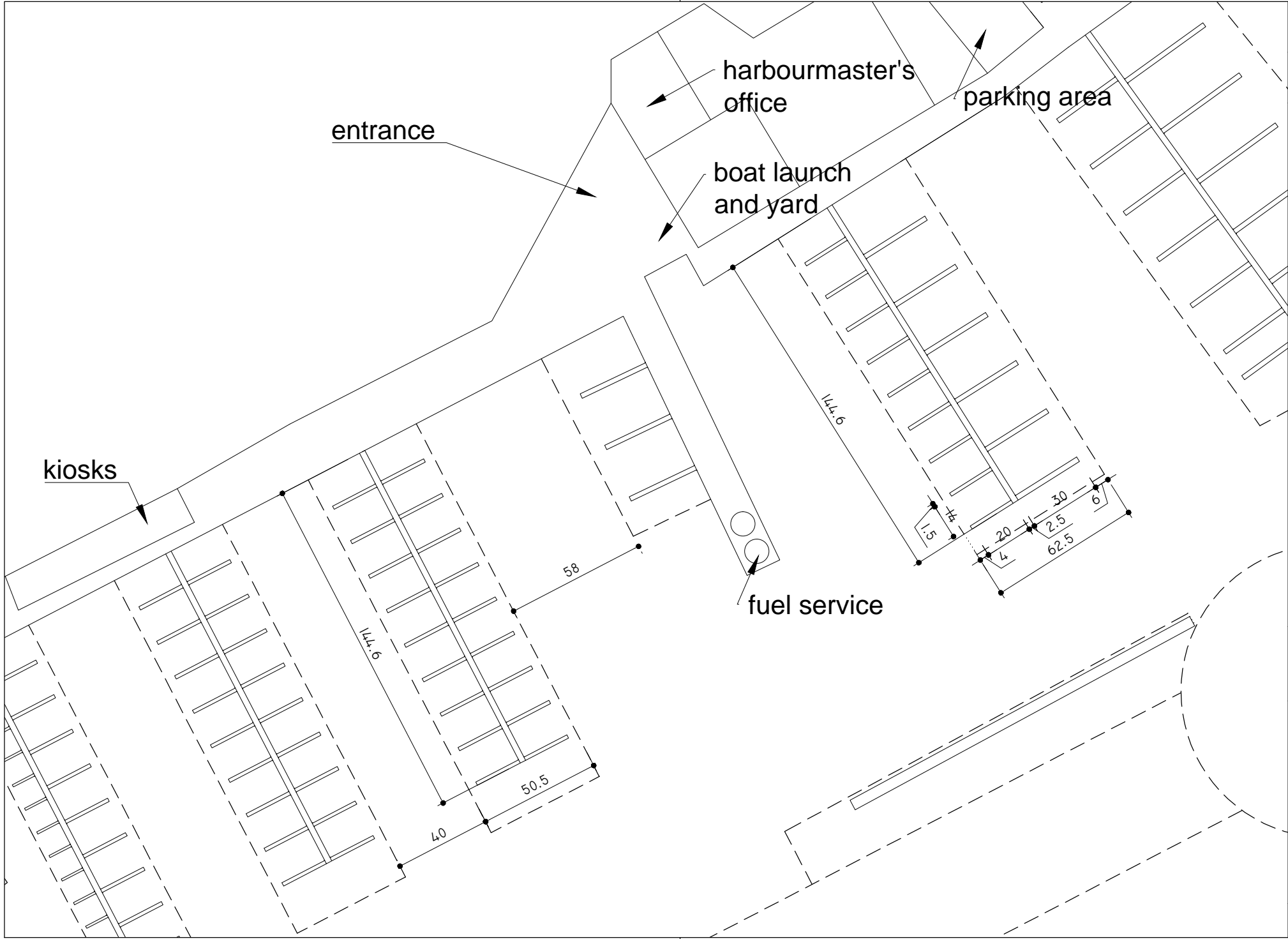
fuel service

marina reception

Draw no	03	Project group	Tourist Port Havana	Date	04/05/13	Subject	Marina - floating breakwater	
							Format	A4
							Scale	1:2000
							Unit	m



Draw no	04	Project group Tourist Port Havana	Date 04/05/13	Subject Marina - detail eastern part	Scale	1:2000
					Format	A4



entrance

kiosks

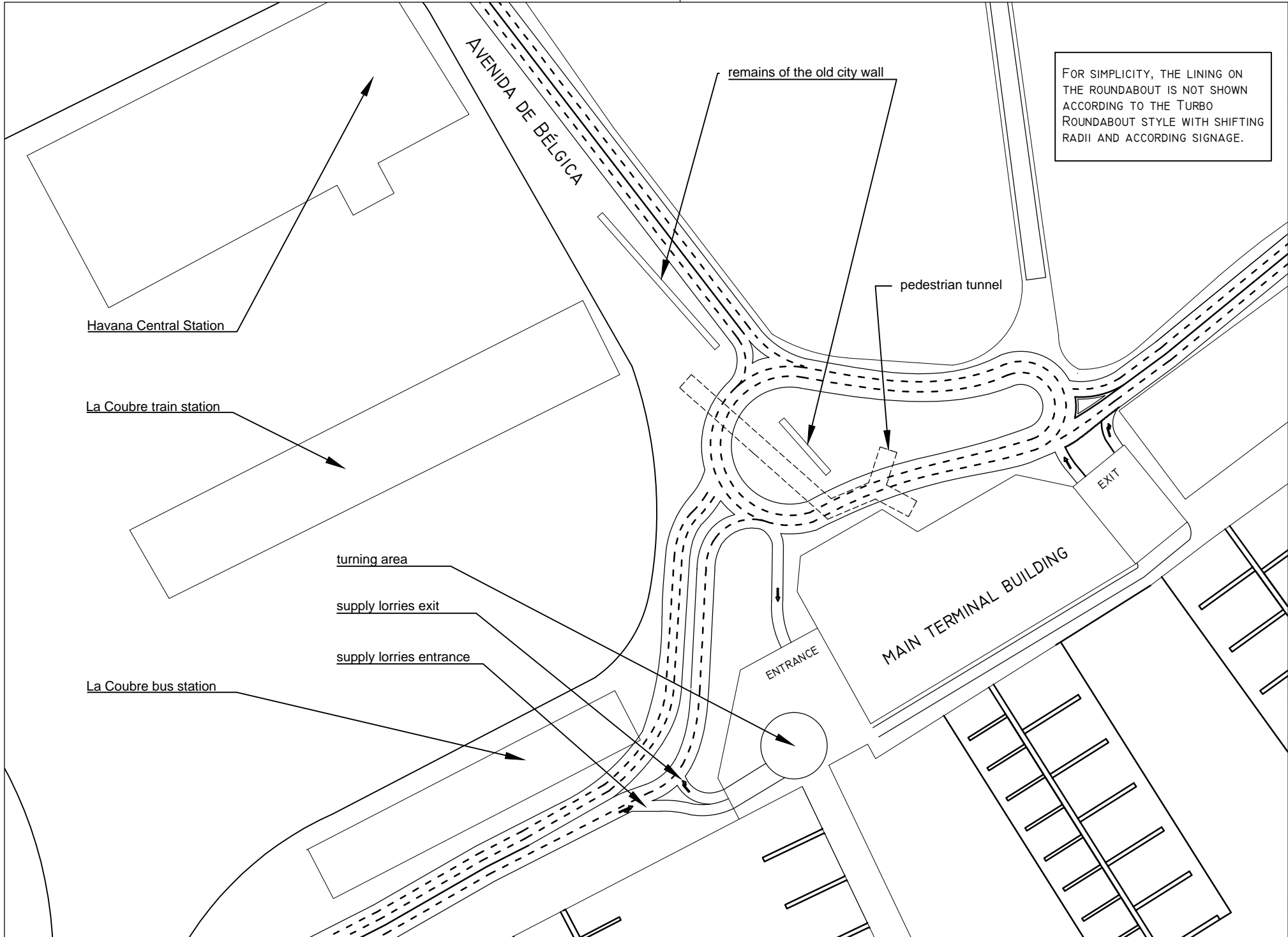
harbourmaster's
office

parking area

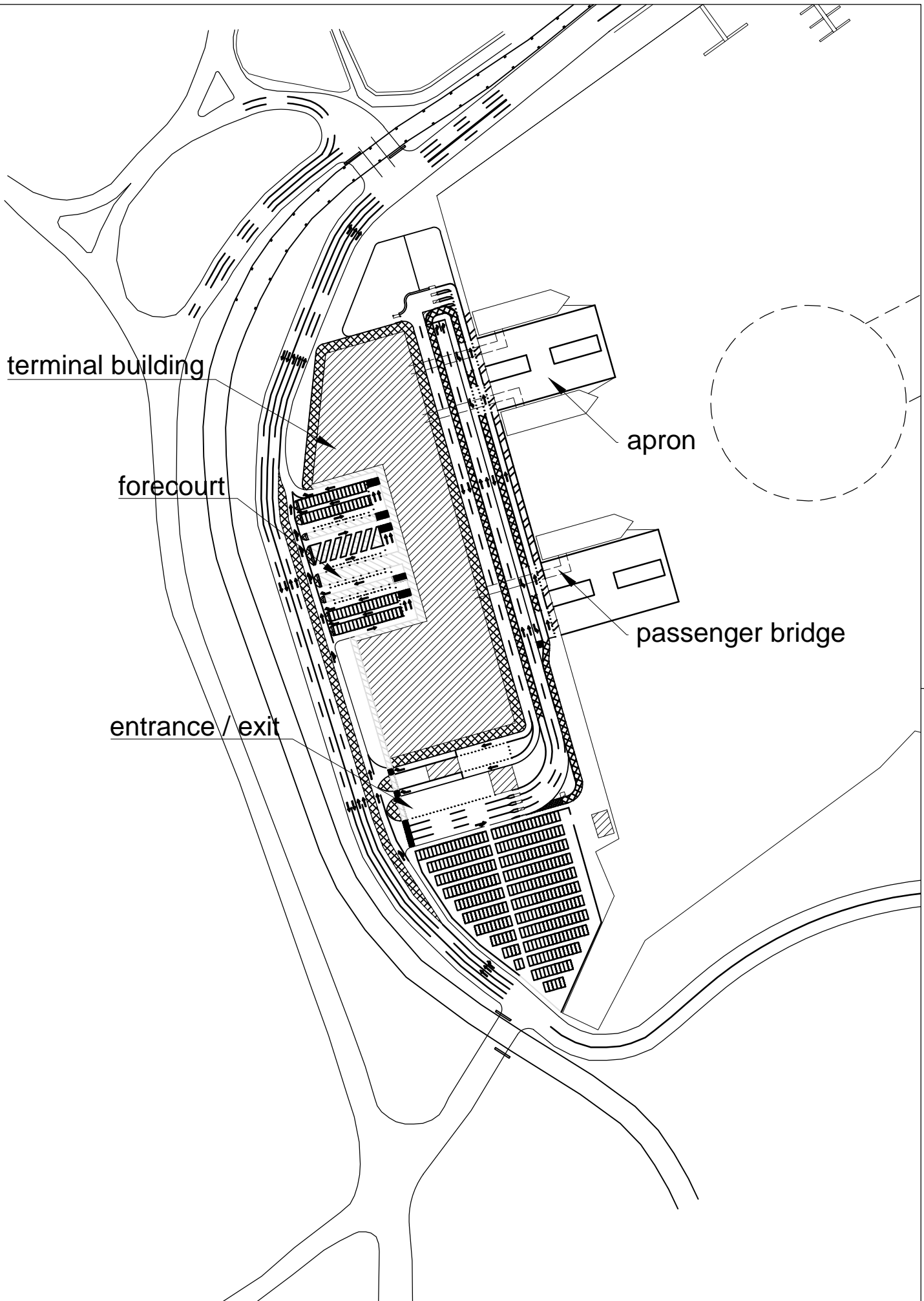
boat launch
and yard

fuel service

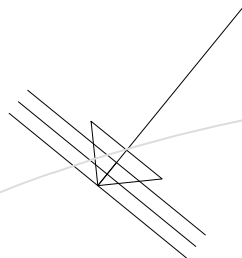
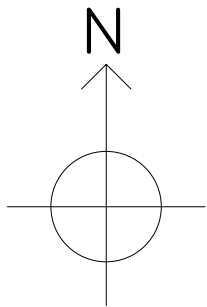
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	Project group
Date	04/05/13
Subject	Marina - detail Espigón La Coubre
Format	A4
Scale	1:2000
Unit	m



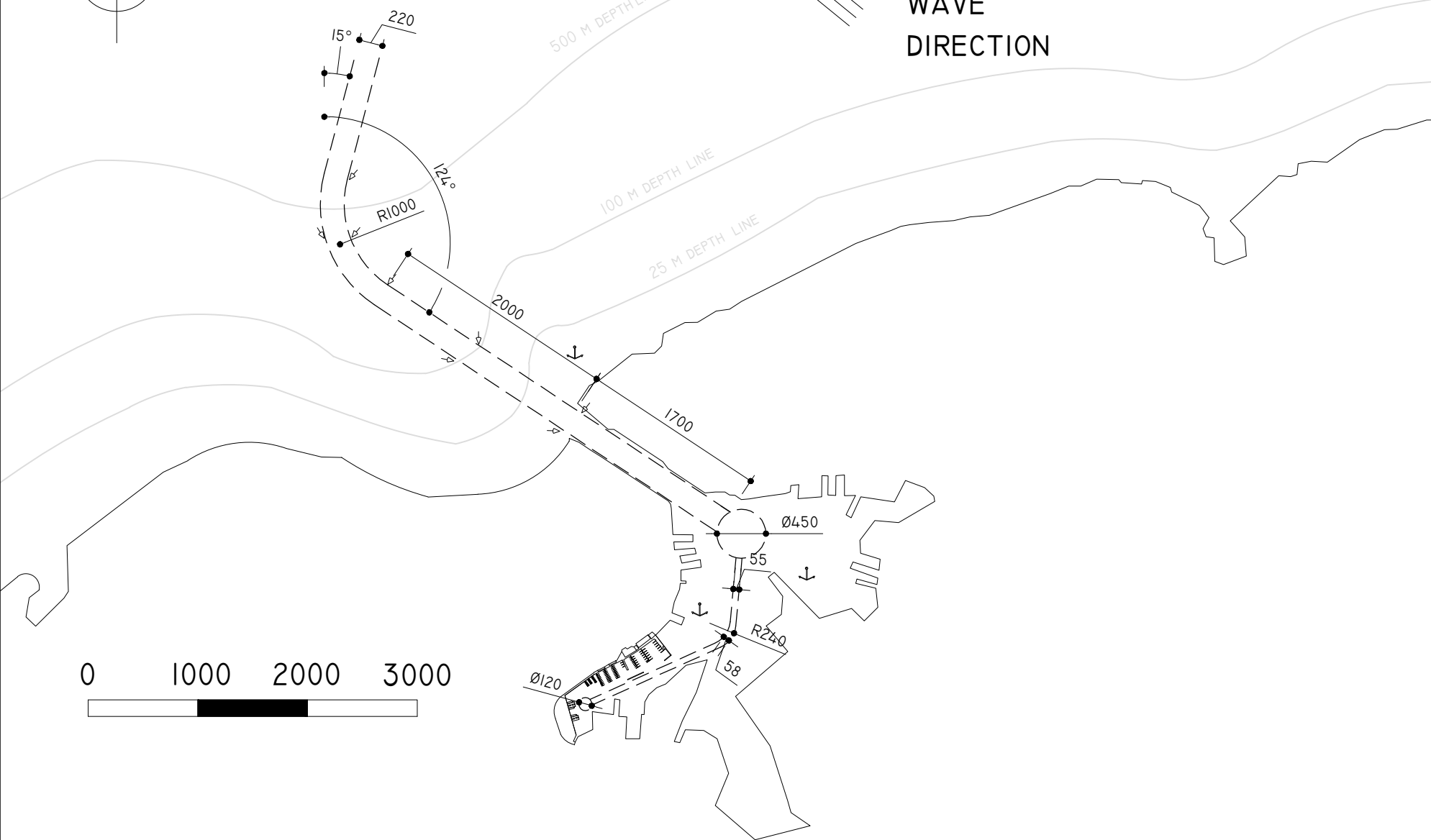
Draw no	07	Date	04/05/13	Subject	Marina - connections
Project group	Tourist Port Havana				
Format	A4	Scale	1:2000	Unit	m



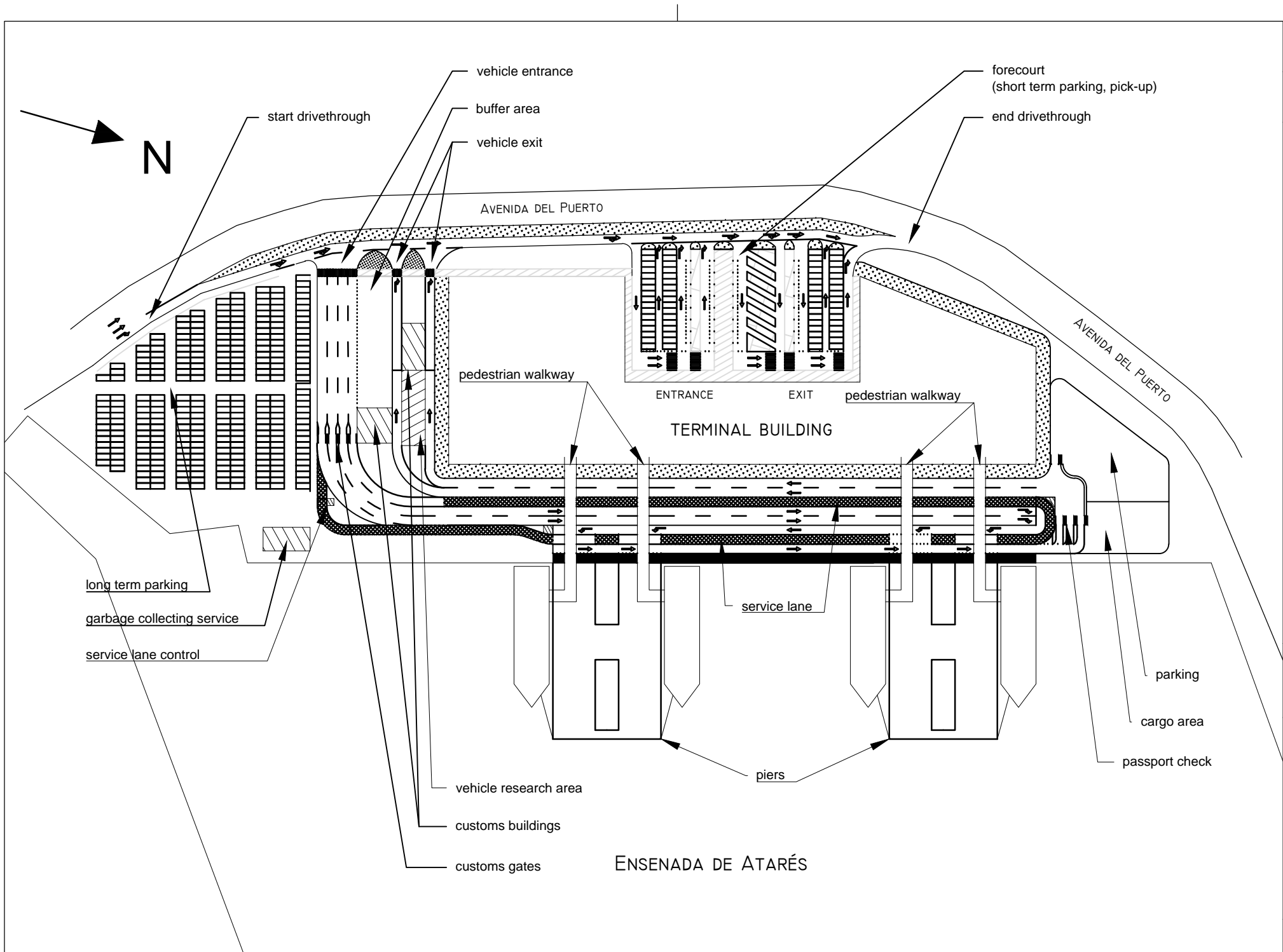
Draw no 08	Project group Tourist Port Havana	Date 04/05/13	Subject International Ferry Terminal	Format A4	Scale 1:3000
				Unit m	



PREVAILING
WIND AND
WAVE
DIRECTION



Draw no	09	Project group	Tourist Port Havana	Date	04/05/13	Subject	Nautical design		
							Format	Scale	Unit
							A4	1:50000	m



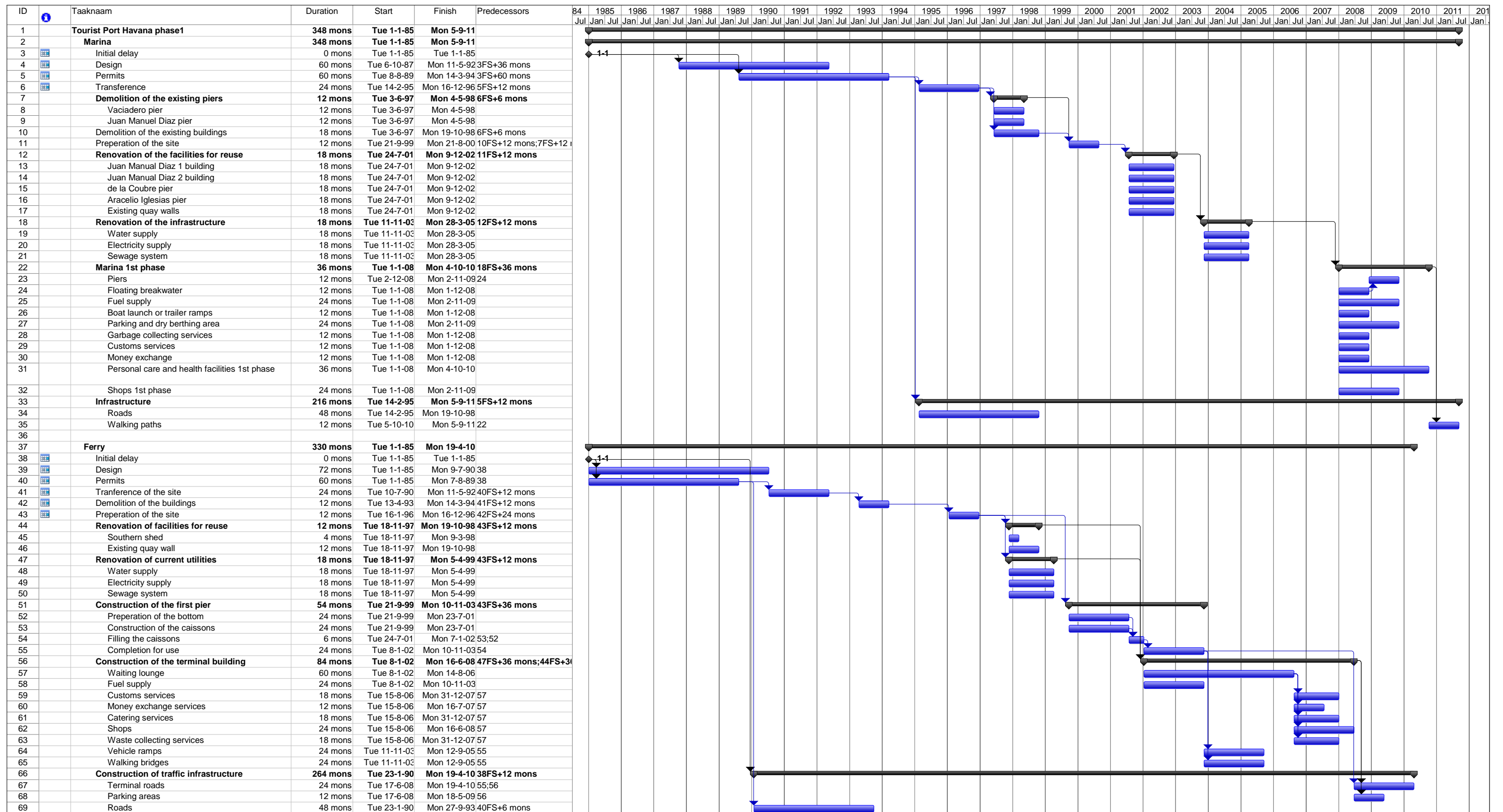
Draw no	10	Project group Tourist Port Havana	Date	04/05/13	Subject Havana International Ferry Terminal - detail	Scale	1:2000
			Unit	m		Format	A4

Appendix X: GANTT CHARTS

NOTE: Due to limitations in the software program that has been used, it was not possible (1) to exceed a specific date in future and (2) to exceed a specific project duration. Therefore the start date displayed in the charts is set to January 1st 1985. One has to **add 29 years** to each date displayed to get real project values given in Appendix T: Project planning.

ID	Taaknaam	Duration	Start	Finish	Predecessors	1996			1997			1998			1999			2000					
						Apr	Jul	Oct	Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct			
1	Tourist Port Havana phase 2	54 mons	Mon 1-7-96	Fri 18-8-00																			
2	Marina 2nd phase	18 mons	Mon 1-7-96	Fri 14-11-97																			
3	Hotel	12 mons	Mon 1-7-96	Fri 30-5-97																			
4	Catering services	12 mons	Mon 1-7-96	Fri 30-5-97																			
5	Yachting club	6 mons	Mon 1-7-96	Fri 13-12-96																			
6	Supermarkt	12 mons	Mon 1-7-96	Fri 30-5-97																			
7	Recreational services	12 mons	Mon 1-7-96	Fri 30-5-97																			
8	Personal care and health facilities 2nd phase	18 mons	Mon 1-7-96	Fri 14-11-97																			
9	Shops 2nd phase	12 mons	Mon 1-7-96	Fri 30-5-97																			
10																							
11	Construction of the second pier	30 mons	Mon 4-5-98	Fri 18-8-00																			
12	Preperation of the bottom	12 mons	Mon 4-5-98	Fri 2-4-99																			
13	Construction of the caissons	12 mons	Mon 4-5-98	Fri 2-4-99																			
14	Filling the caissons	6 mons	Mon 5-4-99	Fri 17-9-99	13																		
15	Completion for use	12 mons	Mon 20-9-99	Fri 18-8-00	14																		

Project: FastDphase2 Datum: Fri 14-6-13	Taak		Projectsamenvatting		Inactive Milestone		Manual Summary Rollup		Voortgang	
	Splitsing		Externe taken		Inactive Summary		Manual Summary		Deadline	
	Mijlpaal		Externe mijlpaal		Manual Task		Start-only			
	Samenvatting		Inactive Task		Duration-only		Finish-only			

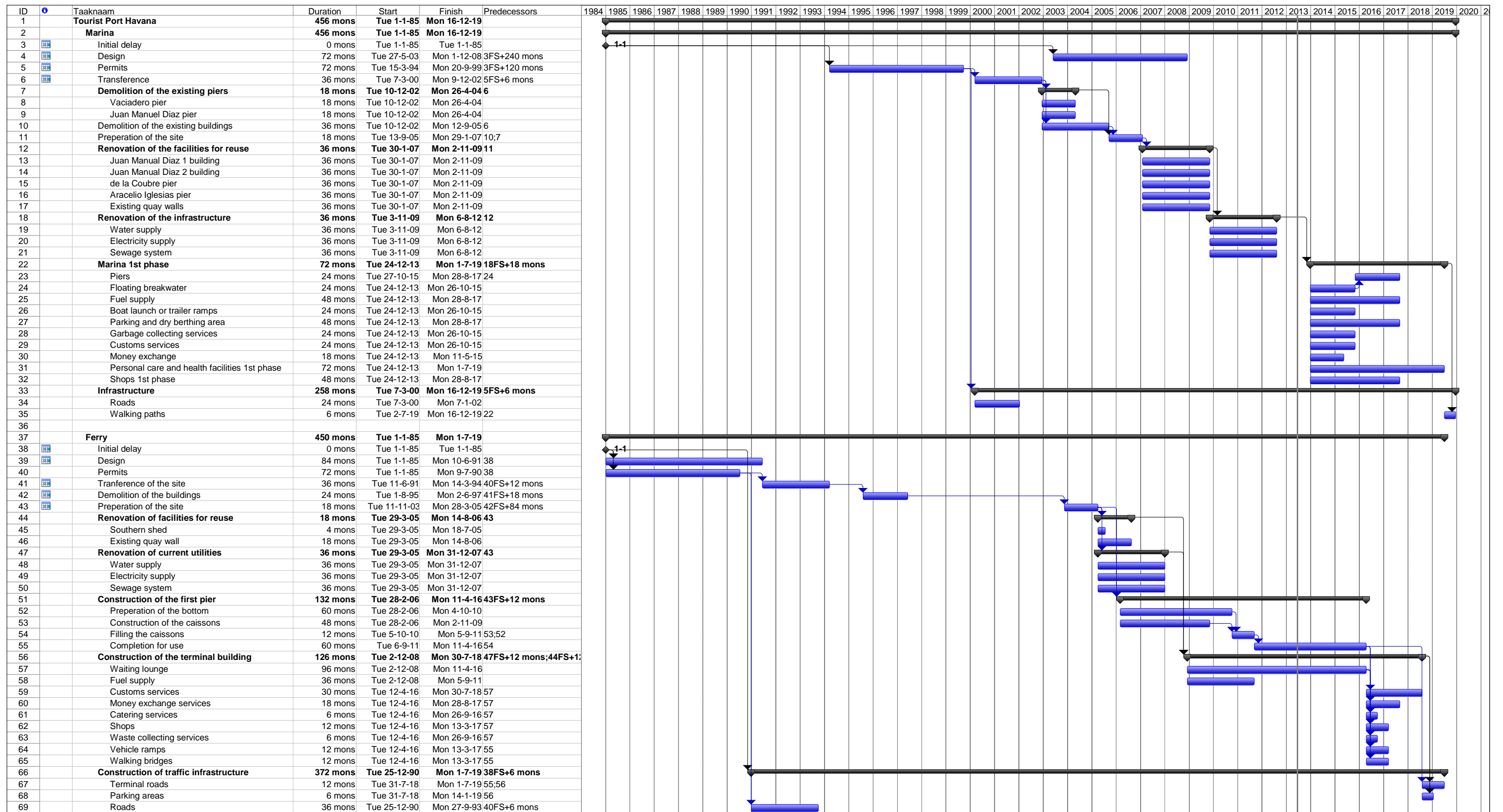


Project: NormalD
Datum: Fri 14-6-13

Taak		Samenvatting		Externe mijlpaal		Inactive Summary		Manual Summary Rollup		Finish-only	
Splitting		Projectsamenvatting		Inactive Task		Manual Task		Manual Summary		Voortgang	
Mijlpaal		Externe taken		Inactive Milestone		Duration-only		Start-only		Deadline	

ID	Taaknaam	Duration	Start	Finish	07	2008		2009		2010		2011		2012		2013		2014
					Jul	Jan	Jul	Jan	Jul	Jan	Jul	Jan	Jul	Jan	Jul	Jan	Jul	Jan
1	Tourist Port Havana phase2	66 mons	Mon 16-6-08	Fri 5-7-13														
2	Marina 2nd phase	36 mons	Mon 4-10-10	Fri 5-7-13														
3	Hotel	24 mons	Mon 4-10-10	Fri 3-8-12														
4	Catering services	24 mons	Mon 4-10-10	Fri 3-8-12														
5	Yachting club	18 mons	Mon 4-10-10	Fri 17-2-12														
6	Supermarkt	24 mons	Mon 4-10-10	Fri 3-8-12														
7	Recreational services	24 mons	Mon 4-10-10	Fri 3-8-12														
8	Personal care and health facilities 2nd phase	36 mons	Mon 4-10-10	Fri 5-7-13														
9	Shops 2nd phase	24 mons	Mon 4-10-10	Fri 3-8-12														
10																		
11	Construction of the second pier	54 mons	Mon 16-6-08	Fri 3-8-12														
12	Preperation of the bottom	24 mons	Mon 16-6-08	Fri 16-4-10														
13	Construction of the caissons	24 mons	Mon 16-6-08	Fri 16-4-10														
14	Filling the caissons	6 mons	Mon 19-4-10	Fri 1-10-10														
15	Completion for use	24 mons	Mon 4-10-10	Fri 3-8-12														

Project: NormalDphase2 Datum: Fri 14-6-13	Taak		Projectsamenvatting		Inactive Milestone		Manual Summary Rollup		Voortgang	
	Splitsing		Externe taken		Inactive Summary		Manual Summary		Deadline	
	Mijlpaal		Externe mijlpaal		Manual Task		Start-only			
	Samenvatting		Inactive Task		Duration-only		Finish-only			



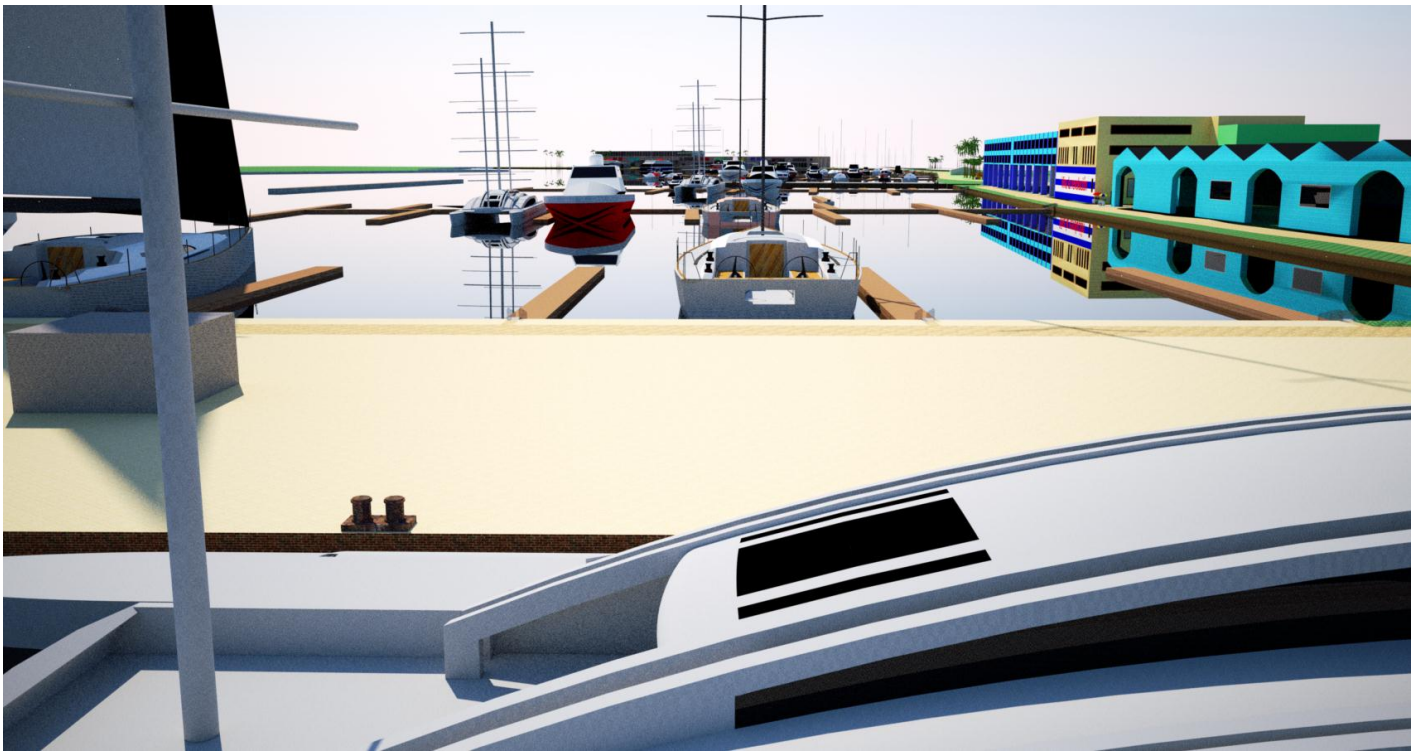
Project: SlowD
Datum: Fri 14-6-13

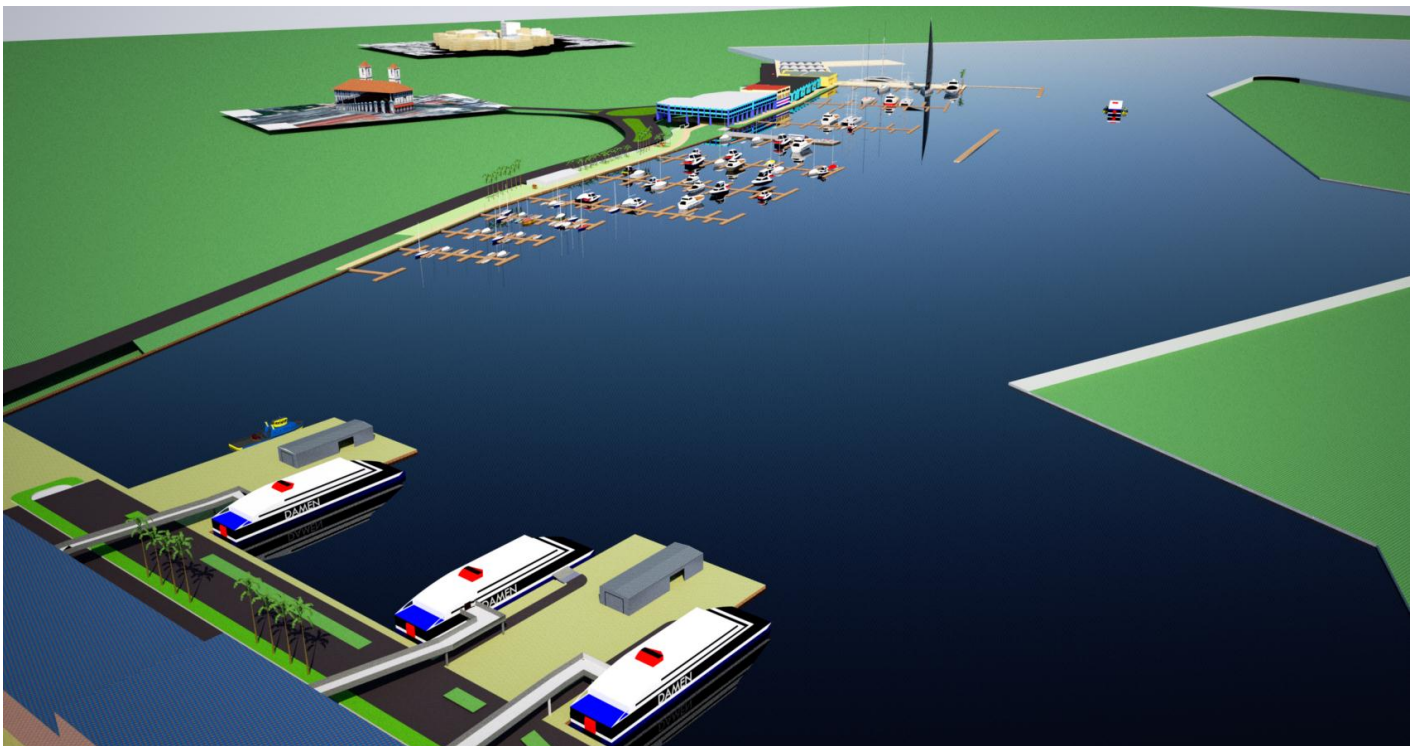
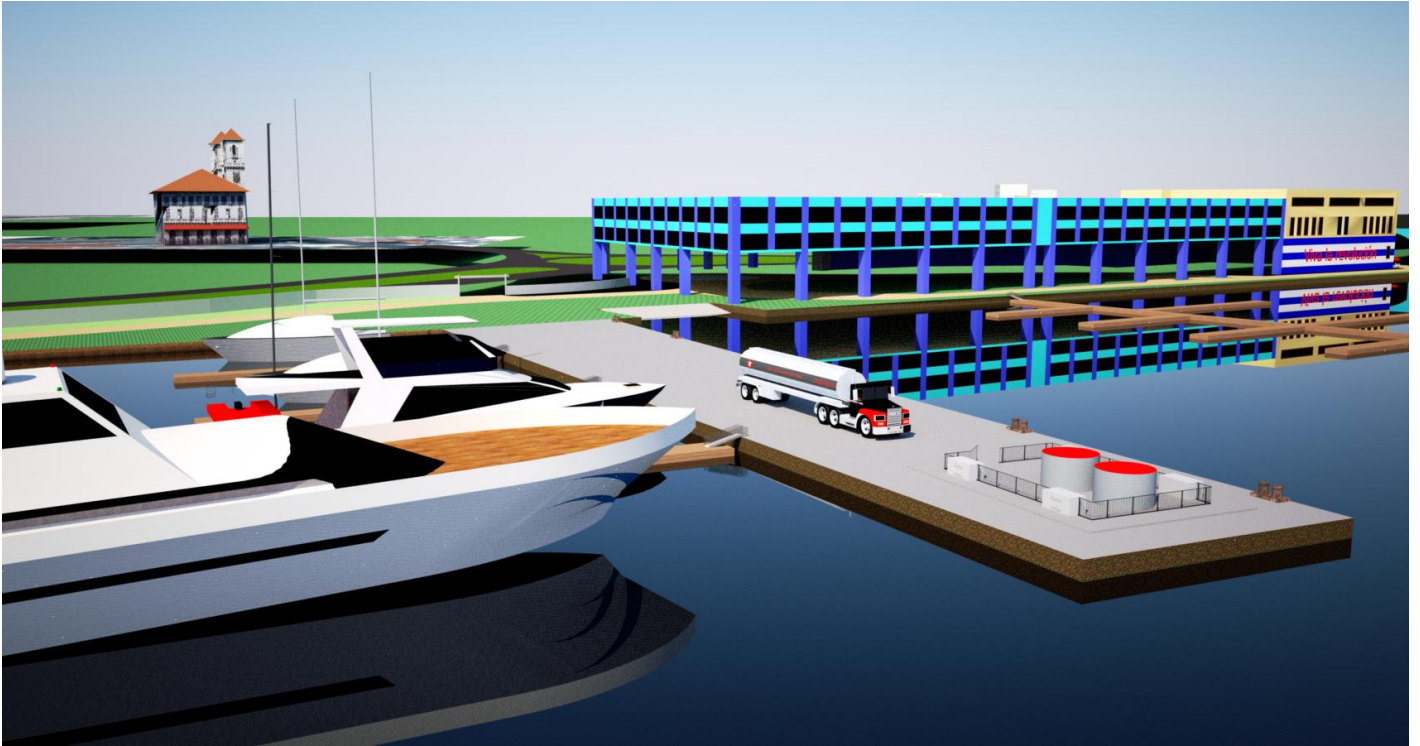
Taak		Samenvatting		Externe mijlpaal		Inactive Summary		Manual Summary Rollup		Finish-only	
Spitsing		Projectsamenvatting		Inactive Task		Manual Task		Manual Summary		Voortgang	
Mijlpaal		Externe taken		Inactive Milestone		Duration-only		Start-only		Deadline	

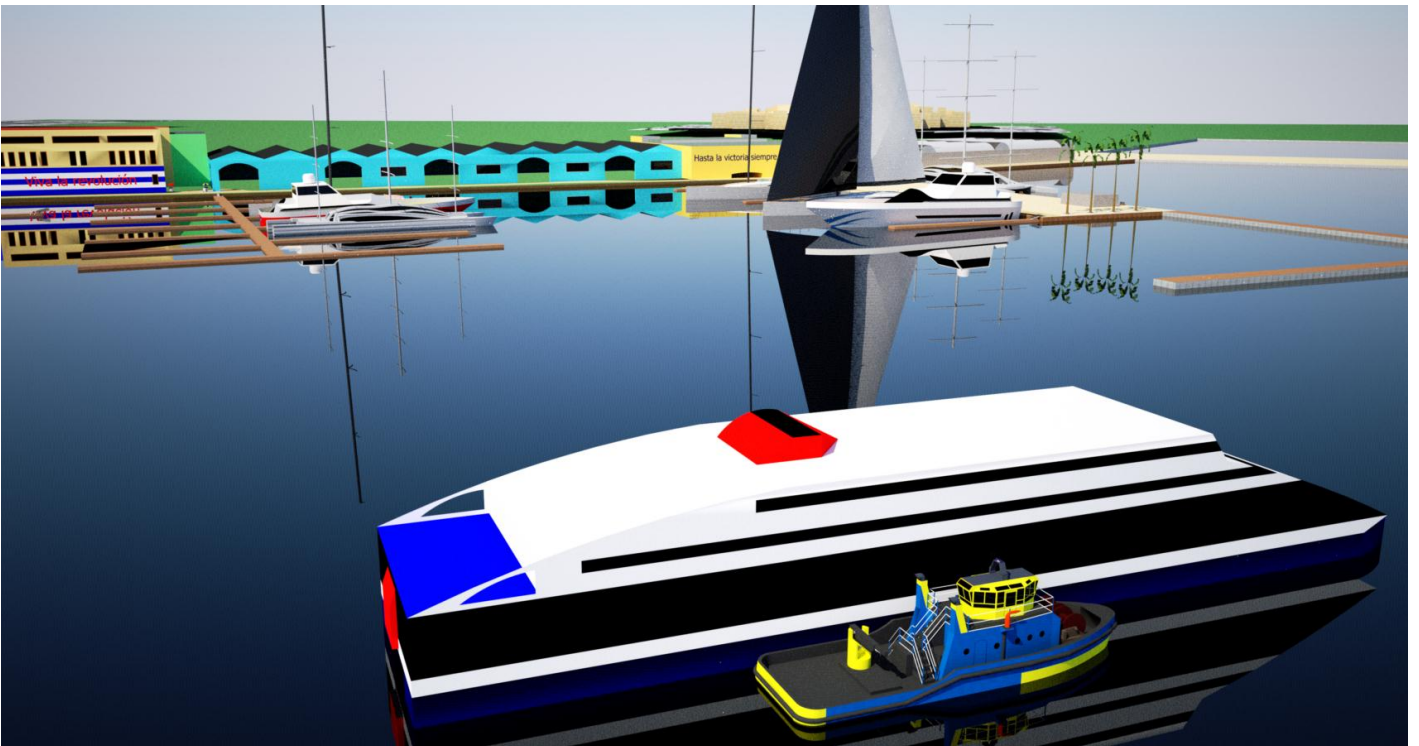
Pagina 1

Appendix Y: ARTIST IMPRESSIONS









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