PROJECT POINT PEDRO

A MULTIDISCIPLINAIRY DESIGN STUDY OF THE POINT PEDRO FISHERY HARBOUR.

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Preface

To broaden our horizon, our project team made use of the possibility of doing a multidisciplinary project abroad. With five people, all in their final stage of their studies, a fishery harbour in Sri Lanka will be designed during eight weeks.

The project team consists of five students, all master students of the faculty of Civil Engineering and Geosciences of Delft University of Technology, though of different disciplines. The aim of this multidisciplinary project is to design a fully fledged fishery harbour located at the northern tip of Sri Lanka, in the town of Point Pedro. This project was provided by EML Consultants, as they are currently developing the detailed design of the Point Pedro fishery harbour and would like to have a suggestion from another point of view.

We would like to thank Eng. C. Fernando, for providing us with all needed information about the project, guiding us throughout the project and giving very helpful feedback. Without him, the project would never been as successful. Also, we would like to thank all other employees of EML Consultants, for providing a pleasant atmosphere at the office and helping out where needed. Secondly, our supervisor H.J. Verhagen helped a great deal by setting up the initial contact between the project team and EML Consultants. Without his personal contact with C. Fernando, this project would not have happened. We would also like to thank J. Verlaan and D.J.M. Ngan-Tillard, for being our supervisors for this project. Furthermore, we would like to thank CDR International for supporting us in this project. Lastly, the Embassy of the Netherlands in Colombo was so kind to welcome us at the start of the project and were interested in hearing the outcome at the end of our stay in Sri Lanka.

CDR Profile

CDR International BV is a fully independent coastal, river, water management, and port engineering and consultancy firm having its roots in the Netherlands. CDR stands for Coasts, Deltas and Rivers, the environment and field of our expertise in broadest sense. CDR International is focusing on project initiation and development, management, design, contract management and engineering services, in the water and maritime sector worldwide. CDR International services cover the range of project idea development, master planning, feasibility studies, detailed mathematical modelling and design studies to supervision during the construction phase.

CDR International started in 2012 and operates with own specialist staff and a selected team of specialists, with whom CDR International can cover the entire range of our services. The team consists of coastal, rivers, port, water management, metocean, hydraulic, morphological, mathematical modelling, environmental and geotechnical specialists. CDR International often complements the services with partners, for instance for site investigations, urban development aspects on land reclamations and specialist in the field of finances, economics and public private partnership transaction advisory services.

The CDR International team is formed by enthusiastic and committed junior, medior and senior experts, who are originating from a wide range of world renowned companies in the maritime, water management, port and oil & gas sector. Because of this setting, CDR International is very flexible and can anticipate directly on the needs of Clients, offering high quality and expertise while keeping the lines short, communication easy and prices competitive. CDR International is characterised as flexible, higher-end consultancy 'contractor' having focus on serving our Clients tailor-made and providing top quality in the design work. Moreover, since part of the team has ample site experience on several projects CDR International is capable to merge theoretical and practical aspects in engineering studies and deliverables.

Because of the partners and large network, CDR can offer a very wide range of professional services, with a focus on the following:

- Coastal Protection and Integrated Coastal Zone Management
- MetOcean & Hydrodynamic Numerical Modelling
- Breakwaters, Revetments and Marine Structures
- Port Master Planning
- Land Reclamation
- Flood Protection and Integrated Water Resource Management
- Urban Drainage
- Inland Waterway Transport (IWT)
- Climate Change Studies
- Floods and Droughts
- Geosynthetics Engineering
- Breakwater Health Scan (BHS)

Excecutive Summary

In Sri Lanka, the government and the Liberation Tigers of Tamil Eelam waged a civil war between 1983 and 2009. During this period the social and economical development in the north and east of the country was disrupted. Due to this disruption a development opportunity for this region is the expansion of the fishery industry. In 2016, the Sri Lankan government proposed the Northern Province Sustainable Fisheries Development Project, in which the construction of a harbour at Point Pedro in the Jaffna District is included. This harbour should become the second largest fishery harbour in Sri Lanka.

This report covers the design study of the Point Pedro harbour project, the goal of this study is to design a safe, economically efficient and socially accepted harbour at Point Pedro. To achieve this goal, the following research question *"How can safety, economic efficiency and environmental impact be combined optimally in a harbour design for Point Pedro in the Jaffna District?"* is answered.

In Figure 1 the final design of the harbour can be seen. This design is focussed on the optimal combination between safety, economic efficiency and environmental impact. Because these criteria are conflicting, they are prioritized as follows: (1) safety, (2) economic efficiency and (3) environmental impact. Safety is provided by constructing breakwaters around the harbour, providing sheltered water conditions in the harbour basin. Also, the harbour entrance is constructed in a way that monsoon waves cannot directly intrude into the basin. Economic efficiency is accounted for by constructing the quay wall close to the central located fish processing facilities. This optimizes the supply chain, resulting in a smaller loss in the fish production (compared to the current situation). The costs are optimized by reusing all dredged material inside the breakwater or for land reclamation. Additionally, the location of the harbour entrance is minimizing the sailing routes as much as possible, without creating safety issues due to wave intrusion. Finally, the negative effects of social impact are limited by involving local fishermen and residents during the entire development process. Because these stakeholders are potential blockers of the project, it is important to include their opinions in the design. This can also be done by broadening the scope, in which touristic facilities and accommodations can be included in the project. Other negative impacts of the harbour can be either mitigated or minimized. However, because the environmental impact is determined as the least important criteria, it is not able to solve every issue.

Figure 1: Final design Point Pedro harbour

This design is considered to be the most optimal combination for the harbour design of Point Pedro, regarding the criteria of safety, economic efficiency and environmental impact. It is recommended to EML Consultants that three characteristics of the proposed design should be implemented in their final design for Point Pedro: (1) apply building on the reef for land reclamation inside the harbour, (2) cluster the fish processing facilities near the unloading quay walls, because it optimizes the fish supply chain and reduces fish loss, and (3) construct the jetties for large boats (in the east of the harbour) as proposed, because it optimizes manoeuverability inside the harbour using minimal space. The final recommendation is to perform additional research to make a more accurate design, as the main limitation of the report is the limited amount of available data. Additional research should be done in the fields of; wave data, ground conditions over the entire harbour basin, cost estimation and sedimentation.

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1. INTRODUCTION

In the first chapter of the report the project outline will be described. The context of the research is explained and the goal and boundaries are given. Also the research question and its subquestions which will be answered in the report are presented. Finally the methodology, which is used to answer the research question, as well as the reader guide are given.

Source: own picture, taken atWeligama

1.1 Context of research

In July 1983 a conflict between the government and the Liberation Tigers of Tamil Eelam resulted in a civil war in the northern and eastern part of Sri Lanka (Peace direct, 2013). During a period of 25 years this civil war disrupted the social and economical development in the north and east of the country. When the war ended in 2009, it gave large opportunities to develop economic attractive industries in these areas. One development opportunity for Sri Lanka is the expansion of the fishery industry in the Northern Province of the country, see Figure 2.

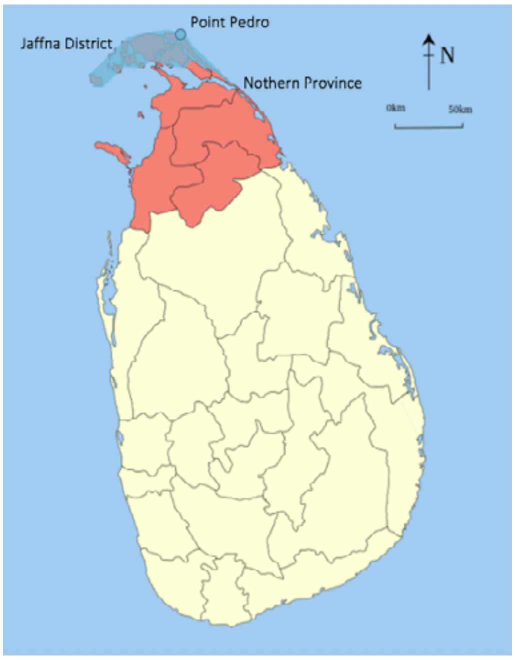


Figure 2: Map of Sri Lanka (Kiriella, 2004)

In the year of 2016, the Sri Lankan government proposed the Northern Province Sustainable Fisheries Development Project (NPSFDP), in which two fishery harbours, seven anchorages, and 21 landing sites will be constructed in the Northern Province of Sri Lanka. One of the two fishery harbours is the Point Pedro harbour, located in the Jaffna District. This location seems especially interesting for the development of a fishery harbour since the Jaffna District was one of the leading fishing regions in the country before the civil war (University of Moratuwa, 2016b).

The village of Point Pedro is located at the most northwestern tip of the Jaffna District, see Figure 2. The District (green in Figure 1) has 583,000 inhabitants of which 47,000 people live in Point Pedro (Divisional Secretary's Division, 2012). In Jaffna there are 20,000 households in total whose income is dependent on fishery (FGZ ANZDEC and RDC, 2017). The amount of fish caught in the Jaffna District dropped severely during the civil war. As this conflict belongs to the past, this region can now help to serve the growing demand in the country.

Currently, only small fishery harbours are situated in this region. These small harbours are not able to accommodate the large fish demand in Sri Lanka. According to the government, building a new harbour at this location will lead to a growing fish supply and thereby reducing scarcity. To finance this harbour project the Asian Development Bank granted a loan to the Sri Lankan government.

1.2 Goal and boundaries

The University of Moratuwa provided a feasibility study of the implementation of a new fishery harbour in Point Pedro. However, this feasibility study does not cover all aspects and additional research is required. An important part of this project is the final harbour design at Point Pedro and how this harbour can be implemented in the environment. This is where this multidisciplinary project focusses on. The goal of this project is to design a safe, economically efficient, and socially accepted harbour at Point Pedro.

To provide a complete report, within eight weeks time, some boundaries are set. First of all, the report does not elaborate on the Northern Province Sustainable Fisheries Development Project (NPSFDP), which is the umbrella project of the Point Pedro project. The report will only focus on the design of the harbour in Point Pedro, which is described as Output 1 in NPSFDP. Furthermore, the location of the Point Pedro harbour has already been decided upon (P.C. Fernando, personal communication, 14/09/2017). Therefore, the rough project location is set and no additional research for external site areas is considered. It has been set that the harbour should be developed within the area showed in Figure 3.

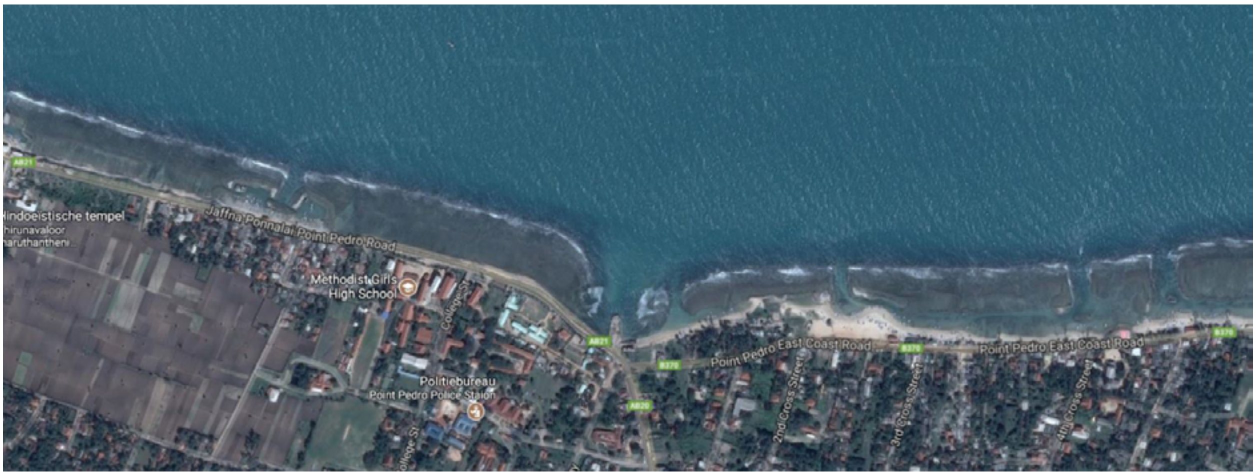


Figure 3: Spatial project scope of Point Pedro project (Google Maps, 2017)

The last boundary set is focussed on regulations and standards. Dutch building regulations are known and familiar to the project team, while Sri Lankan regulations are not, for this reason this research will be based on Dutch regulations and European standards.

1.3 Research question

To achieve the goal that has been set, the following research question has been formulated:

"How can safety, economic efficiency and environmental impact be combined optimally in a harbour design for Point Pedro in the Jaffna District?"

To be able to answers this research question five subquestions have been formulated:

1. What are the critical environmental conditions which have to be taken into account when designing a harbour at Point Pedro?
2. What is the optimal harbour design at the project location?
3. What will be the impact of the harbour on Point Pedro?
4. How should the most important stakeholders be engaged during the development process?
5. How could the master plan be implemented optimally?

1.4 Methodology

By making use of the V-model (Powell-Morse, 2016), the report is structured in a logical and understandable way. As shown in Figure 4, the V-model is integrated in the research methodology.
The main sources of this project are based on information provided by Eng. C. Fernando of EML Consultants. This sources include reports of feasibility studies of comparable fishery harbours in Sri Lanka, technical details of the project location, environmental issues and a suggested harbour design. Additional information is required from TU Delft literature, internet sources and other literature. At last, personal communication with Eng. C. Fernando and other employees of EML Consultants resulted in valid information.

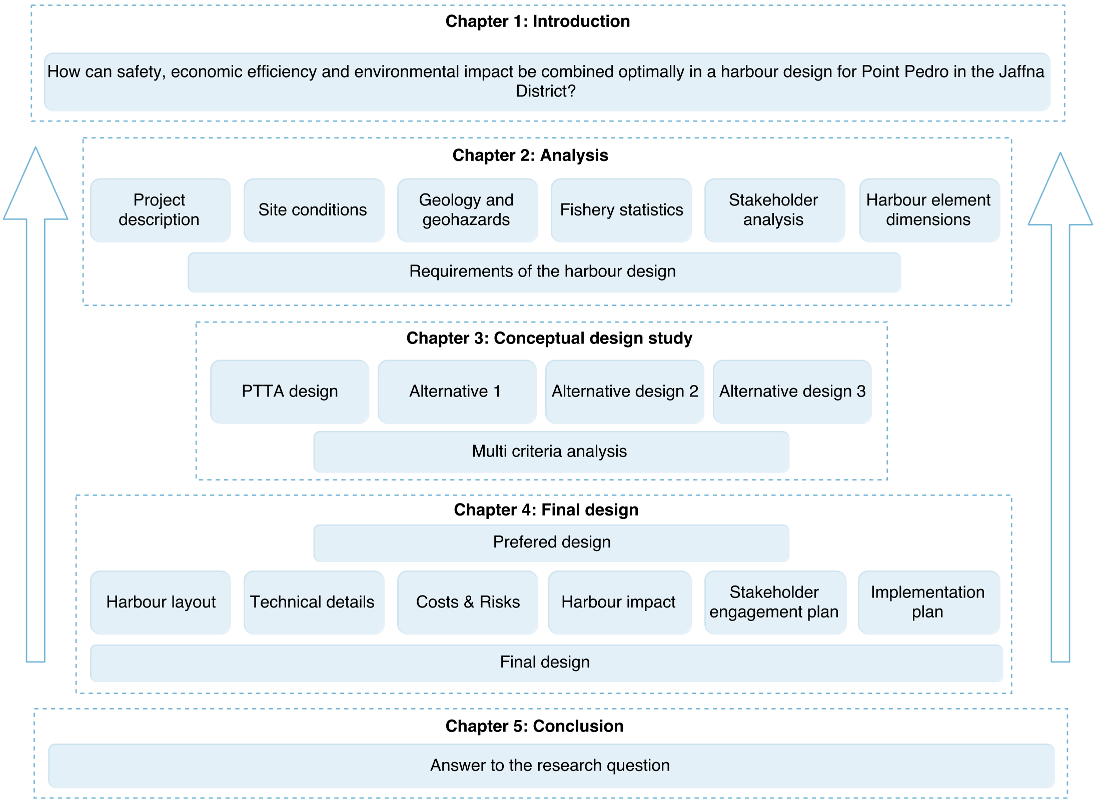


Figure 4: Research methodology (own illustration)

1.5 Reader guide

As shown in the research methodology (Figure 4), this study is subdivided into three main parts. First, all known information is structured and elaborated on in the analysis phase. Subquestion one will be answered in this part of the report. Next, the conceptual design phase will take place, wherein several different harbour designs will be presented and discussed. Criteria will be set up to scale the different alternatives and to be able to make a well substantiated decision on which alternative to further elaborate upon and which design requirements should be taken into account. In the last phase of this report, the final harbour design will be determined and technical details will be provided. This part of the report is called 'Final Harbour Design', and will also provide an answer to subquestions two, three, four and five. Of course, at the end of the report, the final conclusion, as well as, the recommendations and limitations will be provided.

2. ANALYSIS

The second chapter of the report contains the overall analysis of Project Point Pedro. First of all, the project as proposed by the government is explained. Furthermore, the site conditions, environmental conditions, geological aspects and the current fishing situation in Sri Lanka are described. Also, an elaborate stakeholder analysis is performed. The last paragraph, harbour dimensions, serves as a basis for chapter 3.

Source: own picture, taken at Point Pedro

2.1 Project description

To provide a thorough understanding of the project, this paragraph will focus on the explanation of the overarching project Point Pedro falls under (NPSFDP) as well as the explanation of the project itself. This also includes the structure of companies working together to develop the fishery harbour.

2.1.1 The Northern Province Sustainable Fisheries Development Project

The Northern Province Sustainable Fisheries Development Project (NPSFDP) is initiated by the Sri Lankan government and executed by the Ministry of Fishery and Aquatic Resources Development (MFARD). The Sri Lankan government requested funding from the Asian Development Bank (ADB), which covers investments in four coastal districts in the Northern Province: Jaffna, Mannar, Mullaitivu, and Kilinochchi. The aim of the NPSFDP is to revive the fisheries sector in the Northern province by increasing the fish production in a sustainable way. This will be achieved through three outputs: (i) developed and operational climate resilient infrastructure, (ii) expanded aquaculture, and (iii) strengthened entrepreneurial skills, market links, and credit access for local communities including women. The first output is subdivided into 30 separate projects; two fishery harbours (Point Pedro and Pesalai), improvements on seven anchorage sites in the Jaffna District and improvements on 21 landing sites in all four coastal districts. Point Pedro is by far the largest development in this output, and thus also involves the biggest investment. In the second output, the four subprojects are described as: (i) coastal aquaculture development and training centre, (ii) mud crab hatchery and larval rearing facility (iii) sea cucumber hatchery and associated nursery facilities, and (iv) seaweed tissue culture laboratory and in-vitro propagation facility (FGZ ANZDEC and RDC, 2017a). Output three is not divided in any subprojects.

The scope of this report is the fishery harbour at Point Pedro in Jaffna District, as described in Output one. The location of the proposed harbour in Point Pedro is chosen because of several reasons (FGZ ANZDEC and RDC, 2017a):

1. Point Pedro has the highest district level of fishery boat landings in the Northern Province;
2. The village has the highest current district fish shortage with respect to the pre-1983 landings, before the civil war;
3. The area of Point Pedro is relatively suitable for the construction of a harbour as the bathymetry allows harbour basin depths to support offshore deep sea fishing boats;
4. The location gives access to suitable deep sea and offshore fishing grounds to the north-east and east.

2.1.2 Project Point Pedro

When constructing a fihery harbour, multiple actors are involved. The initiator will not execute the plan, nor will execution party do all the research itself. An overview of involved parties and their tasks during the initiative and designing phase of the Point Pedro harbour is given in Figure 5.

As described above, MFARD initiated the plan to build a fishery harbour in the Northern Province of Sri Lanka, where the ADB provided a loan. Together, the MFARD and the ADB set up a rough plan, and asked the University of Moratuwa to perform a feasibility study. This was checked again by the MFARD and the ADB, and used to set up a rough plan and scope for a Project Preparatory Technical Assistance (PPTA). This PPTA was eventually written by FCG ANZDEC and RDC. When the results were handed back to the MFARD, they wrote out a tender for the detailed design, which was won by EML Consultants. This is the current phase of the project. When the detailed design is finished, it will be handed over again to the MFARD and the ADB, whereafter by the use of a tender, a constructor will be assigned to the project.

Figure 5: Project Life Cycle of Project Point Pedro (own illustration)

2.2 Site conditions

To design an efficient fully fledged harbour at Point Pedro, an analysis of the bathymetry, climate, hydraulic conditions and the environemental conditions is necessary. This analysis will be given in the next subchapters.

2.2.1 Bathymetry

Sri Lanka is an island state with a 1340 km long sandy shore, located in the northern hemisphere southeast of India in the Indian Ocean. The Jaffna District is situated in the northern part of Sri Lanka, therefore the bathymetry is focussed on this area.

Palk Strait

First, a general overview of the northern part of Sri Lanka is considered. The sea between India and Sri Lanka is called the Palk Strait. In the Palk Strait two main geographical aspects can be considered; The Adam's Bridge and the Pedro Bank, see Figure 6.

Figure 6: Overview northern Sri Lanka (own illustration, derived from Google Maps, 2017)

The Adam's Bridge was the former connection between India and Sri Lanka, nowadays this 'bridge' functions as a natural (partly) underwater dam. The Adam's Bridge provides shelter against the southwestern monsoon and large incoming waves. The ocean depth in the Palk Strait is between 20-25 meters.
The Pedro Bank is situated north-east of Jaffna, providing shelter against incoming winds from the north-east. Because of the low depth of the bank the wave climate is less severe compared to the §ern part of Sri Lanka.

Point Pedro

As shown in Figure 6, Point Pedro is located at the most northeastern part of Sri Lanka in a relatively shallow bay. Parallel to the coast a coral reef is located, protecting the shore. UNESCO-IHE (2016b) carried out a bathymetric survey, the raw data is transformed into a bathymetry model, see Figure 7. It can be observed that the reef is located around four meters depth. After 4 meters, the slope of the seafloor becomes steep, while in the area in front of the reef the bottom gently slopes upward creating a sandy beach. The reef is located approximately 50 meters from the shoreline.

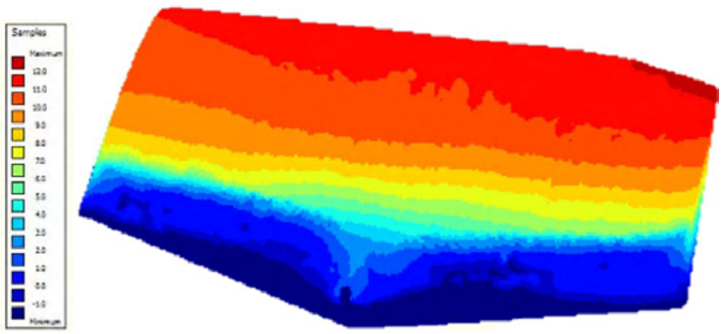


Figure 7: Bathymetry of Point Pedro (compared to MSL, downward positive) (UNESCO-IHE, 2016a)

Landing sites

Currently, small openings in the coral reef provide access for small fishing boats to reach the shore. In Figure 7 the current landing sites are indicated with arrows. The Point Pedro area consists of fifteen landing sites, which supply landing site area for around 1500 small fishery boats. The landing sites consist out of small channels in the coral reef leading to small beaches, created by mankind to facilitate fishery activities. The coral reef also provides shelter against incoming waves.

A general observation made during the site visit of 2016 (UNESCO-IHE, 2016b), is that only small waves, about 0.5 m, break on the outer edge of the reef. The depth of landing sites, behind the reef, is around 0.5 m and strong currents are absent between the reef and coast. However, there is a current in the reef openings of 0.5-0.7 m/s.

Figure 8: Current landing sites Point Pedro, blue rectangle: bathymetry site (own illustration, derived from Google Maps, 2017)

2.2.2 Climate

Due to the diverse topography of Sri Lanka, elaborated in chapter 2.3 Geological analysis, the spatial wind patterns as well as the temperature, humidity and rainfall are affected strongly during the monsoon period. The general climate in Sri Lanka is defined as tropical, with an annual mean temperature of 27,5 ^{0}C. Two strong monsoons, the southwestern and northeastern monsoon, define four seasons during the year, see Figure 9.

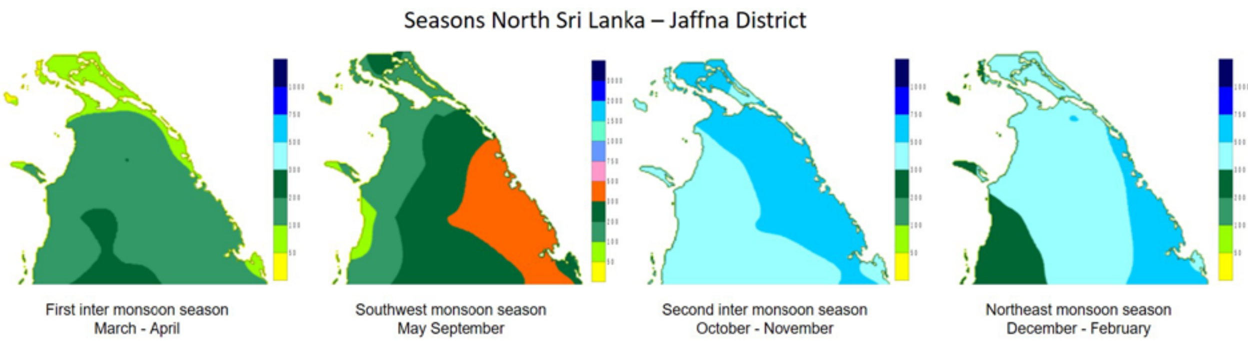


Figure 9: Seasons north Sri Lanka (Centre of Climate Studies, 1999)

Wind characteristics

As the monsoon directions suggest, the wind directions in the open sea north of Palk Strait are coming from south-west during the southwestern monsoon and from the north-east during the northeastern monsoon. The wind speeds vary in the southwestern monsoon period from 3 to 15 m/s and during the northeastern monsoon period between 3 to 12 m/s, as Figure 10 indicates. For the design of the harbour, the main wind direction will be as indicated in Figure 10a. The south-west monsoon winds will travel over land, and will not cause major wind waves at the project location.

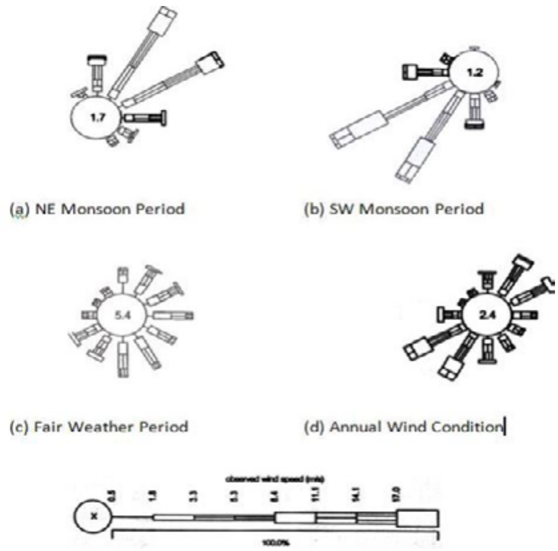


Figure 10: Wind roses for Open Sea North of Palk Strait (Tuticorn Port Trust, 2005)

Cyclones

During the north-east monsoon period cyclonic activities in the Jaffna District bring heavy rains and high wind speeds, causing storm surges with severe flooding. The Jaffna District is vulnerable for cyclonic storms as Figure 10 shows. Cyclone Nisha, the most recent cyclone which caused severe flooding, swept through the Jaffna District in November 2008. During peak period the wind speed reached up to 23.6 m/s and a rainfall of 765.5 mm in six days, causing more than 200 deaths (FGZ ANZDEC, 2017).

The Northern Province appears to be vulnerable for severe cyclonic events as shown in Figure 12 (Hazard assessment by Wijetunge, 2013). Storm surges can reach the Jaffna District in the order of four meters

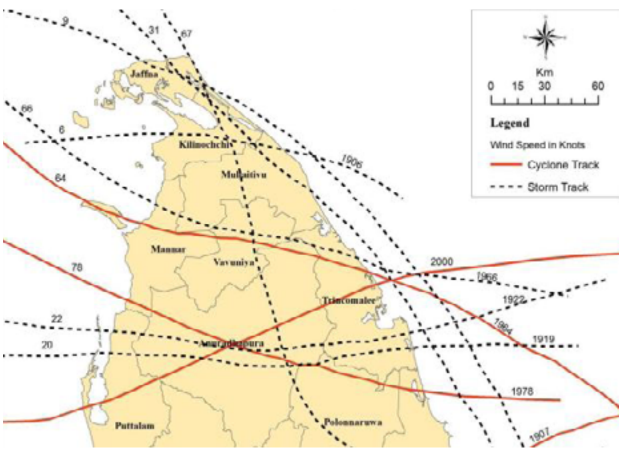


Figure 11: Tracks of cyclonic storms (Meteorological Department)

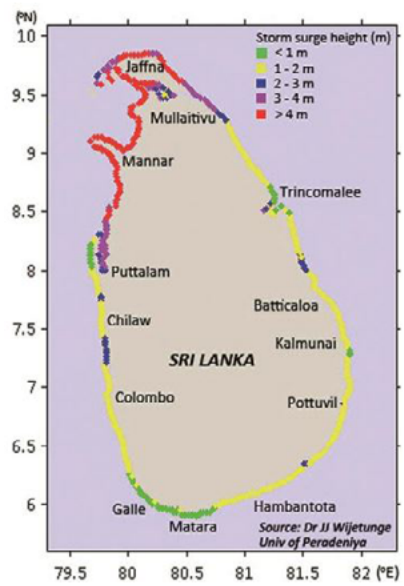


Figure 12: Storm surge hazard assessment to a Cyclonic Scenario (Wijetunge, 2013)

height.

Climate change

For a proper harbour design, climate change considerations should be consideres as well. The main considerations for the project are sea level rise.

The Disaster Management Centre published Reference-Hazard Profiles of Sri Lanka with the worst case scenario of sea level rise (University of Moratuwa, 2016b):

- Change of sea level since the establishment of the datum = 0.068 m
- Change of sea level due to high tide = 0.300 m
- Sea level rise due to climate change (100 years) = 0.590 m

The harbour will be designed for a lifetime of 50-years. The worst case scenario for sea level rise will be:

$$0.068 + 0.3 + \left(\frac{0.59}{100} \text{ x } 50\right) = 0.658 \text{ m}$$

Other data is provided by the Interagency Panel on Climate Change Recommendations, which projected the rise of the sea level for the next 100 years as 400 mm. 200 mm of sea level rise is suggested for the coming 50 years. The sea level rise of 200 mm will be considered as the most optimistic value and the sea level rise of 658 mm will be seen as the most pessimistic value. A realistic value is determined as the main between the optimistic and pessimistic value, being 429 mm in 50 years.

$$\frac{200 + 658}{2} = 429mm$$

2.2.3 Hydraulic conditions

A large site study of the hydraulic conditions and offshore data at Point Pedro is done by Lanka Hydraulic Institute Ltd and The Ministry of Fisheries & Aquatic Resources Development (2017). Measurements are done during the months January, February, and March 2017. In this paragraph the influence of tides, waves, currents and sediment transport is investigated at the proposed project location Point Pedro.

Tidal conditions

The island of Sri Lanka has two main types of tides; the west coast of Sri Lanka can be characterized as mixed with a large contribution of the semidiurnal tide, , and the east coast can be characterized as a semidiurnal tidal climate. Since Point Pedro is in the North of the island, further elaboration is required.

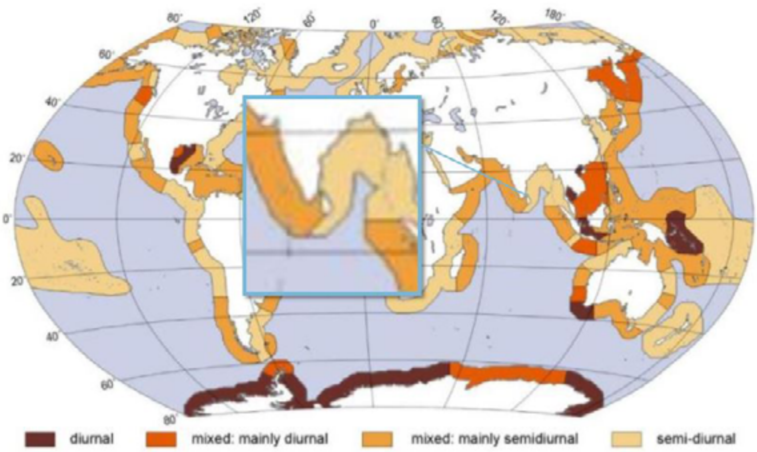


Figure 13: Tidal environment world, Sri Lanka (Stive, 2015)

To determine the tidal behaviour at Point Pedro, measurements of UNESCO-IHE (2016a) are used. These continuous measurements during two months resulted in the semidiurnal and diurnal tidal components occurring at Point Pedro. These components were used to calculate a form factor (F). This form factor is the ratio between the main diurnal components and the main semi-diurnal components: for the Point Pedro site, this is equal to 0.2. This value indicates that the tide at the proposed harbour site can be characterized as semidiurnal. For more detailed information about the calculation, see Appendix A.

According to the Admiralty Charts from the United Kingdom Hydrographic Office, the spring tidal range at the coastline of Point Pedro is 0.6 m. The neap tidal range is 0.3 m at the Point Pedro coastline (United Kingdom Hydrographic Office, 1978).

Wave climate

A site study of UNESCO-IHE (2016a) lead to a nearshore wave rose at the Point Pedro harbour location (measurement location has a depth of MSL - 14.3 m), visualized in Figure 14. From this wave rose, it can be observed that the dominant wave direction is the north-east direction. This is logical since the Point Pedro location is sheltered from the southwestern monsoon by Adam's bridge.

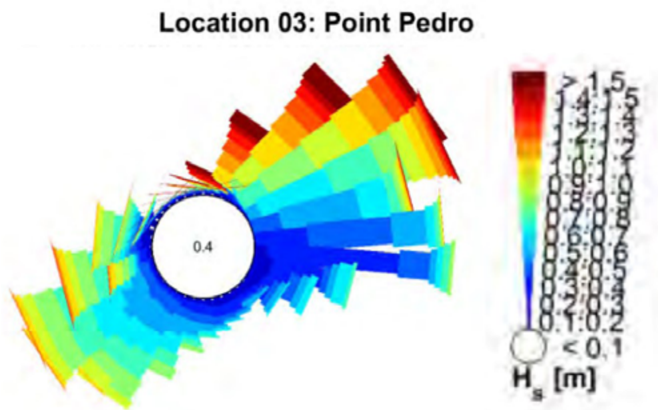


Figure 14: Nearshore wave climate (UNESCO-IHE, 2016b)

This nearshore wave rose was used for determining the characteristic wave height for the harbour. In the technical reports of ANZDEC (2016), a characteristic wave height (H_s) of 3 m was found. This wave height is based on the construction lifetime of the harbour, which is 50 years. The mean wave period was found to be eight seconds (ANZDEC, 2016).

The swell offshore of Point Pedro is composed of both southerly long distance swell from south of the equator, and local short period swell generated in the Bay of Bengal. According to Swan (1983) the coast of Jaffna is not affected by medium and long period swell as it faces seas that are less than 13 m deep.

Ocean currents

The two monsoon winds together, with different salinities and temperatures of the water, are the main drivers of the ocean currents around Sri Lanka. As Figure 14 and Figure 15 show, the currents depend fully on the monsoon type. The southwestern monsoon creates currents almost contrary to the northeastern monsoon. At the northern coast the main driving forces for large scale currents are wind and tide.

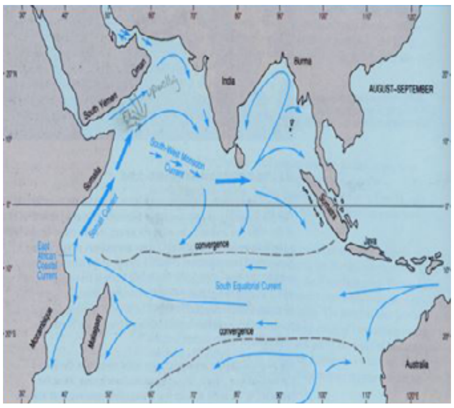


Figure 15: SW Monsoon current (University of Moratuwa, 2015)

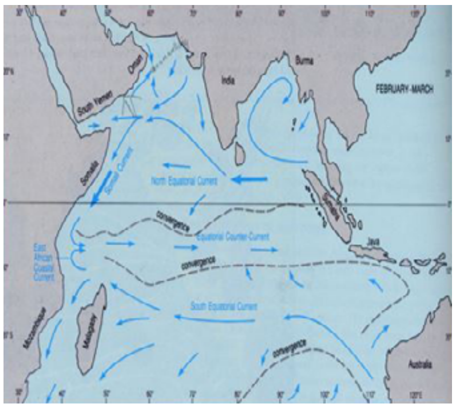


Figure 16: NE monsoon currents (University of Moratuwa, 2015)

The effect of the ocean currents on the harbour site at Point Pedro is limited. This is mainly caused by the Adam's bridge and the Pedro Bank (Figure 6). The water depth is shallow in this areas causing a flow constriction through Palk Strait. According to UNESCO-IHE (2016), strong currents are not expected near the harbour. Currently, the strongest currents are measured in the small reef inlets, which are providing access to the landing sites. These currents are caused by a return flow after waves did overtop the reef, leading to a current velocity of 0.5-0.7 m/s. These return currents only occur after overtopping of waves, as overtopping is constricted in harbours it is expected that these current are not normative for the harbour design.

Sediment transport
Important for the location of a harbour is the nearshore sediment transport. The sediment transport at the proposed harbour location consist out of two components: (1) sediment transport inside the reef (blue arrows in Figure 16), and (2) sediment transport outside the reef (white arrows in Figure 16).

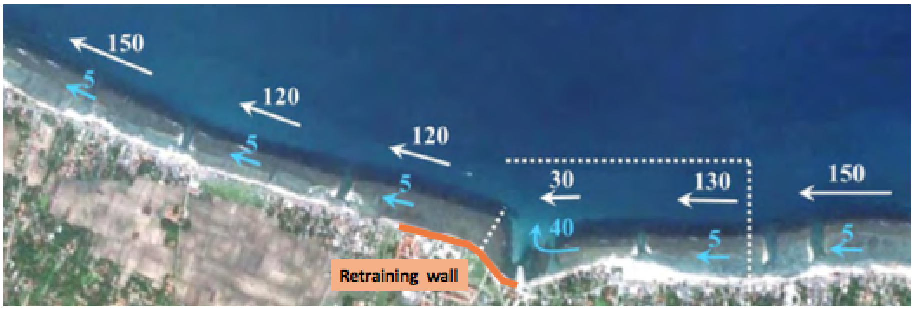


Figure 17: Sediment budgets at the proposed harbour location at Point Pedro (own illustration, derived from UNESCO-IHE, 2016b)

The sediment budgets shown in Figure 16 are based on a coastal model of UNESCO-IHE (2016). According to this study, the annual net longshore sediment transport is deviating between 30.000 m^3/year and 150.000 m^3/year along the coastline of Point Pedro. According to Eng. P.C. Fernando, this longshore transport numbers are highly uncertain. His statement is based on local fishers saying that the beach was not eroding in the last couple of years. Since the beach is protected by the reef, sediment budgets are much lower than outside the reef. Sediment transport at this location is not visible for fishers (depth is at least four meters).

Due to erosion problems west of the Point Pedro anchorage pier, many years ago a retaining wall was constructed to prevent erosion from wave attacks. However, this wall has been partly damaged due to the seasonal longshore erosion (FGZ ANZDEC and RDC, 2017b).

Google Earth images of the shore in 2002 and in 2017 at three locations give an indication about the amount of erosion and sedimentation, see Figure 18 and Figure 19. The area' behind the reef openings show signs of erosion, while in the more calmer areas sedimentation occurs. At location 2, the retaining wall is situated, explaining the fact that little shoreline changes are visible.

Figure 18: Locations shoreline change (own illustration, derived from Google Maps, 2017)

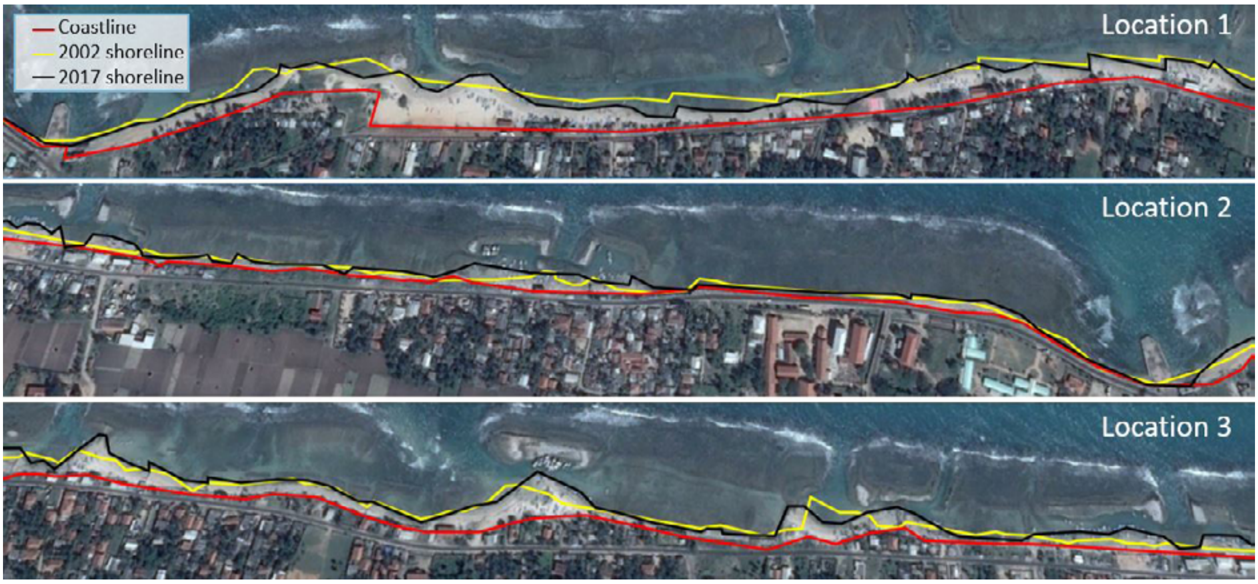


Figure 19: Visible shoreline changes between 2002 and 2017 (own illustration, derived from Google Maps)

The influence of the tide on the sediment transport near the Point Pedro coast is limited. According to Eng. P.C. Fernando tidal currents are not strong enough to initiate sediment transport. If tidal currents and wave induced currents are combined, it can lead to longshore sediment transport. Since severe wave attacks come from north-east direction it can be assumed that longshore sediment transport only occurs from east to west direction. Not enough forces act on grains to induce a sediment transport from west to east (Eng. P.C. Fernando). This is an important notice for the design and positioning of the harbour entrance.

2.2.4 Environmental conditions

Coral reefs protect the whole beach at Point Pedro. This reef is mainly sandstone and devoid of living coral, as turf algae covered the living coral. Granite boulders above the water level provide resting areas for seabirds and crows and provide suitable habitats for rock crabs (Grapsus sp.) and other molluscan species. Two threatened species are found in the Point Pedro area, the 'Sterna sandvicensis' and the 'Scotophilus heathii', a bird and a bat species (Central Environmental Authority, 2014). As the effects of the environmental impact of the harbour on the threatened species are unknown, no additional constrictions will be used in the design stage. An indication of the current environmental vlaues of the Jaffna District can be seen in Figure 20.

Figure 20: Existing coastal and marine conservation areas (own illustration, source FGZ ANZDEC, 2017)

2.3 Geological analysis

To determine the expected limitations and challenges when designing a civil construction the geology of the site needs to be analysed. In this report the possible geohazards are derived from an initial desk study, using the Total Geological History Approach, and secondly the geohazards are derived by using a more in depth desk study of Jaffna and the Northern Province.

2.3.1 Total geological history approach

A first analysis of the geology of Sri Lanka is made using the Total Geological History Approach. This method is used to anticipate the site conditions and is based on a paper by P. Fookes (2000). The method is subdivided into three subdivisions: tectonic models, geological models and geomorphological models. Each of these models contain factors that affect the local geology at different scales.

Tectonic models

Sri Lanka is located quite central on the Indo-Australian Plate, however earthquakes occurring closer to the island suggest that this plate is breaking up, illustrated in Figure 20. Sri Lanka is not situated on or near a plate boundary, indicating that intraplate settings apply. Sri Lanka consists of metasedimentary rocks such as granites, migmatites and gneisses (Dahanayake & Ranasinghe 1985).
The data suggests that the type of intraplate setting will be cratons, the model suggesting this is represented in Appendix B. However, as the site is located at the Jaffna Peninsula, which is relatively flat and mainly consisting of limestone, there is a second tectonic model which could apply: The platform sediments & basins. This model is also schematically represented in Appendix B on page 103 (Vethanayahan, 2013).

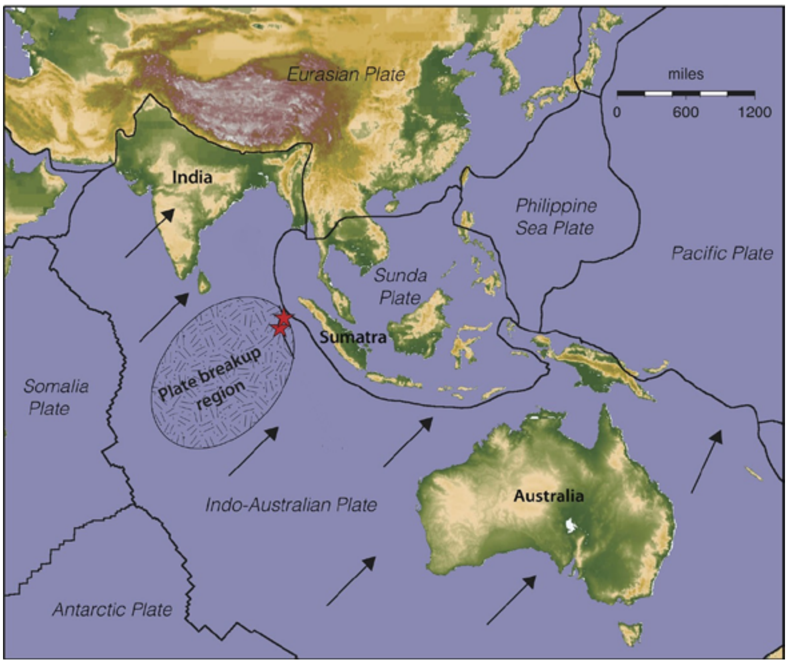


Figure 21: Tectonic map of the Indo-Australian plate (Shen, H. 2012)

Geological models

As the tectonic model confirmed, the types of rock that can be expected in the site are limestone, gneiss, granites and migmatites. It can be expected that the limestone is the upper layer as this layer did not experience any metamorphosis and is a sedimentary rock. Below the limestone the metamorphic gneiss, granites and migmatites can be expected as these layers are older. No metamorphic rocks are expected on top of the limestone, as this would probably have resulted in metamorphism of the limestone.

For this reason, two geological models apply, a sedimentary and a metamorphic model. The sedimentary model can be expected to be shelf carbonates and evaporates as the Jaffna Peninsula is flat and lagoons and reefs are present, both producing carbonates. The metamorphic model is expected to be gneisses and migmatites, as the tectonic model and the article by Dahanayake and Ranasinghe (1985) suggest the presence of gneisses, granites and migmatites. Both models are represented in Appendix B.

Geomorphological models

The local geomorphology of the project site can be described with the coastal model since the harbour will be located at the coast. Key aspects of a coastal regime are dominated by wind and wave action, lagoons and tidal flats. The Ambassador of the Netherlands in Sri Lanka spoke about the salinisation of the northern region, indicating the presence of a coastal geomorphological model. A schematic representation of this model is also given in Appendix B.

2.3.2 Geology of Jaffna

First, the general geography of Sri Lanka is described. After this, the geology of Sri Lanka and especially the Northern Province is defined using several articles and a geological map. Together with the Total Geological History Approach, a complete picture of the local geology is created. First, the formations which form Sri Lanka are given, after this the formation which forms the Northern Province is elaborated.

Geography

Sri Lanka has a greatly varying geography. The south central part of the country is mountainous with a highest point of 2424 meters, the mountains are rounded and the mountain peaks are not very distinguished. The valleys in this region are sloping westwards, at the western coast the hills are barely distinguishable. To the north of these mountains one finds gently sloping hills extending up to 160 kilometers to the north. The northern part of the country, the Jaffna Peninsula, is a relatively flat area which is formed and mostly affected by the ocean (Cameron, 1977).

Geology of Sri Lanka

The geology of Sri Lanka can be divided into five different formations: the Highland Complex, the Vijayan Complex, the Wanni Complex, the Kadugannawa Complex and the Limestone Complex. These are present as can be seen in Figure 21. In the southeastern part of the country one finds the Vijayan complex, which consists of alkaline granitoid gneisses and sedimentary xenoliths. To the west of this formation the Highland Complex is located. This consists of interlayered, predominantly granulite facies, granitoid gneisses and clastic to calcareous shallow water metamorphosed sedimentary rock. The Highland Complex is exposed in several Klippe, according to the widest accepted theory, which are situated in the region of the Vijayan Complex. The presence of these Klippe suggest the presence of a thrust fault, in turn suggesting that the Highland Complex is of older age than the Vijayan Complex. More to the north-west of the Highland Complex the Wanni Complex is situated, this consists of granitoid, grabbroic, charnockitic and enderbitic gneisses, migmatites, minor metamorphic sedimentary rocks and post-tectonic granites.

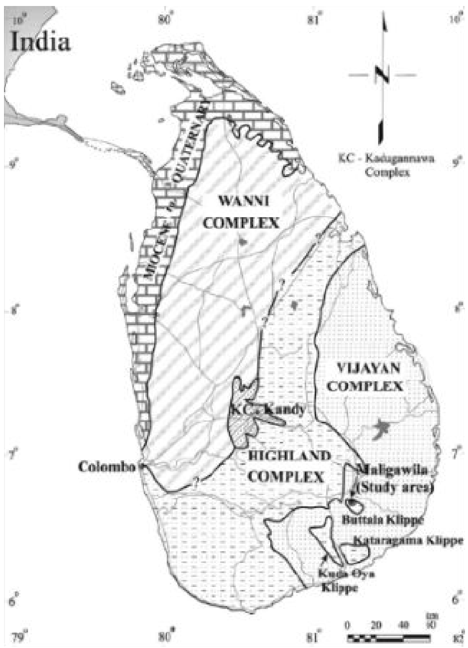


Figure 22: Map showing all formations of Sri Lanka. (Aravinda Ravibhanu Sumanarathna, S.M.)

Between the Highland Complex and the Wanni Complex the Kadugannawa Complex is present. The Kadugannawa Complex can be seen in the cores of the six doubly plunging synforms in the region surrounding Kandy. These synforms are dominated by hornblende-biotite gneisses, granites, granodiorites and tonalites. These types of rock are identical to those of the Wanni Complex, due to this, the Kadugannawa Complex is sometimes included in the Wanni Complex. In the north and northeast of Sri Lanka the Limestone Complex is located. The Limestone Complex, a sedimentary deposition from the Miocene, is much younger than the other formations which have their origin in the Precambrian. The Limestone Complex is deposited as a thick reef consisting mostly of fossiliferous limestone which is now the basis of the whole Jaffna Peninsula. The limestone is almost flat bedded and karstic caverns are found throughout the whole peninsula. On the Jaffna Peninsula, above the limestone, some Pleistocene deposits are found, these deposits consist of laterite (Aravinda Ravibhanu Sumanarathna, n.d.). The geological observations which were done during a site visit of the project location are described in Appendix C: Site visit on page 105.

2.3.4 Geohazards

From the previous geological desk study the geohazards which could affect the design of the harbour are derived. These geohazards are used to indicate the possible effect on the designs. The considered geohazards are earthquakes and karst.

Earthquakes

The break up of the Indo-Australian plate relatively close to Sri Lanka can be a source of new occuring earthquakes. As this new plate boundary is forming a triple junction with the plate boundary at the Java-Sumatra trench, it is safe to assume that the hyperactivity of the Java-Sumatra plate boundary will have considerable impact on the newly forming Indo-Australian plate boundary. It is discovered by scientists from the University of Melbourne that the Indo-Australian plate is under considerable stress resulting in earthquakes up to 7.0 on the Richter scale once every 30 years (Sandiford, Coblentz, & Schellart, 2005). These earthquakes could very well influence the project location (Dissanayake, 2005).

As this plate boundary is below an ocean, tsunamis are a possible resulting hazard from an earthquake as became clear in December 2004. As Point Pedro is located in the very north of the country it might not experience the full force of a tsunami but it is expected to experience some effect. The magnitude of this effect is dependent on the location of the earthquake. No documentation on tsunamis other than the tsunami of 2004 is available, therefore it is not possible to make a proper assessment of the consequences of a tsunami originating from an earthquake up to 7.0 in the Richter scale.

Karst

As the entire project region is situated on limestone bedrock, typical problems which may arise with limestone should be considered. All problems are due to the occurrence of karst, the dissolution of limestone in rainwater. The process of karst is more severe in warm and wet climates. As the north of Sri Lanka is a region with relative high temperatures and medium rainfall, karst is a serious option. This can result in pinnacled rockhead and sinkholes. Pinnacled rockhead can be tall, narrow, unstable or loose and may only be supported by soil. Possible fissures are not excluded, the rockhead relief can be more than 20 meters. Sinkholes are the result of soil down-washing into fissures and shafts in the limestone. These can be problematic as locations of occurrence are totally unpredictable. As the limestone is covered by the Pleistocene sands the subsidence is expected to happen slowly (Waltham, 2009).

As karst is expected but since it is unclear what the exact position will be and if it is present at the project location, a more extensive analysis of the ground conditions at the project location needs to be conducted. With a more extensive analysis dangerous regions can be indicated and avoided.

2.4 Fishery industry

The Point Pedro harbour will be designed to increase the fishery industry of Sri Lanka. A study about the current situation of the fishery industry, the current and future fleet, and the desired capacity for the Point Pedro harbour are required and will be elaborated in the following paragraphs.

2.4.1 Current situation of fishery in Sri Lanka

An important industry in the island country Sri Lanka is the fishery industry. Currently the fishery sector contributes 1.8% to the Gross Domestic Product (GDP) of Sri Lanka. Maybe more important, 2.6 million people are (direct and indirect) dependent on the fishery industry (University of Moratuwa, 2016b). Fishery in Sri Lanka consists of three sectors, the contribution of each sector can be found in Table 1.

Table 1: Fishery sectors in Sri Lanka (2015). (University of Moratuwa, 2016b)

Subsector	**Production (MT)**	**Contribution to total production (%)**
Inland fishery & agriculture	67,300	13
Coastal fishery	269,020	52
Offshore/Deep sea fishery	183,870	35
Total	520,190	100

The annual catch of offshore/deep sea fishery and coastal fishery is currently processed by nineteen fishery harbours, mainly situated in the south and west of the country, see Figure 22. In Figure 22, the governmental plans to build ten new fishery harbours as part of the NPSFDP can be observed. Eight harbours will be constructed in the northern part of the country, with Point Pedro as largest fishery harbour.

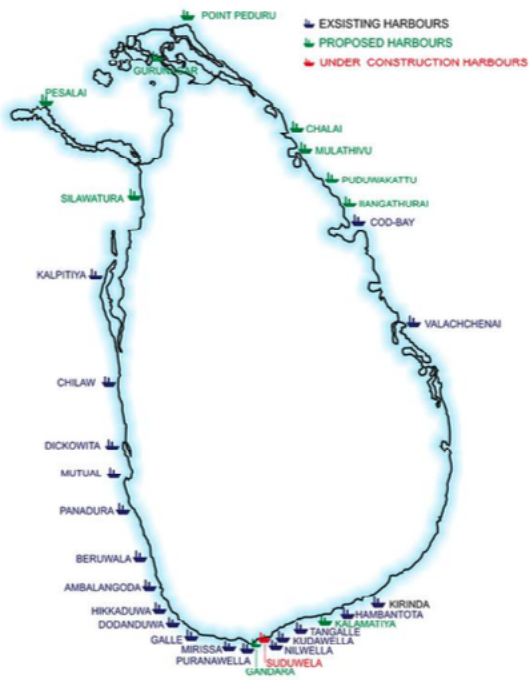


Figure 23: Fishery harbours in Sri Lanka (University of Moratuwa, 2016b)

Besides these constructed harbours, statistics of 2014 show that 58 anchorages and 891 landing sites contribute to the annual fish production in Sri Lanka. The continental shelf of Sri Lanka is on average 22 km wide (University of Moratuwa, 2016b). Fishing on this shelf is characterized as coastal fishery, which is currently the largest contributor to the fish production (Table 1).

The other contributor to the marine fish production of Sri Lanka is the deep sea and offshore fishery. Fish production from deep sea areas is mainly caught by multiday fishing boats in three areas in the 'Exclusive Economic Zone of Sri Lanka', see Figure 23. Since Sri Lanka has a tropical climate with monsoonal winds, operation time in two out of the three fishing zones is limited. During the southwestern monsoon (May to September) the fishing zone in the northwestern (NW) part of the country is limited accessible. On the other hand, during the northeastern monsoon (December to February) the fishing zone north-east of Sri Lanka (NE) is limited in its operation. The southern fishing zone (S) is operating without monsoonal limitation (Kariyawasam, Gestsson & Knutsson, 2010). Since the proposed harbour location at Point Pedro only gives access to the north-east fishing zone in Sri Lanka, operations of deep sea fishery from the harbour will be limited during the northeastern monsoon.

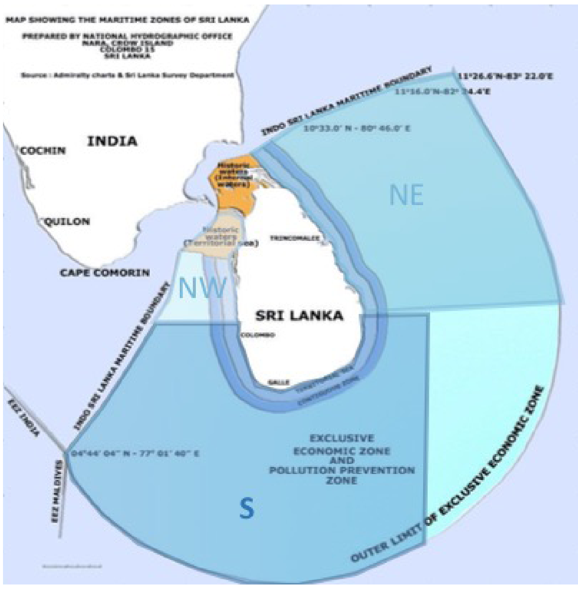


Figure 24: Deep sea fishing zones Sri Lanka (own illustration)

Targets of fishery in Sri Lanka

The government of Sri Lanka set some import targets for the fishery industry. These targets have two purposes: creating economic growth for Sri Lanka and increasing the health of the population of Sri Lanka.

The first target is creating economic growth for Sri Lanka. MFARD is aiming for an export rate of fish of 530,000 MT by 2020. In 2012 Sri Lanka exported only 18,500 MT of fish, which means that the export rate of fish should increase by a factor of 27 in eight years (CBI & LEI Wageningen UR, 2012). An important development for increasing the export has been achieved in April 2016. This is when the European Union decided to lift the ban on Sri Lankan fish import (University of Moratuwa, 2016b).

The second target is facing the lack of protein consumption of the Sri Lankan population. Currently the Sri Lankan people consume 44.6 gram of fish a day on average. According to the Sri Lankan government an average consumption of 60 grams a day is required for a healthy person (University of Moratuwa, 2016b). Currently, 80% of the Sri Lankan fish consumption is originating from its own fishery sector and 20% of the consumption is imported (CBI & LEI Wageningen UR, 2012).

Combining both targets leads to the annual target of fish production by the year of 2020, shown in Table 2. In order to reach this demand, Sri Lanka launched the development project NPSFDP. This project is focussing on encouraging districts to expend their deep sea and offshore fishery industry.

Table 2: Fishery development Sri Lanka (FCG ANZDEC and RDC, 2017b)

	2012 (MT)	**Target for 2020 (MT)**
Production for domestic use	486,170	373,120[1]
Production for export	18,500	530,000
Total	504,670	903,120

The third target of the government is to reduce the loss of fish during the production process. According to data from 2010, 30% of the fish catch is currently lost as a result of the lack of knowledge and onshore facilities. The target of the government is to reduce this loss to 5% by 2020 (CBI & LEI Wageningen UR, 2012).

Contribution of the Northern Province and the Jaffna District

Historically, the Northern Province of Sri Lanka is one of the most important contributors to the national fish production. In 1983, before the start of the civil war, the Northern Province had a 40% share in the national fish production. The center of gravity of the fishery was the Jaffna District, the Jaffna District contributed 26% of the total national fish production. The civil war resulted in a major impact on the fishery industry in the Northern province. Figure 24 shows the contribution of the Northern Province and the Jaffna District to the national fish production before and during the civil war (data is retrieved from University of Moratuwa, 2016b) .

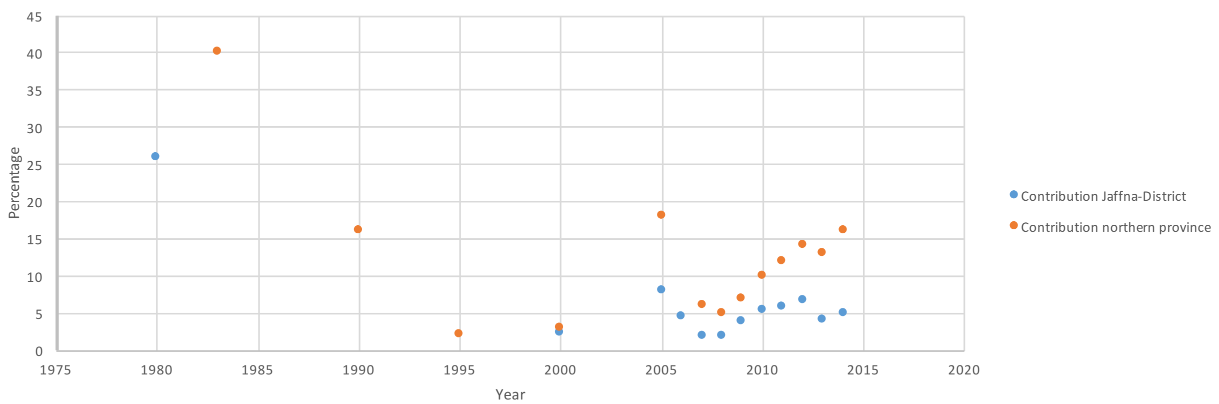


Figure 25: Contribution of Northern Province & Jaffna District to the total fishery production over the years (own illustration)

It can be observed in Figure 24 that the Northern Province and the Jaffna District are slowly recovering after the end of the civil war. Nevertheless, the contribution of the Northern Province is not comparable with the contribution before the start of the civil war. An opportunity to increase the market share is the NPSFDP, and the targets the government set for the annual fish production. In Figure 25 the contribution of the Northern Province and the Jaffna District can be observed with respect to the production target of the whole country (market shares are retrieved from data in University of Moratuwa, 2016b).

1 This number is based on the fish demand for 21.2 million people in Sri Lanka (Google, 2017), assuming that there is an import rate of 20% of the fish consumption in Sri Lanka.

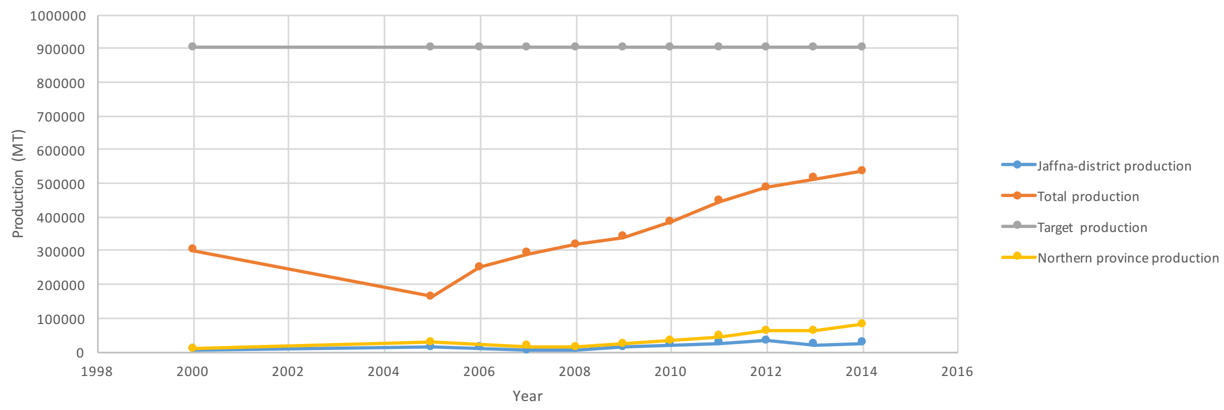


Figure 26: Recovery of Northern Province & Jaffna District fishery industry (own illustration)

2.4.2 Fleet

One of the most important things in the analysis phase is to determine the amount of vessels that will use the harbour. In this chapter, a forecast of the usage of the harbour is made, also the characteristics of the common boat types in Sri Lanka are given.

Boat types

Characteristics of different types of boats have influence on the harbour design. In Table 3, the dimensions of different types of fishery boats operating in Sri Lanka are shown.

Table 3: Largest type of fishery boats (University of Moratuwa, 2016b)

	Length (m)	**Width (m)**	**Draught (m)**
OFRPB	6.0	1.5	0.4
IDAY	9.0	3.0	0.9
IMUL	15.0	4.5	2.5 - 3.5
IIMUL	30.0	5.0	3.5 - 5.0

OFRPB = Outboard motor fiber reinforced plastic boats
IDAY = One day boats with inboard engines
IMUL = Multiday boats
IIMUL = large size multiday boat

Current fleet size

Another important aspect in the harbour design is estimating the amount of vessels that will use the harbour. To be able to give a prognosis of the current fleet sizes in Sri Lanka, the annual amount of boats in the Jaffna District and at Point Pedro are used, Table 4.

Table 4: Fleet sizes per boat type (University of Moratuwa, 2016b & FCG ANZDEC and RDC, 2017a)			
	Sri Lanka (in 2015)	**Jaffna District (in 2016)**	**Point Pedro (in 2016)**
NBSB	1,174	Unknown	90
NTRB	21,963	2,904	349
MTRB	2,720	558	47
OFRPB	23,982	3,412	961
IDAY	876	82	29
IMUL	4,447	58	25
Total	55,142	7,014	1,501

NBSB = Non-motorized beach seine boats
NTRB = Non-motorized traditional boats
MTRB = Motorized traditional boats

As Table 4 indicates, the boat type data of Sri Lanka is not retrieved in the same year as the data from Point Pedro and the Jaffna District. It is assumed that the data of Sri Lanka in 2015 give a good representation of the composition of the fleet size in the country.

Fleet size forecast Point Pedro harbour

In the feasibility study conducted by FCG ANZDEC (2017b), the fleet size forecast for the new Point Pedro harbour is based upon the performance of five other fishery districts in the country that already have an operating fishery harbour. Based on the average of the fleet sizes of these harbours, it is expected that 27% of the future boats will be IDAY or IMUL boats, resulting in a five-year forecast for the Point Pedro harbour (Table 5).

Table 5: Five-year forecast Point Pedro harbour (FCG ANZDEC and RDC, 2017b)		
	Current No.	**Five-year projected No.**
IDAY	35	50
IMUL	19	150
IIMUL	-	25

From Table 5, it is estimated that in five years the berthing capacity of the harbour will be 225 vessels. All estimates from FCG ANZDEC (2017b) are based on the data of five districts. The use of only five data points already gives uncertainty. Secondly, the used data has large variations, the IDAY+IMUL percentage per fishery district is fluctuating between 16% and 36%, which indicates that the assumption of 27% is highly uncertain.

This uncertainty should not be underestimated, therefore three scenarios will be used in this report: an optimistic scenario, a realistic scenario and an pessimistic scenario. It is assumed that the projection of FCG ANZDEC (2017b) is a realistic scenario, since it is an average of comparable districts in Sri Lanka. The optimistic and pessimistic scenario are based on average fish productions of boats in Sri Lanka and fleet sizes. The annual production of all types of fishery boats used in Sri Lanka can be found in Appendix D: Fleet forecast on page 106. In Table 4, recent fleet sizes of the Jaffna District and Point Pedro can be found. Table 1 indicates that on average 35% of the total fish catch comes from offshore and deep sea fishing. Since the inland fishery and agriculture contributes 13% and the coastal fishery contributes 52% to the total fish production, it can be concluded that about 40% of the marine fishery (sea fishery) production comes from deep sea and offshore fishing. Since the fishery industry in the Jaffna District only consists of marine fishery, the government will be striving towards this 40% contribution of deep sea and offshore fishery of the production in the district.

For the forecast of the pessimistic scenario it is assumed that this 40% is only reached for the Point Pedro area. In the optimistic scenario it is assumed that the deep sea and offshore fishery from the new Point Pedro harbour will be 40% of the total fish production in the Jaffna District. It has also been assumed that increasing the coastal fishery is not sustainable, based on the information that a survey in 1985 already concludes that there was no scope for expanding the coastal fishery in the Palk Bay and Palk Strait as overfishing can occur (Sivasubramaniam & Maldeniya, 1985).

The assumptions for the pessimistic and optimistic productions have to be expressed in a number of boats in order to be able to determine the capacity of the harbour, and therefore the size. The offshore and deep sea fishery can be done by three types of boats: IDAY (offshore), IMUL and IIMUL (deep sea). In order to translate the fish production into a number of boats, a distribution between these three boat types has to be found. The distribution assumed is 50 IDAY, 150 IMUL and 25 IIMUL, which is the same distribution as used in the forecast of FCG ANZDEC (2017b). The forecast of boats in the three scenarios can be found in Table 6. More detailed information about the estimation of the forecast can be found in Appendix D.

Table 6: Fleet size forecast for Point Pedro harbour

	IDAY	**IMUL**	**IIMUL**
Pessimistic	22	67	11
Realistic (Five-year approximation)	50	150	25
Optimistic	102	307	51

2.5 Stakeholder analysis

In this chapter, the stakeholders will be closely examined and analysed. This will be done by describing the potential stakeholders, their interest, problem perceptions, and goals. Also, the typology of the stakeholders will be determined by mapping their power, interest, and attitude. This results in a stakeholder typology as described by Murray-Webster and Simon (2006). After analysing and typifying the stakeholders, the issues and the network connections between the stakeholders will be shown in diagrams.

2.5.1. Stakeholder analysis

Before being able to analyse the stakeholders, all stakeholders must be identified. In Table 7, all potential stakeholders are presented. Some stakeholders include several others; they act as a body, so these stakeholders are not separately mentioned. For clarity, only the name of the overarching stakeholder is given in the next following paragraphs. Next, the ten most important stakeholders are described in Table 8 'Stakeholder description'. Finally, the interest, problem perception, and goal of these stakeholders are described in Table 9.

Potential stakeholders

Table 7: Potential Stakeholders

No.	Stakeholder	Role
1	EML Consultants (Includes CDR International)	Consultancy
2	Asian Development Bank (ADB)	Funder
3	Ministry of Fishery and Aquatic Resources Development (MFARD) (Includes: CFHC, NAQDA, DFAR, NARA)	NPSFDP Execution Agency (EA) Client
4	Output 1: Ceylon Fishery Harbours Corporation (CFHC) Output 2: National Aquaculture Development Authority (NAQDA) Output 3: MPRRRHRA	NPSFDP Implementation Agency (IA) Harbour operation & maintenance
5	Ministry of Mahaweli Development and the Environment (MMDE) (Includes: CECB, CEA, CCCRMD, MEPA), DWC, MDM, MIAWDCA, DA)	Governmental authorities regarding environment
6	Ministry of Tourism Development and Christian Religious Affairs (MTDCR)	Governmental authority regarding tourism
7	Divisional Secretaries of Point Pedro	Local government
8	Fishing communities	Local fisherman
9	Local residents/landowners	Inhabitants
10	NGO's	Non-profit organisations

NPSFDP	Northern Province Sustainable Fisheries Development Project
DFAR	Department of Fisheries and Aquatic Resources
NARA	National Aquatic Resources Research and Development Agency
MPRRRHRA	Ministry of Prison Reforms, Rehabilitation, Resettlement and Hindu Religious Affairs
CECB	Central Engineering Consultancy Bureau
CEA	Central Environmental Authority
CCCRMD	Coast Conservation and Coastal Resources Management Department
MEPA	Marine Environment Protection Authority
DWC	Department of Wildlife Conservation
MDM	Ministry of Disaster Management
MIAWDCA	Ministry of Internal Affairs, Wayamba Development and Cultural Affairs
DA	Department of Archaeology

Stakeholder description

Table 8: Stakeholder description		
Nr	**Stakeholder**	**Description**
1	EML Consultants	EML Consultants is the civil engineering consultancy firm based in Colombo, which is hired by the Ministry of Fishery and Aquatic Resources Development to design and develop the fishery harbour in Point Pedro. EML Consultants hired consultants of CDR to review their plans. When EML Consultants proposes any changes to the design, it has to consult MFARD and ADB first for approvement.
2	ADB	ADB is the main funder of the NPSFDP and therefore has great influence. Not only do they fund the whole project, they also compel their social and Environmental Safeguard Policy within the project. With this Safeguard Policy they aim to protect local residents from the negative impacts of the new harbour and safeguard measures during and after the construction phase.
3	MFARD	The MFARD, is part of the Sri Lankan government, has taken the initiative to build the fishery harbour in Point Pedro and is accountable for the development of the harbour. Therefore, MFARD has hired EML Consultants to design and construct the new harbour.
4	CFHC	The CFHC is responsible for the coordination and oversight of the two new to be build harbours located at Point Pedro and Pesalai, the seven new anchorages in the Jaffna District and the 21 to be improved landing sites in the Northern Province of Sri Lanka. They are in close contact with MFARD and EML Consultants during the development phase.
5	Governmental authorities	The MMDE, DWC, MDM, MIAWDCA and DA are all governmental authorities that try to minimize the environmental impact and ecological footprint that is left by the project. This is done by applying strict regulation on both the design and construction phase of the new Point Pedro harbour.
6	MTDCRA	The MTDCRA tries to improve and control the tourism in Sri Lanka. By increasing the tourism industry in Sri Lanka, they aim to improve the economy, which helps the country to develop quicker and improve the quality of life of its inhabitants.
7	Divisional Secretaries of Point Pedro	As the Divisional Secretaries of Point Pedro represent the local community, they should serve the best interest of the locals in meetings with other stakeholders of the Point Pedro project.
8	Fishing communities	The fishing communities that will make use of the harbour in Point Pedro all live in the Northern Province of Sri Lanka and will be affected by the development of the fishery harbour. As they will be the end users of the project, it is highly important they are satisfied by the fishery harbour and its facilities in order to make the harbour successful.
9	Local residents / landowners	The local residents near the building site at Point Pedro will all be harmed by the construction of the harbour due to nuisance and pollution. Their needs will have to be heard, as they can oppose to the project easily, which might harm the progress of the project. Furthermore, local landowners that posses private land on which the new facilities will be built need to be compensated.
10	NGO’s	NGO’s are non-profit organisations that stand for the protection of wildlife and coastal environment. Their power within Sri Lankan projects is limited, however they could create (international) opposition against the project.

Stakeholder interests, problem perception and goal

Table 9: Interest, problem perception and goal

No.	Stakeholder	Interest	Problem perception	Goal within project
1	EML Consultants	Deliver a complete and successful detailed design that lives up to their reputation and earn money by delivering the project.	An unsuccessful project due to an insufficient harbour design can harm the reputation of EML Consultants.	Fulfil the detailed design within time and within budget.
2	ADB	Fund projects in developing countries in a sustainable way.	The chance of not receiving the funding back, when the fishery harbour does not live up to its expecta-tions financially, or is not constructed according their Safeguard Policy.	Help the Sri Lankan government by funding the project and apply the ADBs 'Social Environmental Safeguard Policy' to make sure the project is constructed in a sustainable way.
3	MFARD	Develop the Northern Province fishery harbours, anchorage points, and landing in a sustainable way.	The Point Pedro fishery harbour does not live up to its expectations.	Develop and deliver a well-per-forming harbour in Point Pedro that satisfies the needs of the fishermen.
4	CFHC	Deliver quality fishery harbour related services and provide the fishing community with modern infrastructure and facilities, as well as a safe and easy navigable harbour.	The new harbour related services do not live up to the correct quality require-ments of a modern fishery harbour.	Operate and maintain the Point Pedro harbour.
5	Govern-mental authorities	Safeguarding the wellbeing of the coastal region, ecology, environment and wildlife in Sri Lanka.	Loss of valuable natural areas, which will harm the Sri-Lankan environment.	Minimize the negative effects of the development and operation of the Point Pedro harbour by controlling the environmental impact with strict regulations.
6	MTDCRA	Increase tourism by improving Sri Lankan touristic facilities.	A new harbour might not attract more tourists.	More tourist that visit the Northern Province and Point Pedro.
7	Divisional Secretaries of Point Pedro	Improve living standards in Point Pedro.	Harbour of Point Pedro does not fulfill the needs of the local residents, who feel the Divisional Secretary is responsible for.	Receive social and economical benefits by developing the Point Pedro harbour.
8	Fishing communities	Increase benefits of fishing.	Smaller fishing boats might catch less fish because larger fishing boats are overfishing.	Improve fishing possibilities due to better facilities and bigger boats.
9	Local residents / landowners	Pleasant living environment.	Increase of pollution and nuisance due to increase in traffic.	Enhance positive effects of the development of the Point Pedro harbour, while minimizing the negative effects of the development.
10	NGO's	Protection of wildlife and coastal environment.	Loss of habitat for existing wildlife and coastal environment.	Limitation of the negative environmental impact due to the harbour.

2.5.2 Typology of stakeholders

In this subparagraph, the identified stakeholders will be further analysed by placing them in a Power vs. Interest grid, and by classifying them on how likely it is that they support the project or that they oppose to it. This information results in a typology of actors, which tells how to approach the different stakeholders, who to watch out for and who to befriend. When it is known how stakeholders will behave during the project, the project manager can use this information to the projects benefit.

Power vs. Interest grid

The first step in the process to typify the stakeholders is to place all main stakeholders in a Power vs. Interest grid. This is done by analysing all known information about the project, using the expertise of Eng. C. P. Fernando and internet based research. This resulted in the illustration which can be seen in Figure 26. On the next page, the four quarters and the stakeholders mentioned in those quarters are explained.

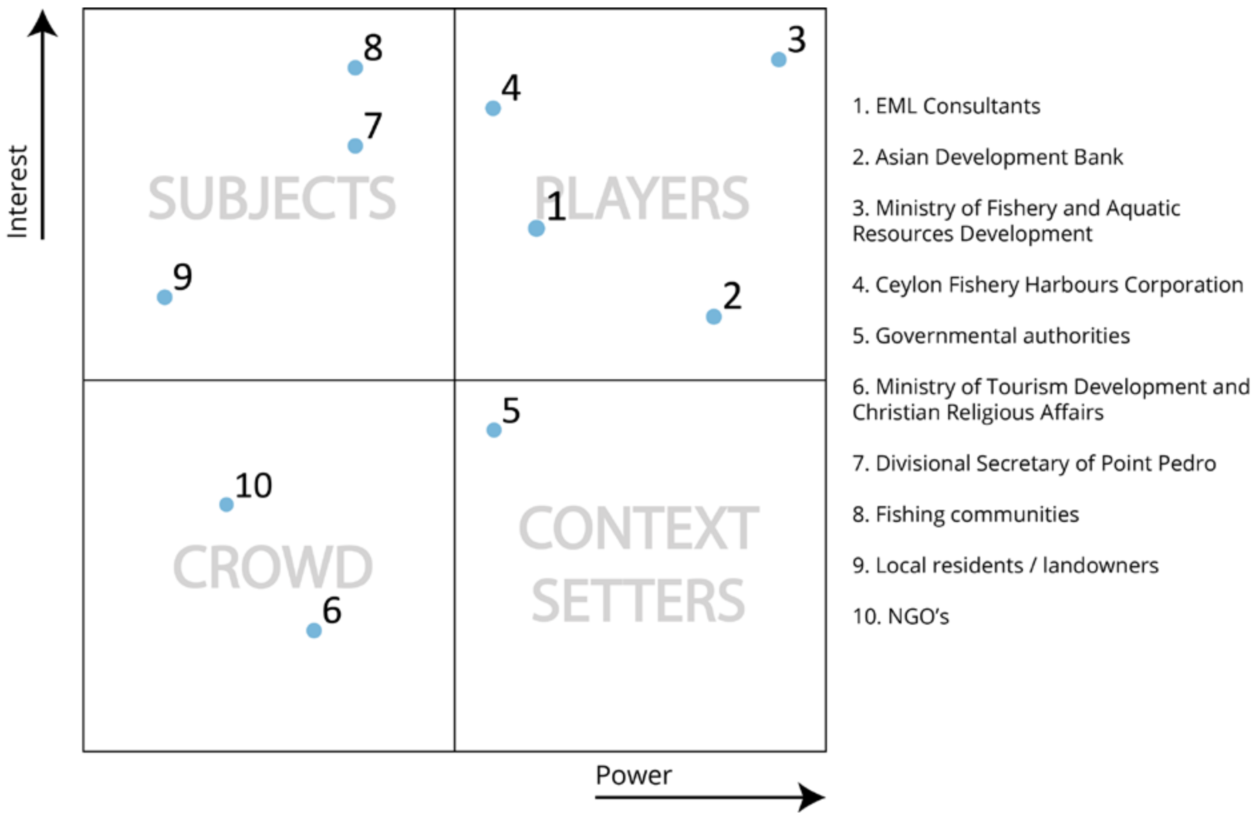


Figure 27: Power vs. Interest grid (own illustration)

‘Players’ are stakeholders with both high power and high interest in the project. Because they have a great influence on the project, they should be managed closely throughout the whole project life cycle. MFARD is the biggest ‘Player’ since they took the initiative for the project and are the execution agency of the entire NPSFDP. A successful project is of great importance to them because their goal is to improve and extend the current fishery industry in the Northern Province of Sri Lanka. EML Consultants and ADB are of equal importance but in totally different ways. EML Consultants has a lot of interest in the project because they, as reliable consultants, are responsible for designing and delivering a successful project. Because of this responsibility they have a considerably amount of power, however, their reputation also depends on it. The ADB funds the project, and therefore has a lot of power since they control the financial status of the project. Because the ADB also compels their Safeguard Policy on the project, their power increases even more. Since ADB is such a big company and must monitor not only the NPSFDP but also a lot of other projects, their interest will be slightly lower. The last player is the CFHC. Since this party must operate the harbour when it is finished, they have a lot of interest in the project. As they operate under the MFARD, they can execute a great deal of power on to the project, to influence the decisions made.

‘Subjects’ are stakeholders with high interest in the project, but with less power. These stakeholders; divisional secretaries Point Pedro, fishing communities and local residents/landowners, need to be kept satisfied during the development of the new harbour. The divisional secretaries of Point Pedro, fishing communities and local residents/landowners all have high interests in the project as they are located in the area of Point Pedro and will face the consequences of the changes that will be made on the project site. The divisional secretaries of Point Pedro and fishing communities are of equal power but differ slightly in interest. The fishing communities have a higher interest in the project because the development of the harbour will have influence on their direct daily lives. The local residents/landowners have less power and less interest than the other ‘Subjects’.

‘Context setters’ are stakeholders with high power and low interest in the project. The only stakeholder in this quarter of the grid is the body of governmental authorities involved in the project. The governmental authorities are responsible for the monitoring of the project regarding the regulations laid out in the initial environmental examination. As they have little interest, they should only be kept informed during the project. Relatively seen, they have a lot of power because they can stop the development if the project does not follow the regulations.

‘Crowd’ are stakeholders with low interests and low power. However, they are still involved in the project and should therefore be monitored. First of all, the MTDCRA does want to keep track of the development of the project, since major changes in the Northern Province might have an impact on tourism. However, both interest and power of this stakeholder are low. NGO’s are mainly focused on wildlife, the environment, and the ecological footprint of the project. As long as the development of the project stays within the environmental regulations, NGO’s will be of no harm. However, if the development harms the nature, they might create (international) opposition against the project. This would increase the power of the NGO’s, which might harm the development of the project.

Support-Opposition vs. Power map

Figure 27 shows the correlation between the attitude and power of the ten main stakeholders. The power of the stakeholders has been extracted from the Power vs. Interest map, while their attitude has been determined by looking at how supportive they are to the project during the development process. Factors that influence the support or opposition of the stakeholders are for instance local or governmental benefits, environmental impact, nuisance, economic growth and local development.

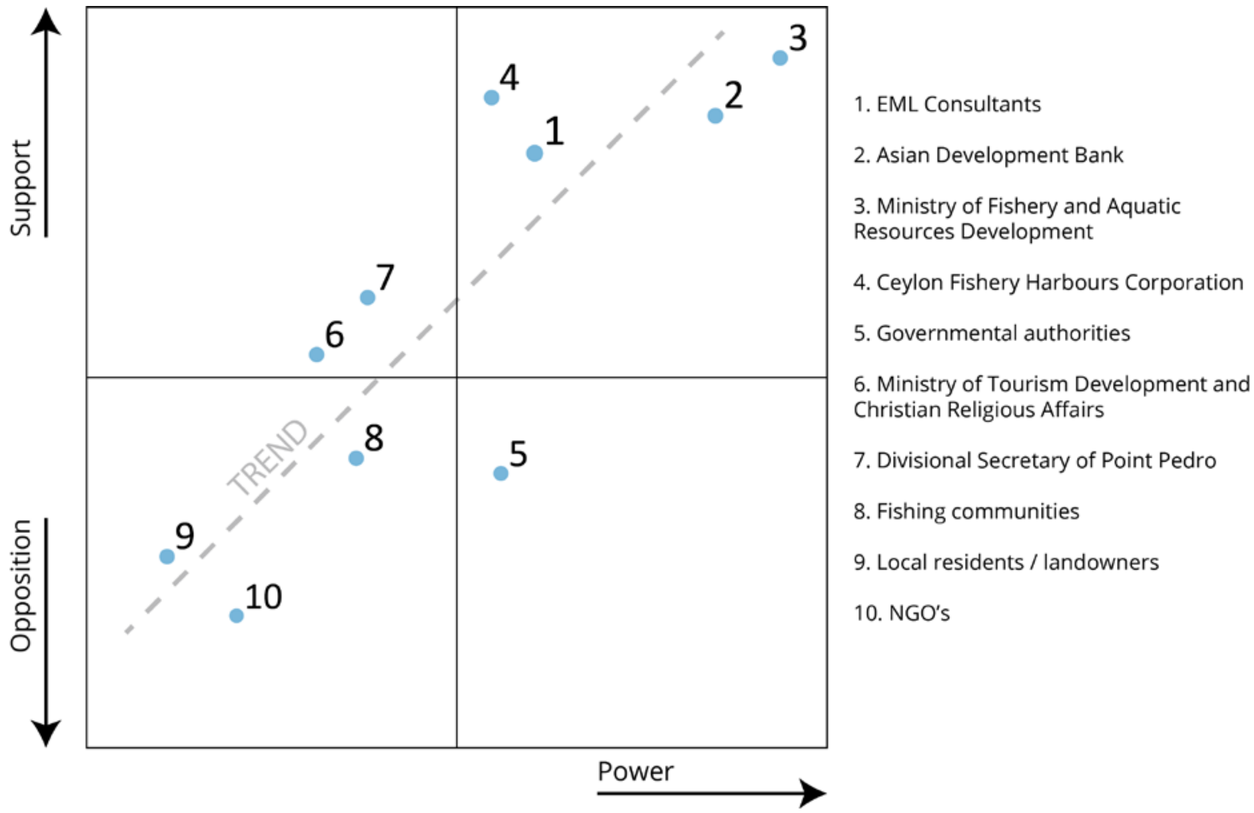


Figure 28: Support-Opposition vs. Power map (own illustration)

A certain trend has been found by mapping out the correlation between support/opposition and power. As the power increases, the support of the stakeholders regarding the project also increases. Since the most powerful stakeholders are the most supportive, decisions can be made quickly and without any large opposition. However, when less powerful stakeholders group together, they can still form a powerful front against the supportive stakeholders.

Stakeholder typology

The typology of each stakeholder is determined by the use of Figure 29 (Murray-Webster and Simon, 2006). All actors are scaled upon the axes 'power', 'attitude' and 'interest'. Both the 'power' and 'interest' axes were obtained from the Power vs. Interest diagram. The attitude axis was obtained from the support-opposition vs. power diagram. By combining these three characteristics, the actors can be assigned to a specific typology, as shown in Table 10.

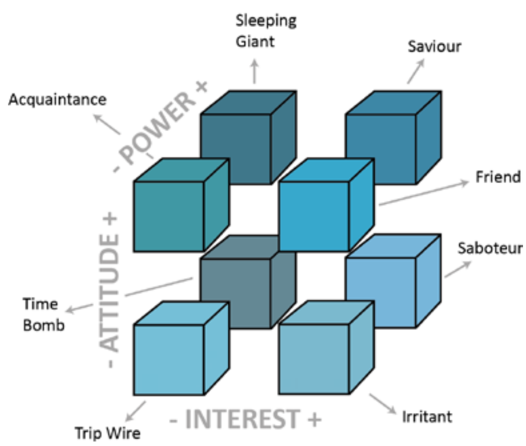


Figure 29: Figure 28: Typology of actors (own illustration, based on Murray-Webster and Simon, 2006)

Table 10: Typology of stakeholders			
No.	**Stakeholder**	**Typology**	**Explanation**
1	EML Consultants	Saviour	EML Consultants is a 'Saviour' within the project: influential, active and a backer. These are all characteristics of a stakeholder with high power, interests and a positive attitude.
2	ADB	Sleeping Giant	ADB is a so called 'Sleeping Giant': influential, passive and a backer. ADB differs from EML Consultants in the fact that they are passive instead of active. This is because of their lower involvement in the project.
3	MFARD	Saviour	MFARD, as the client and execution agency, is a typical 'Saviour'. In comparison to EML Consultants, they have higher interests, power and a better attitude, which makes them more influential within the project.
4	CFHC	Friend/ Saviour	CFHC is typified as a 'Friend/ Saviour': also active and a backer, but more insignificant than the other players. This is mainly due to their lower power within the project at this stage. However, during the development of the project their power and influence will increase, which will shift to them to a 'Saviour'.
5	Governmental authorities	Time Bomb	In general, the governmental authorities are typified as 'Time Bomb': influential, passive and a blocker. Because most of these authorities are ministries regarding the environment, they have high power and do not support the project. However, they would only come into action when the new harbour does not meet the environmental regulations.
6	MTDCR	Acquaintance	MTDCR has the characteristics of an 'Acquaintance': passive, insignificant and a backer. MTDCR is a backer because a new harbour will create new possibilities for tourism. However, they will be a passive backer since it is unknown in what manner the new harbour would improve the tourism in the Northern Province.
7	Divisional Secretaries of Point Pedro	Friend	The Divisional Secretary of Point Pedro is a 'Friend': their power is insignificant, but on the other hand, they are an active backer of the project because of their high interest and supportive attitude.
8	Fishing communities	Irritant	The fishing communities are characterised as 'Irritant': insignificant, active and a blocker. Even though the harbour will be used by the fishing communities, their power within the development process is quite low. As they are happy with the current anchorage pier and situation, they don't support the new harbour.
9	Local residents / landowners	Irritant	The local residents/ landowners can also be indicated as 'Irritant'. For them, there is no need to built a new harbour. Landowners have to be expropriated and the construction could cause a lot of nuisance and pollution.
10	NGO's	Tripwire	NGO's are typical 'Trip wires': insignificant, passive and a blocker. They have no power (yet), and will not become interested unless the project would start to harm wildlife or the coastal environment. When they become active, they will try to find more opposition against the project, which will increase their influence.

2.5.3 Stakeholder issues

After having a clear image of the typology of all stakeholders, the engagement plan can be sketched. This is done by identifying the issues that the project will face during its lifetime. Thereafter, all issues are connected to the relevant stakeholders, to give an insight in the complexity of the issue, as well as to see which issues will create friction between stakeholders. When knowing these frictions in advance, the course of the process will be smoother as the project manager knows what to expect.

Stakeholder issue diagrams

The following issues must be dealt with during the design stage of the project, since these issues can cause friction between several stakeholders. It is important to realize the presence of those issues, and a plan should be created on how to tackle these issues while satisfying the majority of the stakeholders involved. All issues mentioned below were extracted from the minutes of several public meetings in Point Pedro, where the initiators explained the project and its progress and where interested locals could join to express their doubts, ideas and feelings about Project Point Pedro (FCG ANZDEC and RDC, 2017b).

Issue 1: Location of the harbour

The location of the harbour has a great impact on the local community and the fishermen. Almost all other stakeholders are also involved in this matter, since they all have power to influence this decision. The issue of the location of the harbour can be subdivided into three subissues, namely; (i) location, (ii) nature and (iii) connectivity and accessibility.

The location itself is dependent on a lot of factors, such as geology, bathymetry and hydraulic conditions. The flora and fauna within and around the harbour, will also be greatly influenced by the development and presence of a fishery harbour. The harbour must be easily accessible by road, to ensure the fish catch can be transported as quickly as possible.

All stakeholders are involved in the matter of the location of the harbour. However, EML Consultants and the governmental authorities only want to have influence on the decision of the exact project location and the nature, whereas the CFHC does not put the exact location and the nature affected high on its agenda. The NGO's, the ABD and the MTDCRA are only interested in the impact of the project on the environmental conditions. The overview of all stakeholders interested in the three subissues about the location of the fishery harbour is presented in Figure 29.

To give a full explanation of the project, this first issue 'location of the harbour' is included in the stakeholder analysis. However, at time of writing, the decision on where the fishery harbour is about to be located has already been made.

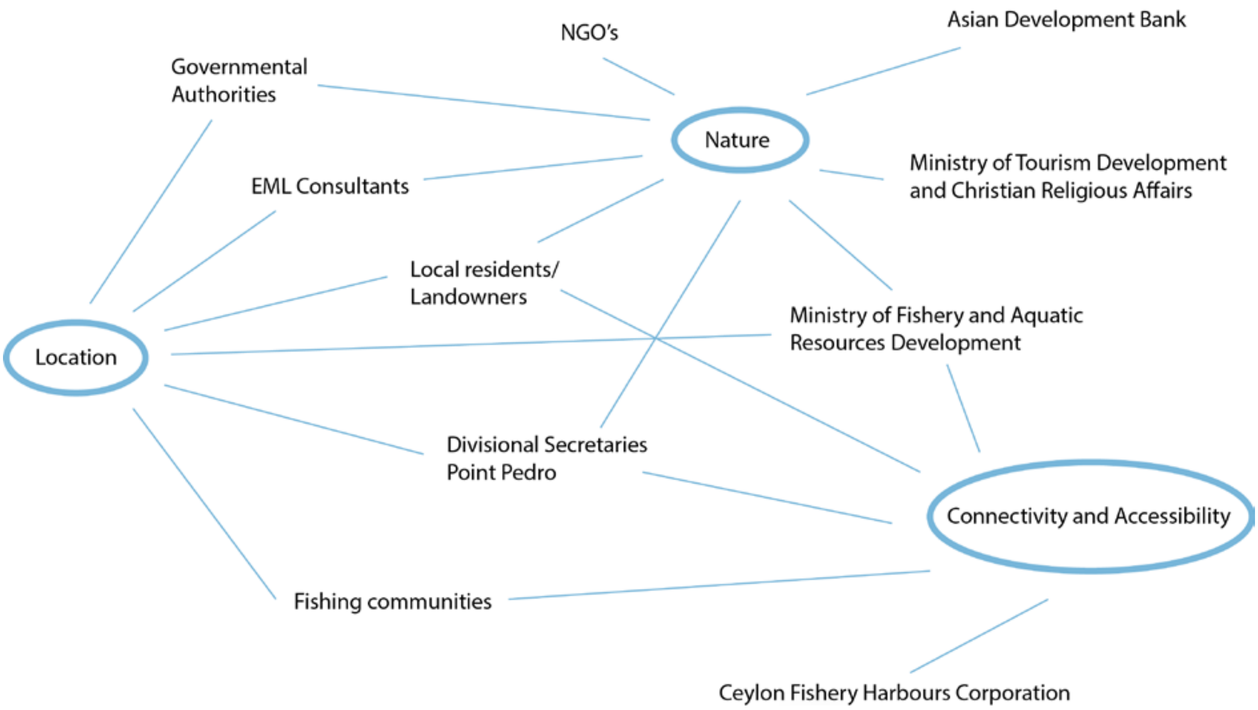


Figure 30: Location of the harbour (own illustration)

Issue 2: Design of the harbour

The second issue considers the design of the harbour. Seven stakeholders are involved in this issue. The ADB, the MTDCR, and the NGO's are considered as less important in the decision making process of this issue. Within this issue, four subissues can be identified; (i) soil erosion and siltation, (ii) security issues due to change of location landing site, (iii) fear of breakwater not protecting the vessels enough, and (iv) the type of services and facilities.

First of all, the local residents expressed their fear about the change in water currents due to the proposed breakwater, which will lead to soil erosion and siltation. Second, the fishermen foresee security issues regarding their fishing gear. Their ships will have to be moored at a different location than before, where they can not keep an eye out to safeguard their possessions. Thirdly, the fishermen placed their doubts about the breakwater itself. They stated that the breakwater may not be high enough and can cause damage to their vessels when waves overtop the breakwater. The last subissue considers the services and facilities which will be present in the harbour. For a harbour to be successful, the harbour must offer good services and facilities, otherwise the fishermen will be reluctant to using the harbour.

Three out of the seven stakeholders involved in this issue have interest in all subissues presented. EML Consultants is not involved in the security issue, the governmental authorities and the Divisional Secretaries of Point Pedro are only interested in two of the subissues and the local landowners/residents only foresee a problem regarding soil erosion and siltation. The visualization can be seen in Figure 30.

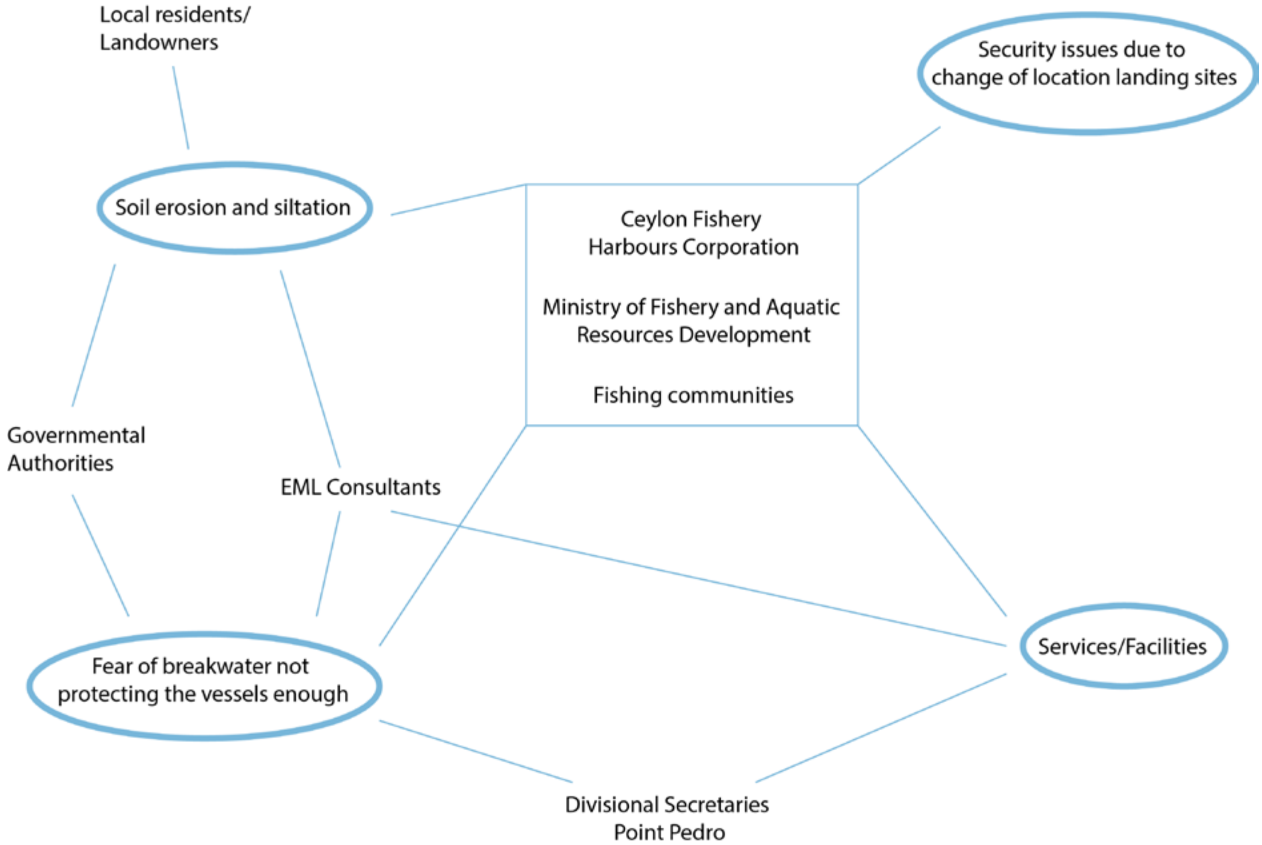


Figure 31: Issue diagram 2: Design of the harbour (own illustration)

Issue 3: Use of the harbour

The last issue that needs elaboration is the use of the harbour. Within this issue, the subissues (i) use of the income and (ii) shared use of the harbour can be identified. As the development of the harbour is already complete in this stage, stakeholders like EML Consultants, Governmental authorities, MTDCR, and NGO's are not included in this issue.

The CFHC will collect the harbour fee from the fishermen and will use this to operate the harbour and invest in other programs. This use of income is important to all stakeholders involved in the use of the harbour, as they want to have influence on where the money will be spent on. Secondly, the Point Pedro harbour will cater a lot of facilities and services, making the harbour attractive to other fishermen as well. The local fishermen fear that they will have to share the harbour and the surrounding waters with fishermen from other parts of the country, or even with fishermen from other countries such as India. This might cause conflicts between the fishermen. The issues, together with the stakeholders involved in these matters are shown in Figure 32.

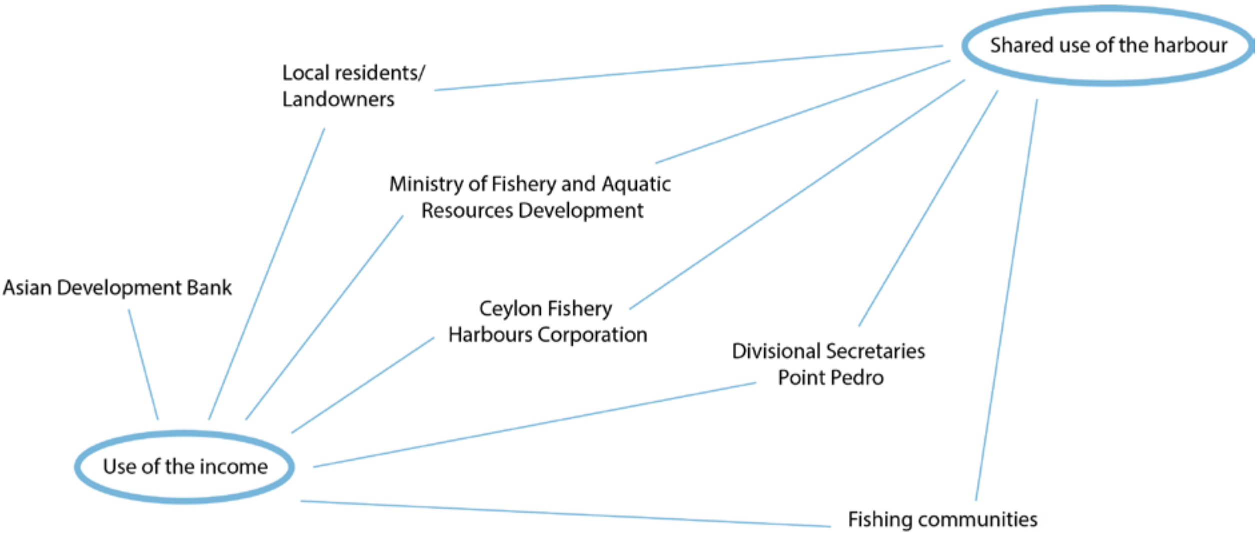


Figure 32: Issue 3: Use of the harbour (own illustration)

Actor network diagram

An actor network diagram is produced in order to give an insight in the relations between all stakeholders involved in Project Point Pedro. This gives insight in the complexity of the project. Due to more connections between stakeholders, more interactions will take place in the project, and this might cause misunderstandings, frictions between different parties and will slow down the process of decisionmaking down. When all interactions between the stakeholders are clear to the project manager, he can use this to his advantage.

In Figure 33, each arrow represents the main direction in which one stakeholder influences the other. If an arrow points in two directions, both stakeholders influence each other in an (almost) equal way.

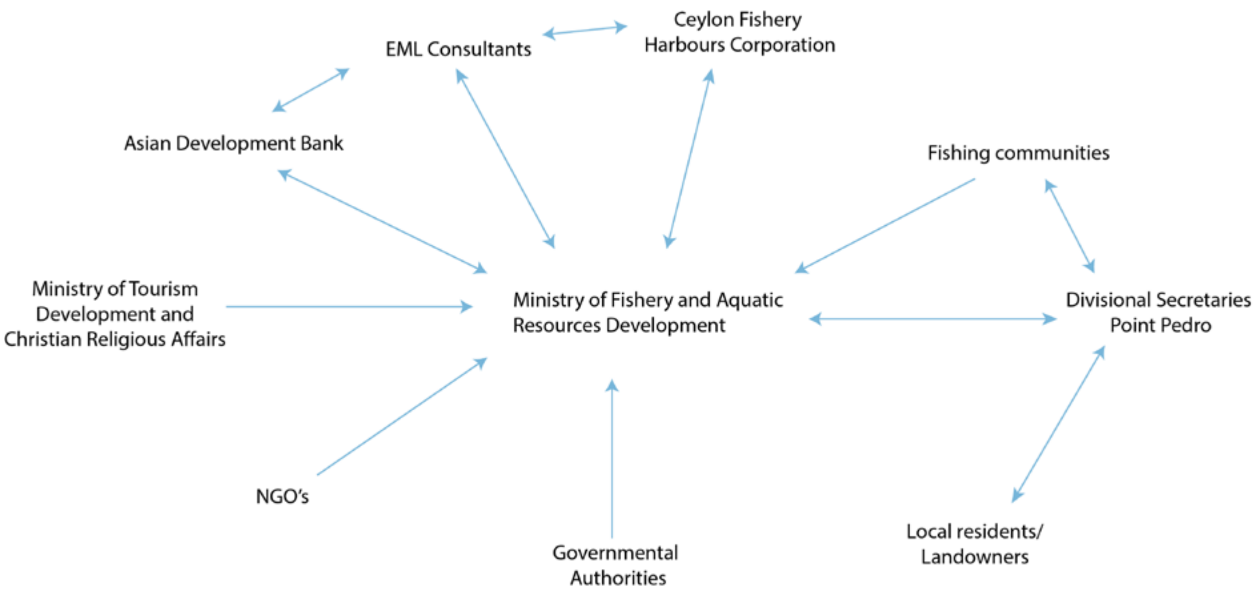


Figure 33: Actor network diagram (own illustration)

2.6 Harbour dimensions

To design harbour alternatives, it is useful to estimate some first design dimensions. For example, the length of the quay wall, the harbour depth, the size of the entrance channel and the fish storage capacity. The dimensions of the three largest boat types are used for calculations as well as the values of the fleet size for pessimistic, realistic and optimistic scenarios. The forecasts for the fleet size in five years and the boat dimensions of chapter 2.4 Fishery industry are used.

2.6.1 Dimensions approach channel and basin

Ligteringen and Veslink (2014) describe in the book Ports and Terminals how to design a fishery port. This information is used to determine the dimensions of the approach channel and the basin. Appendix E on page 108 illustrates how the information is implemented in calculations.

Channel width

According to Ligterink and Veslink (2014) the first step to determine the minimum width of the approach channel is to indicate the amount of lanes. As multiple fishery boats will simultaneously try to enter or leave the harbour, at least two lanes are suggested. Furthermore, conditions as wave action, currents, wind, the manoeuvrability of the boats and extra margins near hard obstacles (breakwaters) should be considered for the channel width. To determine the channel width, the manoeuvring zone, bank clearance zone and ship clearance zone are defined and combined with a safety factor, Appendix E on page 108.

Channel depth

The estimate the channel depth the draught of the boats, tide variation, keel clearance, bottom topography, ship motion and squat are considered. Resulting in the draught of the specific boat plus one additional meter.

Basin width

To determine the basin width, the rule of thumb of 5 to 6 times the length of the vessel is used. This rule of thumb is based on the fact that enough manoeuvring area is needed inside the basin (Ligteringen en Veslink, 2014).

Table 13 gives the outcome of the calculations and the dimensions of the boats. The boat sizes used can be found in Table 3 of chapter 2.4 Fishery industry.

Table 13: Dimensions fishery harbour entrance channel (own calculation, see Appendix E on page 108)

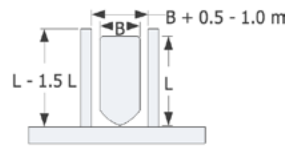
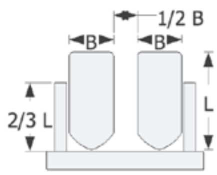
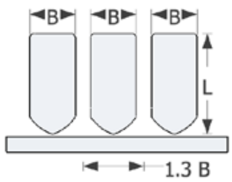
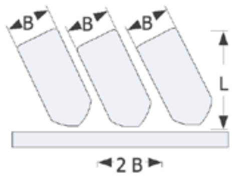
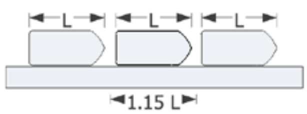
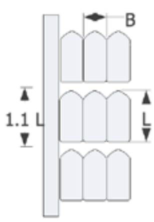
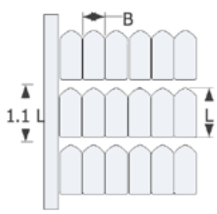
Channel and basin dimensions	**General calculation**	**IDAY**	**IMUL**	**IIMUL**
Inner channel width	9.6 x B_s	28.8 m	43.2 m	48 m
Outer channel width	12 x B_s	36 m	54 m	60 m
Channel depth	draught + 1m	1.9 m	4.5 m	6 m
Basin width	5 - 6 x L	45 - 54 m	75 - 90 m	150 - 180 m

B_s = the maximum beam size of the boat

2.6.2 Berthing possibilities

In a new harbour different design choices have to be made. One important design choice is the type of berthing that will be used. To be able to make a weighed design choice about berthing types, all options for berthing are shown in Table 14. The table gives an indication about the approximated space use per berthing type.

Table 14: Required space per boat for using different berthing arrangements

Berthing arrangements	**Visualization**	**IDAY B = 3 m L = 9 m**	**IMUL B = 4.5 m L = 15 m**	**IIMUL B = 5 m L = 30 m**
Single boat finger pier		Width: 3.8 m Length: 11.7 m (1.25L)	Width: 6.3 m Length: 19.5 m (1.25L)	Width: 6.8 m Length: 39.0 m (1.25L)
Double boat finger pier		Width: 4.5 m Length: 9.0 m	Width: 6.1 m Length: 15.0 m	Width: 6.8 m Length: 30.0 m
Perpendicular to the pier		Width: 3.9 m Length: 9.0 m	Width: 5.9 m Length: 15.0 m	Width: 6.5 m Length: 30.0 m
Oblique berthing		Width: 6.0 m Length: 9.0 m	Width: 9.0 m Length: 15.0 m	Width: 10.0 m Length: 30.0 m
Parallel to the quay		Width: 3.0 m Length: 10.4 m (1.15L)	Width: 4.5 m Length: 17.3 m (1.15L)	Width: 5.0 m Length: 34.5 m (1.15L)
Normal resting quay		Width: 3.0 m Length: 9.9 m (1.1L)	Width: 4.5 m Length: 16.5 m (1.1L)	Width: 5.0 m Length: 33.0 m (1.1L)
Extreme condition resting quay		Width: 3.0 m Length: 9.9 m (1.1L)	Width: 4.5 m Length: 16.5 m (1.1L)	Width: 5.0 m Length: 33.0 m (1.1L)

All berthing types have different properties. For example, berthing parallel to the quay is perfect for unloading of boats, but it is not efficiently using the space of the quay. On the other hand the resting quay types are efficiently using the harbour spaces, but unloading from this berthing type is more difficult.

In a fishery harbour there can be two different types of quays: (un)loading quays and resting quays. In Table 15, it is described which berthing arrangements are useful for the two quay types.

Table 15: Typing of the different berthing arrangements

(Un)Loading quay	**Resting quays**
Single boat finger pier	Perpendicular to the pier
Double boat finger pier	Normal resting quay
Parallel to the quay	Extreme condition resting quay
	Oblique berthing
	Double boat finger pier

It is dependent on the type of boat that will use the quay which berthing arrangement is preferable. For example, a lot of space can be saved when the small IDAY boats will be placed in a normal resting quay instead of in a double boat finger pier.

2.6.3 Required quay length

To be able to propose different harbour designs, an indication about of the harbour size is required. In Table 16 a first estimate of the required unloading quay length and resting area per boats is given. Note that both quay functions can also be combined in one place.

Table 16: First estimate of quay elements in Point Pedro harbour

Quay type	**Scenario**	**IDAY**	**IMUL**	**IIMUL**
Unloading quay length	Optimistic	198 m	340 m	103 m
	Realistic	97 m	172 m	52 m
	Pessimistic	43 m	78 m	52 m
Resting quay area	Optimistic	0.33 ha	2.51 ha	0.93 ha
	Realistic	0.16 ha	1.23 ha	0.45 ha
	Pessimistic	0.07 ha	0.55 ha	0.20 ha

The estimate of the required quay length is based on a formula proposed by Ligteringen and Veslink (2014). This formula is dependent on four main parameters that influence the required quay length:

- The number of boats based at the harbour
- The quay length required per vessel (depending on the berthing arrangement)
- The time that vessels spent unloading
- The influence of fishing seasons and peak periods

In Appendix E on page 108 details about the calculation for the Point Pedro harbour can be found. For an estimation of the quay length the berthing arrangement "parallel to the quay" is used. Important to notice is that a new calculation for the final design is required, taking into account the specific berthing type.

Also, an estimate is made for the required resting quay area. For the Point Pedro harbour this is particularly important, as during the northeastern monsoon offshore and deep sea fishing operations will be limited by the weather. During the severe weather all boats operating from the Point Pedro harbour should be able to get shelter. The estimate for the required resting quay area is based on the amount of boats using the harbour and the average amount of space they need for berthing in a resting area. The calculation of the average amount of space required is based on an average of the space usage of the resting types of berthing arrangements (Table 15). For more information about the required resting area, see Appendix E on page 108.

2.7 Conclusion

Several important aspects can be concluded from the analyses done in this chapter. The site conditions, geological analysis, fishery industry, stakeholder analysis and harbour element dimensions all have several items which could influence the conceptual designs and multi criteria analysis. These conclusions will be discussed below.

The site conditions indicate that Point Pedro is located in a sheltered shallow sea environment, protected with a coral reef parallel to the shore. Monsoon winds define wet and dry seasons with different hydraulic characteristics. The required information about the bathymetry, climate, wind speeds, cyclone tracks, tides, waves, currents, sediment, erosion and environmental effects are provided in subsection 2.2. The hydraulic data during the wet period, the northeastern monsoon, are normative and will be used in the design stage.

From the geological analysis, it has become clear that earthquakes up to 7.0 on the Richter scale can be expected once every thirty years. As the earthquakes are usually occurring offshore, the occurrence of tsunamis is realistic. Additionally, limestone is known to be present in the project area and karst is expected to occur as well. Resulting in the possibility of weaker soil conditions, sinkholes, additional subsidence and highly variable rockhead. Extensive research could be done to determine the high risk location of these events, this to prevent damages and additional costs during the construction and lifetime of the harbour.

The analysis of the fishery industry states that in 1983, the Northern Province provided a 40% share of the national fish production. However, due to the civil war, this share decreased to less than 5%. The government set targets to improve the fishery industry in Sri Lanka. Combining these results, a desired annual fish production of 900.000 MT is estimated. To be able to design a harbour with enough capacity, a forecast has been made of the expected fleet size in five years time. The fleet size forecast consists of three scenarios, a pessimistic, realistic and optimistic scenario.

Regarding the stakeholder analysis, ten main stakeholders have been identified. By describing their interest, problem perception and goal the stakeholders were analysed. Then, a typology was given to each stakeholder by determining their power, interests and attitude within and towards the project. It was found that the stakeholders are connected to each other in several ways, displayed in the actor network diagram. Three main issues were found during the analysis that could create conflicts between the stakeholders during the development process. These issues are: (1) location of the harbour, (2) design of the harbour and (3) use of the harbour.

At last, several dimensions of harbour elements are estimated. With the use of the information of the previous paragraphs, first estimations of the required berthing area, approach channel dimensions and other harbour characteristics are made. These estimations will be used to design the different harbour alternatives. Afterwards, these values will be iterated to the most suitable values in the final design stage.

All information and conclusions in the analysis phase will be the base of the second phase of the report. In this second phase, harbour alternatives will be proposed for the Point Pedro project site.

3. CONCEPTUAL DESIGN STUDIES

Using the information and knowledge presented in chapter 2, conceptual designs are created in this chapter. First the design requirements are set, to which all concepts have to comply. Next, four designs are elaborated on. Finally, at the end of the chapter a multi criteria analysis will be performed to see which concept fits best in Point Pedro.

Source: own picture, taken at Mandaitivu

3.1 Requirements of the harbour alternatives

Requirements need to be set in order to design comparable alternative. All concepts of harbour designs must meet these requirements, as the proposed harbour design will not function when these requirements are not met. These requirements are extracted from the analysis. Also, the required surface area for site facilities, boat resting and (un)loading places need to be estimated. Below, specific requirements regarding the location, harbour dimensions and facilities will be given.

Location

The site scope of the project is limited to approximately one kilometer of shoreline at Point Pedro. According to Eng. P.C. Fernando the most important criteria for the local fishermen is that the West Landing Site and East Landing Site, see Figure 33, will be operable after the development of the harbour. Since the local fishermen are described as potential blockers of the project (see 2.5 Stakeholder analysis on page 24), this criteria should be taken into account during the design phase. The result is that the harbour should be developed on a coastal stretch of 920 m in between the main landing sites.

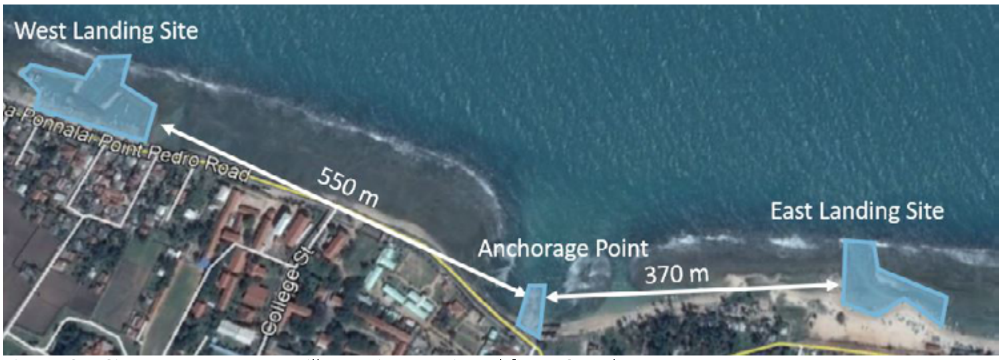


Figure 34: Site area scope (own illustration, retrieved from Google Maps)

Harbour dimensions

To design the harbour alternatives for the Point Pedro harbour, minimal required surface area for the harbour basin functions should be given. For determining these harbour basin dimensions, the 5-year and 50-year design fleet sizes are used. The 5-year design fleet size has been determined by assuming that the required space should be sufficient in 80% of the time in the first five years after development of the harbour (P80-value). This value was obtained by applying the Delphi Method (Nicholas & Steyn, 2011) on the fishery statistics (see 2.4 Fishery industry on page 18), resulting in an average and standard deviation that are used in a normal distribution. From this normal distribution the P80 value is retrieved. Also, a fleet size has to be determined for the lifetime of the harbour. The 50-year design fleet size is found by multiplying the 5-year design fleet size by growth factors. An elaboration on the design fleet sizes can be found Appendix G. The minimal basin area requirements and element calculations, as described below, can also be found in this appendix.

For the conceptual designs it is required that the outer infrastructure will be developed at once, and therefore, the enclosed area (by breakwaters) will be large enough to accommodate the 50-year design fleet size. This results in a required harbour basin area of 11.5 ha. Since a 50-year forecast has a large uncertainty, the harbour basin functions will initially be designed and constructed for the 5-year design fleet size, but a plan should be included to accommodate the 50-year design values in the future. The main functions of the harbour basin are unloading areas, resting areas, refuelling areas and manoeuvring areas. Table 17 gives the minimal requirements for the initial harbour basin, Appendix G elaborates on the outcome of this table.

Table 17: Harbour dimensions for different boat types (5-year design values)

Dimensions	IDAY	IMUL	IIMUL	Total
Outer channel width [m]	36	54	60	n/a
Inner channel width [m]	28.8	43.2	48	n/a
Channel depth [m]	1.9	4.5	6	n/a
Unloading quay wall length [m]	168	145	61	374
Fuelling quay wall length [m]	14	69	23	106
Unloading area [m^2]	5,100	7,000	4,500	16,600
Fuelling area [m^2]	500	4,200	1,900	6,600
Resting area [m^2]	4,400	26,400	7,900	38,700
Total required area [m^2]	**10,400**	**38,700**	**14,600**	**63,700**

Environmental criteria, such as significant waves height and direction, and sediment transport, should also be taken into account in the conceptual harbour designs. The significant wave height (H_s) that has been found to be sufficient during the harbour lifetime is 3.0 m and the dominant waves come from north-east direction. Besides wave conditions, also sediment transport is an important design condition. It is found that sediment can only be transported from east to west.

Onshore facilities

Inside the harbour perimeter, several facilities are needed to make the harbour operational. These facilities include several buildings to auction fish, control the ship movements within the harbour, repair fishing boats and gear, but also an access road needs to be laid down within the harbour. Furthermore, an ice factory and storage room need to be implemented and security facilities have to be present. Appendix H presents all needed facilities in the harbour, as well as the surface area needed to build on and their location within the harbour.

Most surface areas of the facilities presented in this appendix were calculated or estimated by making use of the feasibility study and the harbour layout drawings from the PPTA. The ice plant and storage however, needed some more attention as it was unclear what type of ice (block ice or flake ice) would be used. Furthermore, in the near future, fish will also be cooled offshore on the IDAY and IMUL boats, bringing down the amount of fish that currently goes to waste due to not cooling. This new requirement is also taken into account in the prediction on how much surface area this facility will need.
Appendix I contains calculations on the amount of ice needed, the surface area needed for storage, and the amount of surface area needed for ice production. Eventually, this led to a required surface area of 700 m^2 for all ice related facilities.

The total surface area of the facilities within the harbour comes down to approximately one ha. However, lots of surrounding space around the buildings is needed to manoeuvre vehicles, park vehicles, walk around and for aesthetic appearance. Furthermore, a lot of space needs to be allocated to future development, for instance a fish processing hall can be built in the (near) future. Also, future growth of the harbour needs to be taken into account. Therefore, a total land area of approximately four ha is assumed to be desired-within the perimeter of the harbour of Point Pedro.

3.2 Conceptual designs

From the requirements set in 3.1 Requirements of the harbour alternatives, four alternative designs of a harbour at Point Pedro are created and described. This description includes the harbour layout, environmental impact and future growth. First the PPTA design is discussed, followed by the 'Building on the reef' design, the 'Large pier' design and the 'Artificial island' design. These four alternatives will be the input for the multi criteria analysis explained in 3.3 Multi criteria analysis.

3.2.1 Alternative 1: PPTA design

The first alternative is the design proposed by PPTA. Three similar harbour designs were presented in the PPTA, of which this one was adopted as the final design. Afterwards, this design was also used by the University of Moratuwa, as for them it seemed to fit best at the chosen location.

The fishermen in the area of the harbour initially opposed to this design, as the harbour will be constructed on the most important landing site of Point Pedro. Therefore, it has been decided that the harbour will shift approximately 400 meters westward. In this way, the harbour will be located in between the two main landing sites along the coastline. By doing this, the PPTA design also complies to the requirements as set up in paragraph 3.1 Requirements of the harbour alternatives. A 3D-overview of this alternative is shown in Figure 35.

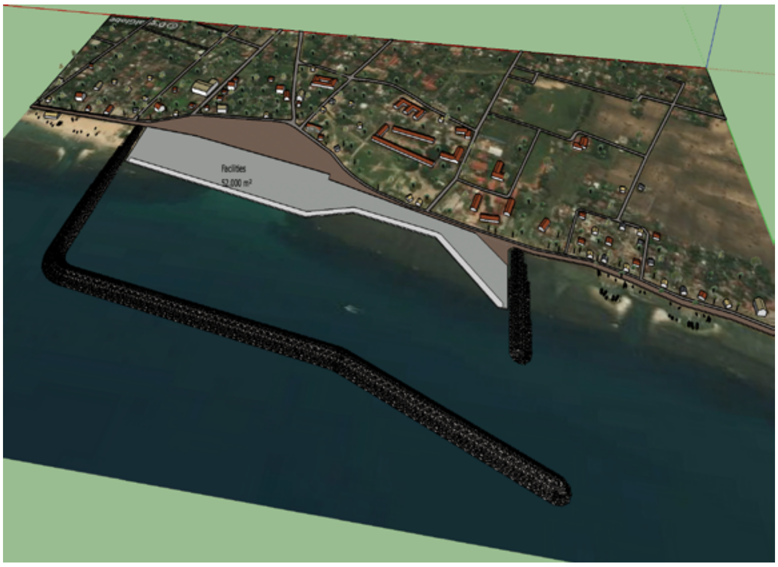


Figure 35: PPTA Design - 3D-overview

Harbour layout

The layout of the harbour, Figure 35, as proposed in the PPTA has a fairly straightforward design. The harbour has a rectangular basin, a large area needs to be reclaimed to build all facilities and all quay walls are placed along the full length of the harbour.

The entrance of the harbour is in the northwest in order to protect the harbour basin from the incoming northeastern waves. Since most boats head to the northeastern fishing area, the distance that needs to be covered to enter the harbour is quite long.

The breakwater is positioned at a maximum depth of 9.5 meters. This deepest point is located at the corner in the breakwater at the northwestern point of the harbour. More to the east, the breakwater gradually slopes upwards to a depth of 7.5 meters. Next to a breakwater, a groin on the west side of the harbour prevents sediment flow into the harbour. This groin has a total length of 150 meters and has a deepest point at minus 6 meters.

Figure 36: PPTA Design - harbour layout

All boats need to load and unload at the quay wall located directly onshore, covering the full length of the harbour. As there is no distinction given in the PPTA design where the different types of boats can load, unload and berth, no exact further information can be given on quay wall positioning. However, due to the presence of the reef at the western side of the harbour, most logically, the IDAY boats will use this part of the harbour, whereas the IMUL and IIMUL boats will use the eastern side of the harbour. This is due to the fact that the eastern side of the harbour can be dredged more easily, since only sand needs to be dredged at that side. Because no layout of the harbour is given in the PPTA, it is unknown in which parts of the harbour all boats will rest.

All land facilities are placed onshore, close to the water in a long stretched area along the length of the harbour. In the ground plan given in the PPTA, the facilities needed for the IDAY boats will be located at the west side of the harbour. The facilities specifically designed for the IMUL and IIMUL boats will be located more eastward. A fuelling station is present at both sides of the harbour.

Environmental impact

The construction of infrastructure always has an impact on the surrounding environment. The amount of material needed to be dredged, the amount of land reclamation required and the effects this will have on the longshore sediment transport will be discussed for the PPTA design.

Because the entire quay wall of the harbour is located in shallow water or onshore, a lot of material needs to be dredged within the harbour to make sure the water is deep enough for all fishing boats and vessels. As it is unclear where the different types of boats will rest, it is unknown at which exact locations within the harbour dredging is required.

In the PPTA design, all facilities will be placed on reclaimed land, located along the shore of Point Pedro. The design of the PPTA reserved 4 hectares of land to place all facilities on. This plot of land had to be reclaimed from sea.

The construction of the harbour will inevitably lead to a change in longshore sediment transport. Because the harbour forms a barrier for the sediment and the net longshore transport is from east to west, sand will cumulate along the eastern breakwater. This also causes erosion on the west side of the harbour. This erosion could cause problems concerning the landing site located on the west side of the harbour, since that beach can erode as well. Furthermore, sedimentation could eventually block the landing site at the east of the harbour. These consequences need to be taken into account when setting up a plan for the maintenance of the harbour.

Future growth

The harbour as presented in the PTTA is designed using the 50-year design values proposed by PTTA. The harbour is capable of handling all fishery boats predicted to make use of the Point Pedro harbour. However, if the fishery sector grows even faster than predicted, the harbour design cannot easily be changed to a design which is capable of handling this growth.

3.2.2 Alternative 2: Building on the reef

The concept of building on the reef is based on land reclamation on top of the existing reef area inside the harbour. This concept is included since there is a lot of reef near the surface at the proposed harbour location and enhanced by the fact that there is limited land available near the shore. Building onshore will create conflicts with property owners and existing infrastructure should be replaced. The design takes into account that the landing sites on the east and west of the harbour will not directly be influenced by constructing a harbour. A 3D-overview of this conceptual design can be seen in Figure 37.

Figure 37: Conceptual design 2 - 3D-overview

Harbour layout

In the harbour design, see Figure 37, it can be observed that two large areas need to be reclaimed to have enough space available for all onshore harbour activities. An important design choice has been made in assuming it is optimal for the harbour productivity to have all unloading quay walls close to the onshore harbour facilities.

Figure 38: Conceptual design 2 - harbour layout

The harbour entrance is designed to be in the middle of the harbour, since this reduces the sailing time inside the harbour. Unloading, refuelling and resting places are all situated near the harbour entrance. The harbour entrance is proposed in the deepest part of the harbour, because the sediment flow will be smaller in deeper water. Combining this with the shape of the breakwater leads to low sediment inflow into the harbour, reducing the required dredging maintenance during the harbour lifetime. In the proposed design, the harbour entrance also shelters from incoming waves from the northeastern direction, which was found to be the dominant wave direction.

The breakwater on the east side of harbour is located at -7 m depth. This relatively shallow depth already provides space for a resting area and an unloading area for IMUL boats. A shallow depth is an advantage for the breakwater, since it reduces the amount of material required for building the breakwater. The western breakwater will be located at a depth of -8 m. The main reason for a deeper breakwater is that the reef is steeper at this side of the harbour. Hence, constructing a breakwater at -7 m would lead to a space limitation inside the harbour.

The quay walls are positioned close to the onshore facilities. Since the arriving times of IMUL and IIMUL boats are difficult to predict, one quay wall will accommodate both boat-types. In this way arriving peaks of IMUL boats can be compensated to make use of the "reserved" place of IIMUL boats (and the other way around). As can be observed in Figure 37, the quay wall for IMUL/IIMUL boats is positioned on the upper edge of the reef. The biggest advantage of this position is that the quay will be built on top of the limestone reef. Since limestone is a material with a large stand up time, horizontal earth pressures on the quay wall will be relatively small, which is favourable for the quay wall design. Building a quay wall at this location, means that a part of the reef slope should be dredged in order to create sufficient depth for IMUL and IIMUL boats.

For IDAY boats, a quay wall will be positioned in the shallow part of the harbour. Although the quay wall is constructed in the shallow part, the quay wall should be able to resist the forces of the IMUL/IIMUL boats, because these boats could be located in that area in the future. Initially, the location for the IDAY quay wall is chosen to limit dredging activities during the construction of the harbour. The refuelling quay is located on the western land reclamation area in the deeper water. In this way the fuelling area is easily accessible for all types of boats.

In the current design a small area is reserved for coastal fishery. This area is designed in the shallowest part of the IDAY boats. Currently, most fish production in Point Pedro comes from these small boats, and therefore, it is important for them to have access to the onshore facilities as well. The governments goal is to enhance deep sea fishing, but the shift from coastal fishery to deep sea fishery takes some time. This shift will take place during the lifetime of the harbour, therefore this coastal fishery area may disappear from the harbour after some years.

The resting area for IDAY boats is located close to the unloading quays for IDAY boats. Since IDAY boats use these facilities everyday, it is important that their comfort is optimal when using the harbour. IMUL and IIMUL will be resting in the deeper water, this means no additional dredging is required for their resting places and the resting places are located close to the harbour entrance.

Most land facilities are based at the east side of the harbour. This location is easy to reach from all quay walls. Another advantage of onshore facilities at this location is that is located close to the main (east) landing site of Point Pedro. In this way, local fishermen have the possibility to make use of the facilities. The refuelling area is located far away from other land facilities. This design choice has been made for safety reasons. Potential problems at the fuel station will not affect the other onshore facilities.

Environmental impact

The environmental impact mainly focusses on the required dredging operations, land reclamation and the effects on the longshore sediment transport. All these factors will have impact on pure environmental aspects and emotional impacts for the local residents and fishermen.

The amount of dredged material is kept as low as possible by assigning places for IMUL and IIMUL boats in the deepest parts of the harbour. Dredging is required for the construction of the IMUL/IIMUL quay wall. Also, for the construction of the IDAY quay wall and the IDAY resting places some amount of material should be dredged. Dredging at this location will be cheaper since only soft materials will be dredged at that location. Initial dredging operations are also limited because the area for future expansion will not be dredged during the initial construction stage. This area will only be constructed when it is needed in order to adapt to the future fleet size.

The land reclamation proposed in this concept is constructed on existing reefs, therefore not a lot of material is required to gain the extra onshore surface inside the harbour. Since the quay wall will be two meters higher than mean sea level, material is needed to heighten the reef. This material will be gained from the dredged material which is won during dredging of the harbour basin.

Implementation of a harbour has large influence on the longshore sediment transport. Since the net longshore is from east to west, erosion will occur on the west side of the harbour. Therefore, the design is constructed with a space between the western landing site and the harbour breakwater. In this way the erosion of the harbour on the landing site is kept as little as possible and nuisance for local fishermen is reduced. On the eastern side of the harbour sedimentation will take place against the harbour breakwater. This causes that the landing site in the east will grow in the future. A disadvantage is that the inlet of the landing site may get clogged with sediment due to the sedimentation in that area. In order to keep the local fishermen satisfied small dredging activities at the landing site can keep the landing site operable. From emotional value point of view, a disadvantage is that currently some houses are situated on the proposed onshore area of the harbour.

Future growth

It is expected that the amount of ships using the harbour will still grow after the first five years. In order to accommodate this growth the harbour breakwater is constructed on the expected neseccary space required during the lifetime of the harbour (50-year design values). Since the applicability of these design values is more uncertain than the 5-year design values, initially only the required facilities for accommodating the 5-year fleet size are implemented.

Implementing only the 5-year design values gives a large amount of unused space in the area. As can be observed in Figure 37, a part of the harbour design is open for future expansion. There will be no construction activities during the initial harbour construction, which reduces the initial investment in the harbour. If expansion of resting places is required inside the harbour, first the central IMUL resting places (in the middle of the harbour) can be expanded. If it is found that the required area to accommodate all boats is not sufficient, a second construction phase can take place. This construction phase consists of relocating the IDAY boats towards the west of the harbour (in the expansion area). The purpose of the IDAY quay wall can be changed into a IMUL/IIMUL quay wall and extra quay wall length can be constructed at the current place for coastal fishery. After this construction phase, the harbour can accommodate the 50-year design fleet size.

3.2.3 Alternative 3: Large pier

As mentioned previously, there is an existing coral reef protecting the coastline, which functions as a natural breakwater for the beach. This design alternative will have the breakwater constructed on the edge of the reef. As the core of the reef is very strong, this natural breakwater will be used as a base for a new designed breakwater in this design. Building a breakwater on top of the reef decreases the costs as a large part is already present. One of the main features of this conceptual design is the large pier in the middle of the harbour. A 3D-overview of this conceptual design can be seen in Figure 38.

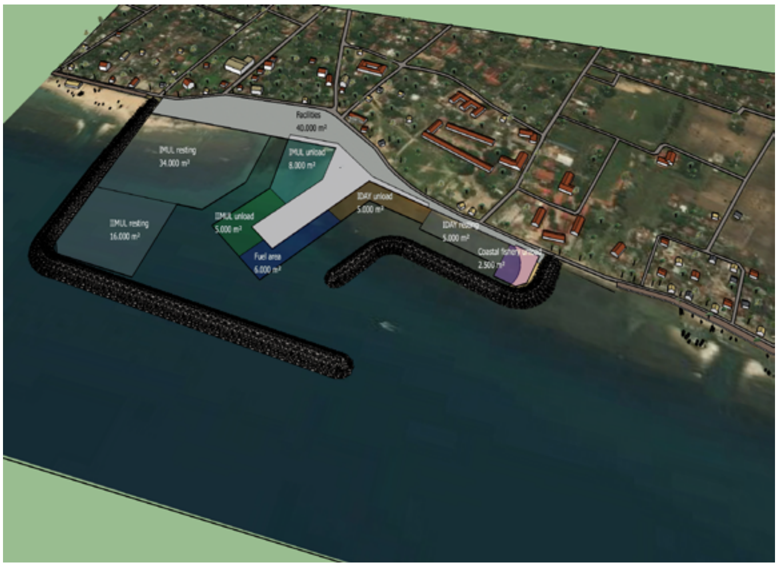


Figure 39: Conceptual design 3 - 3D-overview

Harbour layout

As shown in Figure 39, the harbour shape consists out of two basins: a small basin to the west which uses the natural reef as breakwater, and a large basin east for vessels with a larger draught. An artificial solid pier is dividing the east and the west basin.

Figure 40: Conceptual design 3 - harbour layout

The harbour entrance is located in the northwest, as the breakwater is designed to protect against incoming waves from the northeast. The main fishing area is located in the northeast of Point Pedro, meaning that the ships sailing distance increases compared to a harbour entrance east or centre of the main breakwater. A groin provides shelter against incoming diffracted waves. Inside the harbour, the sailing distances are minimized by placing a large pier with the main quay wall in the centre of the basin.

In this design two separate breakwaters are included. The main breakwater stretches into the ocean and will function as the main wave protector; it will be constructed at a depth of 8.75 m. The second breakwater is located east on top of the coral reef. The deepest point of this groin will be located at -6.5 m. The end of the reef is located 100 m offshore, limiting the available space to 70 m. This basin provides (un)loading and resting area for IDAY boats and smaller coastal fishery boats. The depth of this basin will be shallow, at a depth of 2 m, while the east part of the basin will have a depth of 5 to 6 m. Due to the narrow and shallow area of the western basin the water circulation will be very limited, water quality will decrease.

The quay wall is constructed as an artificial solid pier that reaches till the middle of the harbour basin and continues partly on the landside. The quay wall will be used for loading, unloading and fuelling purposes, but not as resting area. Due to the central location of the quay wall all other harbour areas are easy reachable. The bathymetry profile of the site area is used to optimize the quay wall area. The depth at the IIMUL area is already 6 meters, while for the boats with less draught, the basin is more shallow. The fuelling and IIMUL boats will be allocated to the north of the quay wall. The IDAY boats will be using the southwest part of the quay wall as this is the most shallow part of the quay wall, the southeast of the quay wall will be used for the IMUL and IIMUL boats.

The location of the resting areas is based on the natural depth of the site location. The IIMUL resting areais situated in the deepest part of the basin (-6.5 to -8 m), meaning that for the IIMUL vessels no additional dredging will be necessary as the pier is also located deep enough. The IMUL boats will also rest in the east basin, but have a smaller draught and will be located more towards the shore. Near the shore, the basin becomes shallow and dredging of this area till -5 m depth will be necessary. The IDAY boats will be resting in the shallow western basin with a depth of 2 meters. At the end of the basin a beach will provide easy access for the small coastal fishing boats to (un)load and rest.

The solid pier will have a width of 50 meters, creating space for a two way traffic lane and the most important facilities. Facilities on the pier include ice storage, cold storage, (un)loading equipment, fuel station and a workshop. The other facilities will be constructed at the shoreline. Furthermore, the auction hall will be placed close to the two main roads to provide easy distribution access.

Environmental impact

For a small town like Point Pedro, the development of a harbour of this scale will have a large impact. This impact can be divided into the impact on pure environmental aspects and emotional impacts for the local residents and fishermen. For a first estimation of dredged material it is assumed that only the water basin needs to be dredged. It is assumed that the ground conditions beneath the pier provide sufficient strength for foundation, meaning that no additional ground improvements methods will be necessary. This alternative is designed to make optimal use of the already available depths, minimizing the amount of dredging. Dredging needs to be performed near the shore. The west basin will be dredged till 2 m depth and the east basin till 5 m depth. The dredged material however will mainly consist of strong limestone reef.

The solid pier, the onshore area, and the beach will need land reclamation. To make optimal use of the dredged material, the amount of reclamation land. is optimized. This results in a relatively small amount of dredged material that needs to be dumped.

Currently, the largest net sediment stream is located between the reef and the shore. The breakwater on top of the reef prevents mayor sediment stream. This breakwater traps sediment, creating sedimentation along the outer eastern breakwater. Over the years this sedimentation can create a sandy beach, giving the possibility to expand the eastern landing site. West of the harbour erosion occurs. It is expected that the landing site west of the harbour will experience erosion, however as the reef will still be present major erosion problems will be reduced.

Another important aspect on the environmental analysis is the impact on the locals. In this design the main facilities are located onshore, increasing the amount of activities along the road and thus the amount of noise. Also, the shoreline will change drastically due to the removal of the current beach facilities, which include landing sites for local fishery boats and recreational areas.

Future growth

In the design, future growth can be adapted easily by expansion of the resting areas. The desired quay wall length for 50-years is already implemented during the initial construction phase of the harbour. If the optimal capacity will be reached, no major adjustments in the harbour are required. The basin already provides enough space for unloading, the only adjustment will be the construction of more jetties in the resting areas to enlarge the resting space.

3.2.4 Alternative 4: Artificial island

The main idea behind alternative 4 is the development of an artificial island, as shown in Figure 40. Constructing such an island can be beneficial because it gives place for the dredged material of the harbour basin. Furthermore, loading and unloading for all types of boats can be done very close to the processing area. Additionally, the impact on the current shore line will be as little as possible, as the harbour will use very little of the current shore. This also reduces the number of people affected by the development of the harbour. On top of this, developing an artificial island can be seen as a prestige project in the Northern Province, which can help putting Point Pedro on the radar.

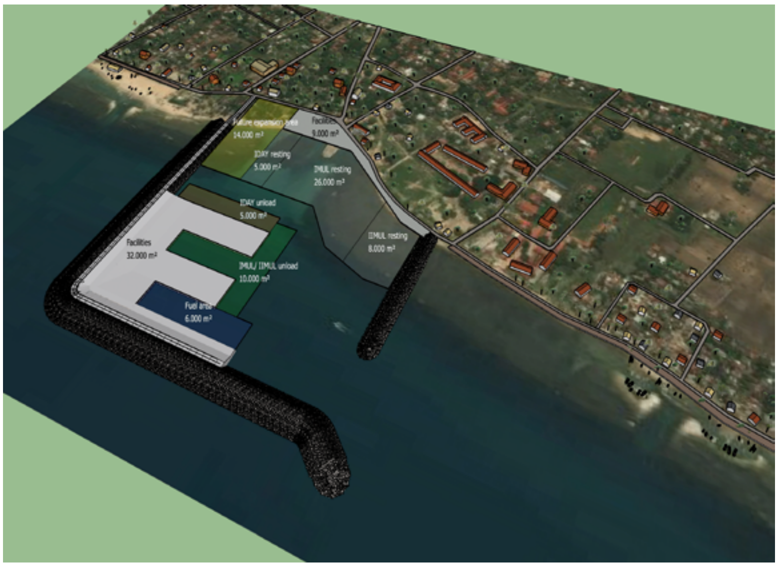


Figure 41: Conceptual design 4 - 3D-overview (own illustration)

Harbour layout

The harbour layout is given in Figure 41. As shown, the harbour will consist of one large basin that contains the artificial island and is surrounded by breakwaters. All sides of the island will consist of quay wall. Furthermore, the resting areas are near the shore and the unloading and refuelling areas will be placed on the artificial island.

Figure 42: Conceptual design 4 - harbour layout (own illustration)

The entrance of the harbour is located in the northwestern corner (Figure 41). The significant waves have an angle of incident of 30 degrees, therefore the largest impact will be in the northeastern corner. Additionally, the end of the breakwater has a part that is constructed in an angle of 45 degrees with the rest of the breakwater. This is done to prevent waves from hitting boats while maneuvering through the harbour entrance and to reduce the amount of sediment that will get washed into the harbour.

For this concept, the area of the facilities onshore is reduced by constructing the most important facilities on the artificial island in the harbour basin. To be able to encircle this island and the other facilities, the breakwater extents deeper into the sea. Due to this, the deepest part of the breakwater will be constructed at -10 to -11 m depth.

The unloading area for all types of boats is located at the artificial island. The IIMUL, IMUL and IDAY boats will unload their catch each at a designated quay wall, maintained at the appropriate draught. Also, the facilities directly involved in the cooling, cleaning and auctioning processes are located on the artificial island. This means that unloading of fish for all vessels is done close to the facilities. The additional space on the artificial island will be filled with facilities which do not immediately benefit from being close to the processing of the fish. The final remaining facilities will be constructed onshore at the allocated space to the south of the berthing areas. On the northern part of the breakwater a quay wall will be constructed to allow boats to refuel. The most western part of this quay wall will be facilitate the IIMUL boats as at that past, enough maneuvering area for large vessels is present.
The island has an 'E'-shape as this requires the least amount of dredged material while giving sufficient quay wall length for the (un)loading of fish. The island is placed against the breakwater at the east side to give the shortest possible drive from the auction hall to the shore.

The resting areas are located close to the shore, which minimizes the walking distance for the fishermen. Because the IIMUL boats have the deepest draught, they are positioned in the southwestern corner as there will be less sedimentation. East of the IIMUL boats, the IMUL boats are stalled. This part of the harbour is naturally deeper, which requires less material to be dredged. To the east of the IMUL boats the IDAY boats are berthing, as this area is most shallow and most sedimentation is expected. Therefore, it is wise to allocate this space for the boats with the smallest draught. An area between the berthing area of the IDAY boats and eastern quay wall will remain beach to moor the smallest boats. This area will also contain a slipway.

Environmental impact
Constructing this new harbour will have impact on the environment as land needs to be reclaimed, dredged material needs to be dumped and other environmental conditions can be disrupted.

One of the advantages of the construction of an artificial island is that the dredged material from the harbour can be used in the construction. Therefore, no dredged material needs to be dumped at an external location. Excess material from other projects might be used in the construction of the island in case the dredged material in the harbour is not sufficient. Additionally, the harbour will not require much dredging of the hard limestone reef, for which the impact on the environment is unsure.

As the harbour will reach quite far into the sea, a new barrier that changes the currents will be created. This will result in a disruption of the longshore sediment transport, sand will accumulate against the eastern breakwater. Furthermore, on the western side of the harbour the shoreline will be eroded. However, the harbour is constructed relatively far away from the western landing site and thus it will experience limited consequences of the erosion.

An advantage of this alternative regarding the impact on the locals, is that the main facilities are located offshore, leaving the current coastline intact. Every operation involved with the fishing industry will be located on the artificial island, keeping the noisy activities isolated. The amount of traffic on the current roads will increase, but the increase in noise will be limited. As the closeby girls school is anxious for noise increase, this alternative will be in their favor. Additionally, because the width of this harbour design is the smallest of all alternatives, it has less impact on the current shoreline and landing sites of the local fishermen.

Future growth

As described in chapter 3.2.2 Alternative 2: Building on the reef, the future growth of the fleet size needs some adaptable space allocated in the harbour. In the southeastern corner of the harbour, there is an area allocated for future growth. In this conceptual design this will be beach where the smallest fishing boats can moor. If the growth exceeds the 5-year design capacity, this area could be used to implement additional quay wall and berthing area.

3.3 Multi criteria analysis

Before the harbour design can be transformed into a final design, a choice needs to be made between the four different concepts presented in the last paragraph; (1) PPTA design, (2) Building on the reef, (3) Large pier and (4) Artificial island. Since all alternatives meet the requirements set up in 3.1 Requirements of the harbour alternatives, all harbour designs could be implemented. However, there are big differences between the alternatives. To be able to make a well based and deliberate choice between the four alternatives, a multi criteria analysis will be performed in this paragraph.

3.3.1 Description of the criteria and weightings

The three main criteria on which the conceptual designs will be scored are Costs, Technical characteristics and Living environment. These three main criteria are further divided into nine subcriteria, which can be seen in Table 18. Appendix J on page 122 elaborates on each subcriteria and provides information on how the criteria should be interpreted when scoring the alternatives.

Before being able to score the design alternatives, consensus needed to be reached on the weighing of the criteria. After deliberation, the weighing was chosen as presented in Table 18, on the left side. First of all, the three main criteria; costs, technical characteristics and living environment were given a score of 40, 35 and 25 percent, respectively. Since all main criteria were split up in three subcriteria, again one hundred percent needed to be divided over the three subcriteria. Multiplying the percentages resulted in the numbers given in the second column of Table 18.

All criteria will be given a score between one and four (1-4), one referring to the worst possible score and four referring to an excellent score. All scores given to the criteria will be multiplied by their weight and added up to give a final score for that particular alternative. This score can be seen at the bottom row of Table 18.

3.3.2 Scoring the conceptual designs

After determining the criteria and weightings, scores are given to each subcriteria. In Table 18, the result of the completed MCA of the conceptual designs can be found. Below the table, an elaboration of the scoring of each subcriteria is given.

Table 18: Completed MCA of the four conceptual designs									
	Weight	**Alternative 1 PPTA**		**Alternative 2 Building the reef**		**Alternative 3 Large pier**		**Alternative 4 Artificial island**	
Critria	100%	Score (1-4)	Score x Weight	Score (1-4)	Score x Weight	Score (1-4)	Score x Weight	Score (1-4)	Score x Weight
Costs	**40%**								
1. Construction (60%)	24%	2	0.48	4	0.96	4	0.96	1	0.24
2. Maintenance (30%)	12%	1	0.12	3	0.36	1	0.12	2	0.24
3. Disposal (10%)	4%	2	0.08	1	0.04	1	0.04	4	0.16
Technical characteristics	**35%**								
4. Harbour layout (50%)	17%	1	0.17	4	0.68	3	0.51	4	0.68
5. Complexity (20%)	7%	4	0.28	3	0.21	2	0.14	1	0.07
6. Adaptability (30%)	11%	4	0.44	2	0.22	2	0.22	1	0.11
Living environment	**25%**								
7. Safety (50%)	12%	2	0.24	2	0.24	3	0.36	1	0.12
8. Flora and fauna (20%)	5%	1	0.05	2	0.10	2	0.10	4	0.20
9. Emotional value (30%)	8%	1	0.08	2	0.16	2	0.16	4	0.32
Total score									
		1.94		**2.97**		**2.61**		**2.14**	

Criterion 1: Costs

1. Construction costs

The grading of alternatives on the construction costs is based on the three largest costs posts in harbour construction; dredging costs, breakwater costs and quay wall costs. The results conclude that alternative 4 is most expensive (approx. 13.1 mln), followed by the design made for alternative 1 (approx. 12.1 mln). The construction costs of alternative 2 (approx. 9.2 mln) and alternative 3 (approx. 9.6 mln) are comparable and will both get full score. Appendix K elaborates on the composition of the construction cost per alternative.

2. Maintenance costs

Both alternative 1 and 3 score low on the maintenance costs. For alternative 1 this is due to larger dredging costs near the harbour entrance, because the entrance is located in relatively shallow water. The low score for alternative 3 is caused by its bad water circulation properties in the IDAY part of the harbour, waste material should constantly be removed from this area and the water quality can cause bad odors. As alternative 4 is located close to the outer breakwater, the onshore facilities may suffer from a larger amount of salt intrusion. Alternative 2 scores highest, because the above mentioned problems will not occur. However, this design allows bigger waves to intrude the harbour which can damage the quay walls.

3. Disposal costs

Disposal costs are mainly focussed on the removal of (vacant) buildings and landmarks in the proposed construction area. Since the disposal of construction materials is assumed to be equal for each alternative and the usage of dredged sediment can be optimized in the final design, these costs were not taken into account in the disposal costs. Alternative 2 and 3 score lowest on disposal costs, because land area should be acquired and current infrastructure or houses should be removed. Next is alternative 1, the large length of the harbour gives relatively high disposal costs. Alternative 4 is graded best since new land will be constructed in order to accommodate for the most facilities.

Criterion 2: Technical characteristics

4. Harbour layout

Alternative 2, 3 and 4 score have relatively high scores compared to alternative 1. The layout of alternative 1 is overdesigned and sailing distances will be large. Another advantage for alternative 2,3 and 4 is that the onshore facilities are located close to the (un)loading areas. Alternative 4 optimizes the sailing distance by constructing the quay wall on a central location in the harbour. Alternative 3 uses the same principle, but the sailing distance of IDAY boats is relatively high compared to alternative 3, therefore a lower score has been given. The main advantage of alternative 2 is the central harbour entrance that makes the harbour easy navigable.

5. Technical complexity

Less complexity increases the operational ease and simplifies the construction process. Alternative 1 is very basic and has little complexity, resulting in a high score. For alternative 3 and 4 however, large reclamation inside the basin is required and a large amount of the hard limestone reef needs be dredged. Alternative 2 decrease its complexity by designing the land reclamation mainly on the reef.

6. Adaptability

Adaptability is based on the possibility to adapt to future growth as the 50-year design value is highly uncertain. Alternative 2 and 4 implemented an expansion area in the design that can be constructed in a later stage, when the demand for the harbour increases. Since alternative 1 and 3 already implemented the 50-year design values for the quay walls, only relatively small construction activities are needed to increase the size of the resting area. However, in case of negative growth, the efficiency of these designs decreases. Another important aspect in adaptability is the possibility of the harbour to cater bigger sized boats, in case in the future they become bigger. Taking this into account, alternative 1 can adapt easily to this change while alternative 4 will need to reshape the outline of the artificial island.

Criterion 3: Living environment

7. Safety

The scores on safety are based on the probability and consequences of events that can damage the harbour or can cause human injuries. Alternative 4 will be vulnerable for storm surges, high wind velocities and overtopping waves because of the offshore location of the artificial island. The wave heights during storm events cause problems for alternative 2. The harbour entrance creates harsh conditions inside the basin, resulting in difficult mooring conditions. Alternatives 1 and 3 the do not have these problems during storm events. Also the layout of the onshore facilities is taken into account in safety. Having refuelling areas close to other facilities brings larger risks with it. In alternative 2, 3 and 4 the fuel stations are located far away from other facilities. Alternative 1 located two fuel stations on its quay wall, thus, this alternative is less safe considering the fuelling stations.

8. Flora and fauna

The change in water currents surroundings at the coastline of Point Pedro will affect the flora and fauna negatively. In all alternatives the reef will be largely affected by the construction of the harbour. Alternative 4 however, has the least impact on the current coastline as this alternative is located offshore with the smallest width at the coast. Alternative 1 is very wide and relatively narrow compared to the other alternatives, enlarging the impact on the current shoreline.

9. Emotional value

Since an old girls school is located near the proposed harbour area and local fisherman want to make use of the two main landing sites, emotional values plays an important role in grading alternatives. To limit the impact on the current landowners, alternative 4 located all the facilities offshore. The other alternatives reclaim land near the shore, increasing the bustle. Therefore, the Methodist Girls High School will experience more nuisance in front of their building. Due to the large width of alternative 1 and the facilities onshore, this alternative will score lowest.

3.3.3 MCA outcome

The final scores of each alternative are respectively 1.94, 2.97, 2.61 and 2.14. Both alternative 1 (PPTA) and alternative 4 (Artificial island) score relatively low and will therefore not be taken into consideration when developing the final design. Alternative 2 (Building on the reef) scores highest, closely followed by alternative 3 (Large pier). Therefore, both conceptual designs are taken into consideration in the final design.

3.4 Conclusion MCA

The requirements for the conceptual design study are based on the conducted analysis in chapter 2. These requirements formed the basis of the conceptual design study as it outlined the main features that each alternative should contain. Eventually, four main alternatives were designed as shown in Figure 42 below.

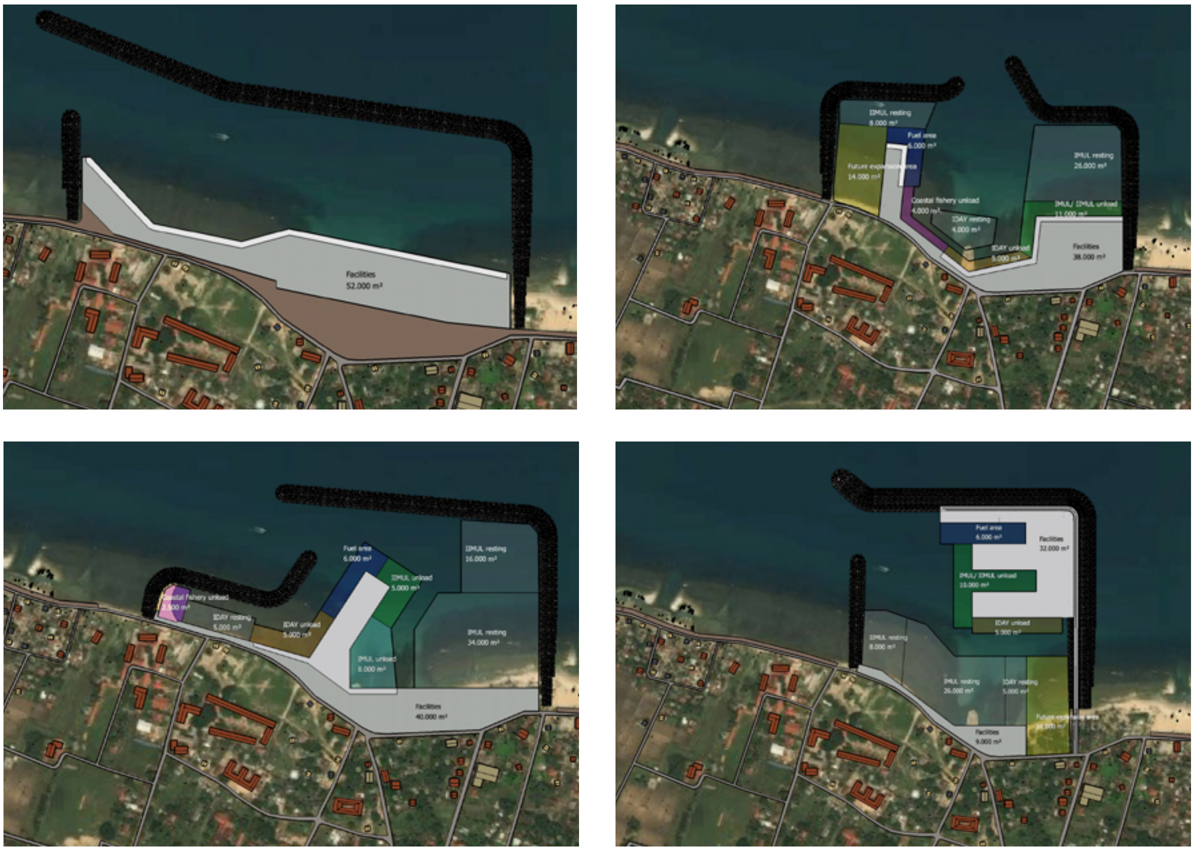


Figure 43: Overview alternatives (from top left to bottom right: alternative 1, alternative 2, alternative 3 and alternative 4

These alternatives are scored by performing a MCA, in which each alternative was scored on nine different subcriteria. Alternative 2 has a higher overall score due to lower maintenance costs, a better harbour layout, and less complexity. Due to this fact, alternative 2 will be used as the main template for the final design. However, alternative 3 has some important characteristics that could improve alternative 2. For instance, making use of the bathymetry of the project location, like alternative 3, can reduce dredging and land reclamation costs significantly. However, more attention should be paid to the water circulation inside the basin in order to reduce maintenance costs. Currently, another disadvantage of alternative 2 is that the shape and location of the harbour entrance allows more wave intrusion inside the harbour, leading to safety problems. This problem could be ersolved by designing the harbour entrance more sheltered, by example as shown in alternative 3.

The efficiency inside the harbour is an important factor, the fishermen and the harbour authority want short sailing routes and optimal use of the land area and quay wall length. In addition to that the harbour should be safe against the incoming waves, except major storm surges and tsunamis.

4. FINAL HARBOUR DESIGN

In this chapter a final design is proposed for the fishery harbour in Point Pedro. This final design is based on the conceptual designs of chapter 3. The concepts explained in chapter 3 give an initial design which can at least accommodate the 5-year design values, with a plan for expansion towards the 50-year design values. In the final design, the 50-year design values are used for designing a master plan. Afterwards, the harbour impact and the stakeholder engagement plan is elaborated upon. Finally, an implementation plan is proposed, which also includes the timeline of the project.

Source: own picture, taken at Point Pedro

4.1 Final design master plan

In this paragraph, a master plan is proposed that can facilitate the 50-year design values of the Point Pedro harbour. As concluded in chapter 3, alternative 2 'building on the reef' was used as a template to create the final design. To transform alternative 2 into a final design master plan, some adjustments and additions had to be made. After analyzing the conceptual design phase, it was found that the final design should be optimized on the five following aspects: (1) harbour size, (2) sailing route, (3) bathymetry use, (4) quay wall usage and (5) safety. In this paragraph, first the harbour layout will be described on basis of the 3D-overview of the final design, as shown in Figure 44. More figures of the harbour design can be found in Appendix L. Afterwards, the technical details and the construction costs of the final harbour design are explained. Finally, a risk analysis is performed.

Figure 44: 3D-overview of the final harbour design

4.1.1 Harbour layout

This paragraph describes the harbour layout of the final design.The harbour layout includes the size and shape of the harbour, the location of the breakwaters, the position of the quay wall, the bathymetry of the harbour basin and the location of the different resting areas. Also, the placement of the jetties in the basin and the facilities onshore are part of the harbour layout. Figure 44 gives a schematic overview of the space allocation of the final harbour design. In the following paragraph, the design considerations are elaborated upon.

The harbour entrance is located central-west of the harbour. Having the entrance face the west gives shelter to intrusion of large waves during the monsoon, leading to calm and safe water conditions inside the harbour (5). Since waves coming from the west are limited in height, wave intrusion from this side will not cause navigational problems. The breakwater at the harbour entrance gives shelter to the entrance channel, in this way risk of collision on the southern breakwater at the entrance is reduced. The location of the entrance in the central-west of the harbour combines safety considerations (5) with having a minimal sailing route (2).

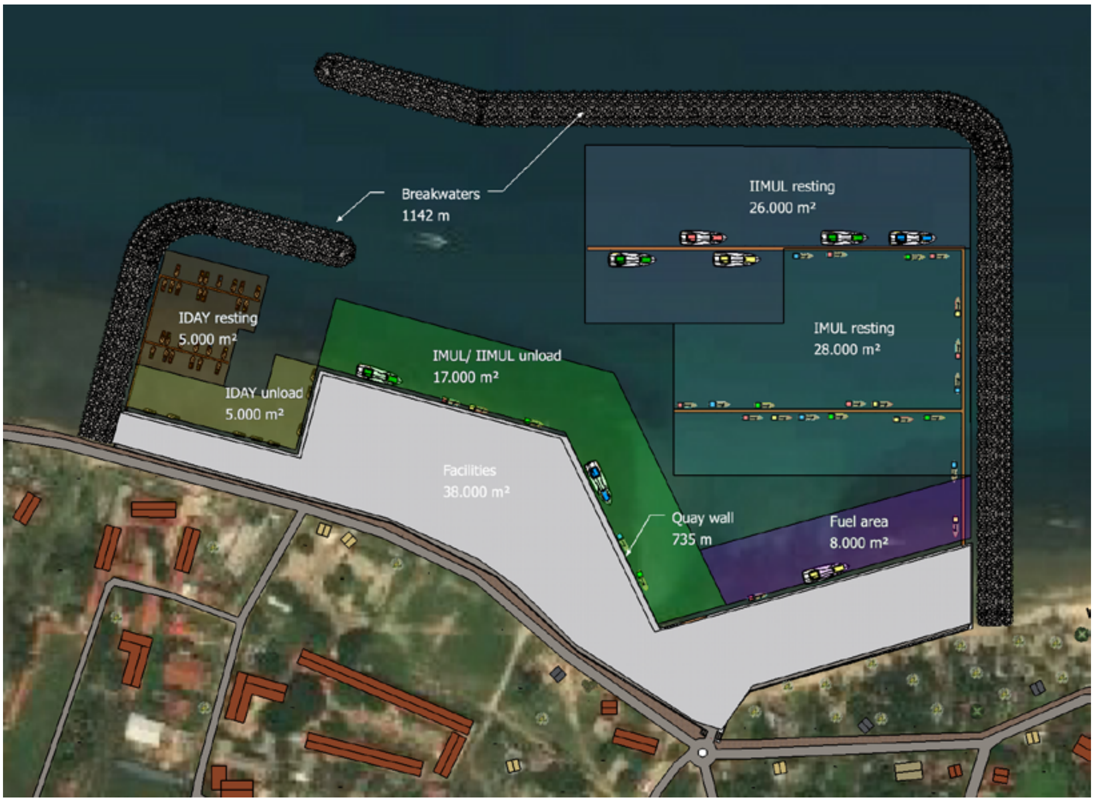


Figure 45: Lay-out final design

The main breakwater is located at -9.5 m MSL. By placing the main breakwater at this depth, the requirements for the basin area are met (1). The width of the harbour is minimized to reduce disturbance for the local communities. The west part of the harbour basin will provide (un)loading and resting place for the IDAY boats, limiting the depth of this part of the basin to -2 m MSL. The IMUL and IIMUL vessels require most of the harbour basin, as can be seen in Figure 44. The depth in this area will be -6 m MSL. For resting, floating finger jetties are designed in this area, see Figure 44. During the fishing season the jetties will provide sufficient length for parallel berthing of all IMUL and IIMUL boats resting in the harbour. This results in easy navigation in these resting areas during the fishing season. The jetties are designed in such a way, that during the monsoon period, all boats can berth at the jetties. In this case the boats need to berth side-by-side, stacked six to nine times, limiting the manoeuvring area. Dredging reef material is expensive, therefore, the final design minimized the amount of reef needed to be dredged by using the reef area as main part of the land reclamation (3).

The quay wall is mainly located on the edge of the reef. By building the quay wall directly next to a vertical slab of reef, the quay wall will have to bear less forces compared to building the quay wall with a backfill of sand. This reduces the costs of building the quay wall. The main facility area will be at the centrally located reclaimed land, this is also the location where IDAY, IDAY, IMUL and IIMUL boats will unload. This facility and unloading area is the most central place in the harbour, optimizing the supply chain. After boats enter the harbour they can immediately unload their catch, which can be stored close to the unloading location.

As described in paragraph 3.1 Requirements of the harbour alternatives, at least 18 different facilities have to be present within the perimeter of the harbour. As the different types of boats have separate (un)loading and resting areas, the facilities are needed at different locations as well. The final layout and placing of the facilities can be seen in Figure 45.

A - Fuelling facilities
B - Net mending hall
C - Auction hall (IDAY)
D - Ice plant and storage
E - Accomodation and CFHC storage
F - CFHC Administrative office
G - Toilet and shower facilities
H - SL Navy and Coast Guard
I - Offloading building
J - Action hall (IMUL/IIMUL)
K - Weigh bridge and control room
L - Workshop and repair yard
M - Water supply
N - Waste water treatment plant
O - Beacon lights
P - Parking facilities
Q - Security facility

Figure 46: Harbour facilities layout

At the far left of the harbour, the facilities specifically designed for the IDAY boats are located. It is impossible for IMUL and IIMUL boats to reach that location, because of the limited depth of the harbour basin at that point. A small fuelling station is located at the western tip of the harbour, to facilitate fuelling for the IDAY boats. On the main pier in the middle of the harbour, the biggest share of facilities is located due to the central location. All of these facilities are easy accessible using the main road, which stretches along the full length of the harbour, as well as by using the smaller road which circles the main pier.
All administrative and coordinating facilities are located in the middle of the pier, because a good overview is needed from these facilities and the entire harbour should be easily accessible from this location. Also, the Sri Lankan Navy and coast guard office is located at the right side of the pier, as from this location, they have the best view over the entire harbour and the harbour entrance.
The workshop area is located in a corner of the quay wall at the right side of the harbour. Corners in a quay wall can not be efficiently used for (un)loading, so the placement of the workshop area does not limit the quay wall length (4).
On the far right, the fuelling area for the IMUL and IIMUL boats is present. This is located in a more remote part of the harbour, in order to lower the consequences in case an accident will happen at the fuelling area. The two action halls are centrally located in the harbour areas dedicated to IDAY boats and the IMUL/IIMUL boats, together with parking facilities. Also, a big parking lot is placed close to the resting areas for the IMUL and IIMUL boats.

4.1.2 Technical details

After having discussed the harbour layout in detail in previous paragraph, the technical details of of seperate harbour elements will be elaborated upon in this paragraph. The technical details are subdivided into the following elements; dredging, breakwater, quay wall, jetties and onshore constructions.
Figure 47 displays the technical drawing of the harbour. All elements and their dimensions are presented, as well as the placement of facilities and resting areas. Table 19 provides an overview of the most important dimensions, surfaces and volumes of the different elements. Sections A-A' and B-B', the sections of the breakwater and the quay wall, respectively, are shown and further explained in Figure 49 and Figure 49.

Table 19: Technical dimensions harbour			
		Amount	**Unit**
Harbour	Basin area	11.8	ha
	Onshore area	3.9	ha
Dredging	Dredged material	267,000	m^3
	Land reclamation	108,000	m^3
	Breakwater material (used for core and toe of the breakwater)	156,000	m^3
	Sediment disposal	3,000	m^3
Breakwater	Length	1140	m
	Material	268,000	m^3
	Average depth	6.0	m (-MSL)
Quay wall	Length (IDAY)	185	m
	Depth (IDAY)	2.0	m (-MSL)
	Length (IMUL/IIMUL)	555	m
	Depth (IMUL/IIMUL)	6.0	m (-MSL)
	Total material	14,000	m^3
Jetties	Length (IDAY)	223	m
	Width (IDAY)	1.0	m
	Length (IMUL)	665	m
	Width (IMUL/IIMUL)	2.0	m

Dredging and land reclamation

Dredging of the harbour serves two purposes; to obtain the required water depth inside the harbour basin and to remove the highly weathered top layer of the reef before reclaiming that land in order to build the harbour facilities on top. In order to guaranty safe manoeuvring in the harbour for IMUL and IIMUL boats, the required basin depth should be 6 m below MSL. This water depth is required in the complete basin except for a small area in the west of the basin, where the IDAY boats will both unload and rest. The required basin depth in this area is 2 m below MSL. To construct the land reclamation, it is required to first remove the weathered top layer of the reef. Excavating one meter is assumed to be sufficient in order to ensure structural integrity of the foundations of the onshore facilities. Additionally, the harbour entrance needs to be maintained periodically to ensure a minimal water depth of 6 meters, as the entrance needs to be accessible for all types of boats under all conditions. Currently, no additional dredging is required in front of the harbour entrance. In Figure 47, the differently coloured areas represent the required depth of dredging at specific locations in the harbour basin. It is found that a total amount of 267,000 m^3 needs to be dredged inside the harbour. Periodical maintenance dredging works are not included in this number.

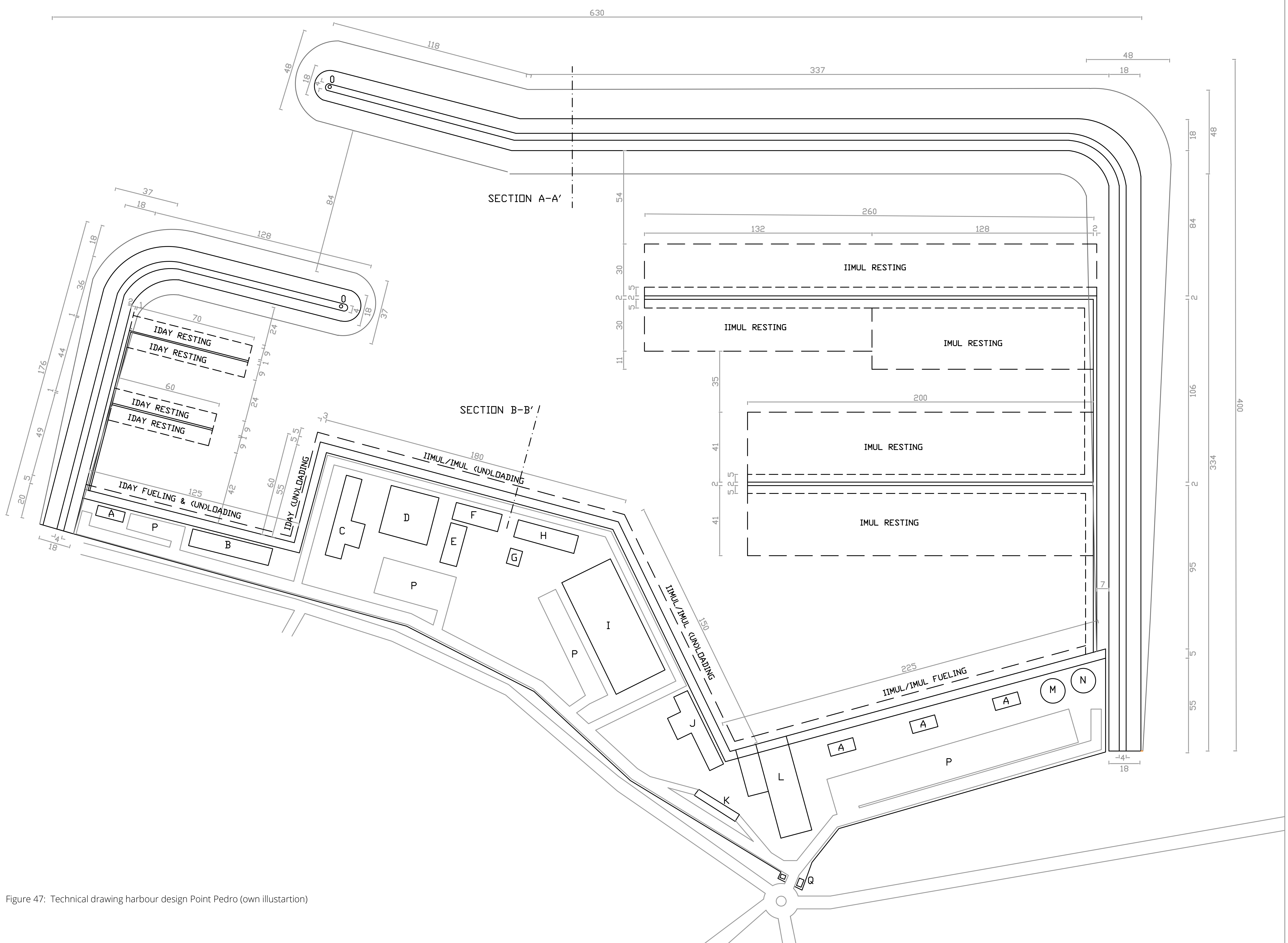


Figure 47: Technical drawing harbour design Point Pedro (own illustartion)

A large part of the dredged material will be used for land reclamation. The amount of material required for land reclamation is approximately 108,000 m^3. This land reclamation should consist of small grained sandy material and will be located at 1.5 m above MSL as this is the required quay wall height. Retrieved dredged material will also be used for the construction of the breakwater, more specifically for the construction of the toe and core of the breakwater. The total required material for the core and toe of the breakwater is equal to 156.000 m^3. However, in order to use the dredged material for the toe and the core of the breakwater, this material should be in the form of large boulders. More information about the required breakwater material can be found in Appendix M.

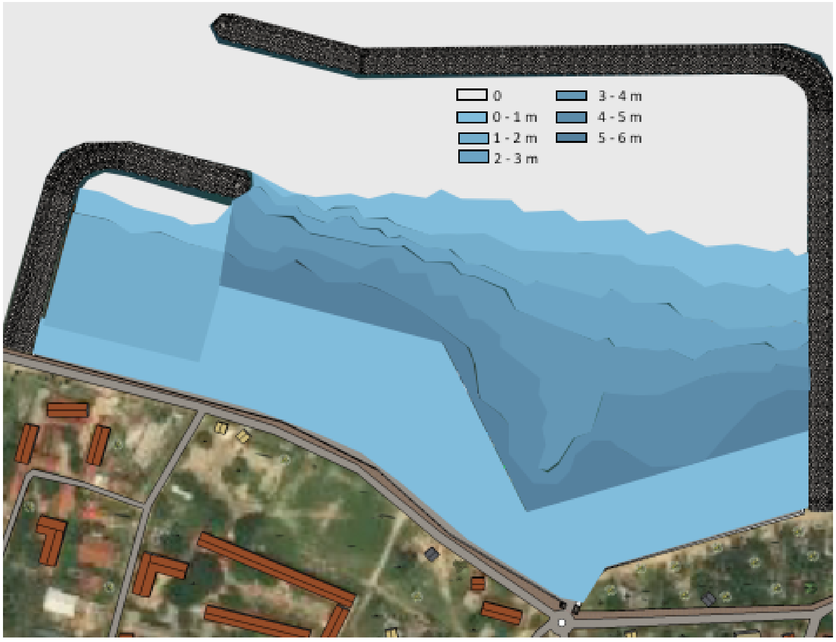


Figure 48: Required dredging operations in the harbour

As explained two different types of dredged materials are required, small grained material and large boulders. Since the top layer of the material in the harbour basin contains loose material only (boulders and sand) this can easily be excavated, for example by using a clamshell dredger or bulldozers. It has been assumed that approximately 122,000 m^3 of material can be removed using this method. This material contains 83,000 m^3 of boulders and 39,000 m^3 of sandy soil. The rest of the required dredging operations consist of dredging the limestone base of the reef. A part of the strong limestone base will be used as breakwater material. To be able to use this material within the breakwater, the excavated material must exist out of large boulders. These large boulders can be obtained by drilling, chipping or blasting of the limestone layer (IADC, 2016). Besides the large boulders that will be excavated, more material needs to be dredged to obtain the correct depths of the harbour basin. This material can partly be used for land reclamation, however, this must be excavated in the form of small grained material. A dredging method that is able to make fine material from the limestone layer is cutter suction dredging. The total amount of limestone in the base layer that needs to be removed is 145,000 m^3. In order to have sufficient material available for construction of the breakwater 73.000 m^3 of boulder should be obtained. The remaining part of dredged material can be processed into fine materials (72,000 m^3). 69,000 m^3 of this processed material is required for the land reclamation, leaving only 3,000 m^3 of sediment disposal.

Breakwater

The breakwater slope reaches down to a maximum depth of -9.5 m MSL, therefore, the technical details of the breakwater at this depth are considered. A rubble mound breakwater with a rock armour layer is proposed at this location, as limestone can be easily obtained from the harbour site. Design calculations showed that the required crest height of the breakwater is 4.0 m above MSL. Thus, the breakwater will reach a maximum height of 13.5 m.

The breakwater consists of three main elements; the armour, the core and the toe. As mentioned earlier, large boulders retrieved from clamshell dredging are used in the breakwater as core and toe material. For the structural integrity of the breakwater, it is important to built the toe with boulders having a minimum average size of 0.66 m. All remaining (smaller) boulders will be used as core material for the breakwater. The required material for the armour layer is not available at the harbour location, therefore this material should be retrieved from an inland limestone mine. The nominal diameter of the armour layer particles should be 1.65 m in order to ensure breakwater stability during its lifetime. A cross-section of the breakwater can be seen in Figure 49.

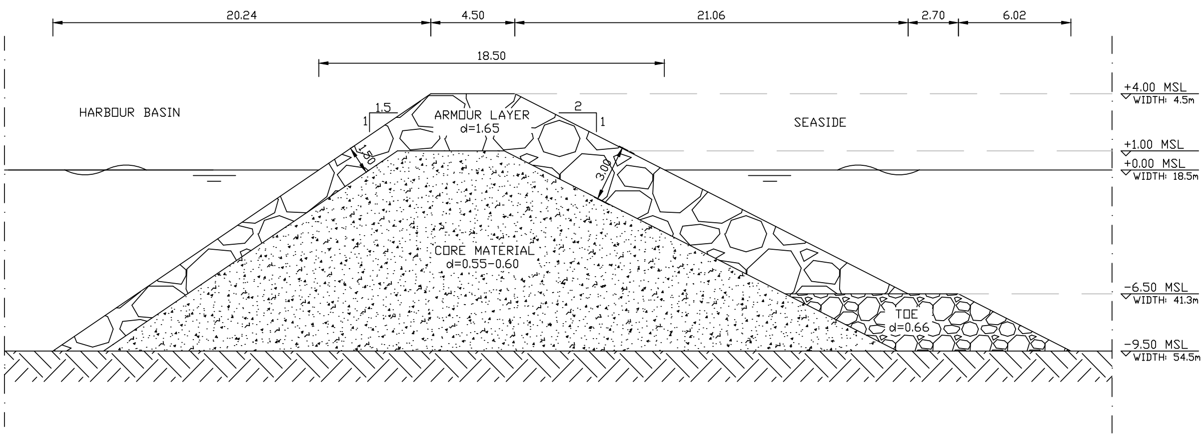


Figure 49: Section A-A' breakwater dimensioning (own illustration)

A remark to the proposed breakwater design is the lack of available wave data, the applicability of the proposed breakwater design is therefore highly uncertain. Further explanation on the breakwater design can be found in Appendix N.

Quay wall

A block wall, which is a gravity based structure, is considered as most suitable type of quay wall for this design. A cross-section of the quay wall design, together with its dimensions, can be seen in Figure 50. The technical details of the quay wall are based on the fact that the quay wall is located at the end of the reef, as most of the quay wall will be constructed here. A strong foundation layer is required as this block wall has a large mass. At the end of the reef, the soil profile consists of one meter dense coral gravel, followed by 1.5 meters of weathered material. This total of 2.5 m from both layers need to be dredged. Calculations and substantiations of the dimensions are elaborated in Appendix O.

The dredged area will be filled with a gravel backfill to increase the foundation strength. Since the characteristics of the reef are very uncertain, it is assumed that part of the reef behind the quay wall needs to be removed as well. After constructing the quay wall, the area will be filled with sand to reclaim land. To prevent sand flowing through the quay wall, geotextile will be placed on the backside of the block wall. The structure needs a minimum width of 3.7 meters and needs to be embedded one meter in the soil in order to guarantee stability. A concrete slab of 0.3 meters will be placed on top of the quay wall to serve as working platform. This slab could be increased to a thickness of 0.8 meters when it is required, due to sea level rise or increasing boat sizes, for instance.

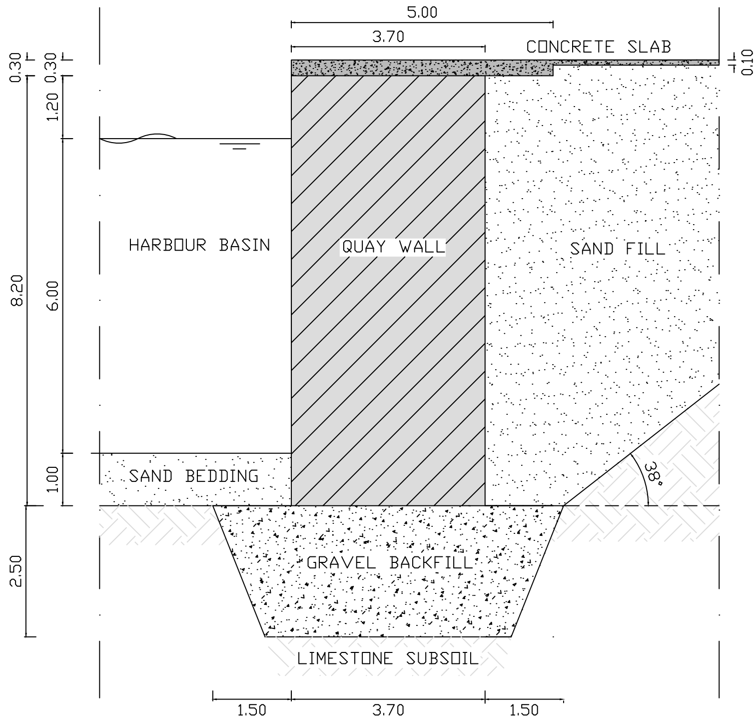


Figure 50: Section B-B' quay wall dimensioning

Based on the ground analysis, it is determined that sliding failure and overturning moment are the two normative failure mechanisms in the quay wall design. After design calculations on these two failure mechanisms, it can be concluded that the provided dimensions described above and presented in Figure 49, guarantee a safe quay wall.

Jetties

Four separate jetties are constructed in the final design. Two of those jetties will be constructed in the area designated for the IDAY boats, the two others will provide berthing places for the IMUL and IIMUL boats. The two jetties used by the IDAY boats will have a total length of 130 m. The jetties will be placed parallel to the shore, and will be connected to shore by a connecting jetty, constructed perpendicular to the shore. This connecting jetty will not be used for berthing. The total jetty length for the IMUL and IIMUL boats will be 665 m. Appendix P elaborates on the calculations of the dimensions of the jetties. The jetties are designed in such a way that during the fishing season, IMUL and IIMUL boats can berth parallel to the jetty. During the monsoon, these boats will be stacked to provide enough berthing area. The spacing between the jetties is composed of the minimum width of the (stacked) boats and the channel width to provide an easy navigable area. For jetties located near breakwaters an additional safety area is provided. This safety zone accounts for wave overtopping and the slope of the breakwater.

As no unloading activities will take place at the resting jetties, no (large) vehicles are allowed on the jetties. This makes floating jetties the most suitable, as these jetties adapt to the tides.

Onshore constructions

The constructions will be located on the reclaimed land; a homogeneous sand layer with an average thickness of 2.5 meters. As this soil is strong, the structures will be build on a raft foundation. From Appendix Q, it is proven that the area of the structures already provides enough strength to bear the expected loads by the structures. Therefore, the raft foundation has the same size as the areas of the structures.

4.1.3 Construction costs

Previously, when comparing the alternatives, a cost estimation was made for the multi criteria analysis by simple calculations and assumptions with only the breakwater material, the quay wall length and amount of dredged material as variables. The additional construction costs, including labour and equipment were neglected. For the final design a more accurate cost estimation will be provided.

FCG ANZDEC and RDC (2017b) computed a cost analysis in the feasibility study of the PPTA harbour design. As these corporations based their cost estimations on recently completed local projects, these unit prices are assumed to be correct for the price estimation of the final design. The precise calculations and price-subdivisions are elaborated upon in Appendix M. The results of this estimations are presented in Table 20: the total costs of the harbour elements. The total price of the harbour is the sum of all individual elements, this sum is €45,542,000.

Table 20: Total construction costs of the Point Pedro harbour

Construction	**Costs**
Dredging	€8,923,000
Breakwater	€5,751,000
Quay wall	€23,500,000
Jetties (50-year design)	€4,934,000
Harbour facilities	€2,434,000
Total	**€45,542,000**

4.1.4 Risk analysis

An important aspect of the design process is a risk analysis to provide a contingency plan and to identify possible threats. In this way the consequences of the risks, during and after construction of the harbour, might be foreseen and can be reduced in advance.

The most important risks that might occur during construction, and over the lifetime of the harbour, are elaborated and divided into six categories (PESTLE): political, economic, social, technical, legal and environmental risks (Leijten, 2017). The risk analysis is provided in Table 21, the possible threats are described and scaled.

Each risk is described by the aspects of cause, risk event and consequence. The risk is then assessed by scoring the probability of occurrence and the impact on the development of the harbour, its environment or its stakeholders. The scores used in this assessment are explained in the legend at the top of the risk analysis table. After the initial response it is determined which stakeholder owns the risk and what the appropriate response should be to reduce or avoid the risk. Thereafter, the risk is assessed with the implemented response and again scored by applying new values for the probability or impact of the original risk. In the last column, the secondary/residual risk is considered, which is the risk that arises or remains after the risk response. Finally, the magnitude of each risk is defined to identify the most important risks. The three risks with the highest scores are discussed below.

The risk with the highest score is "The local people might protest against the government for providing permits for the harbour construction". This risk is scored high because the majority of the citizens are not in favor of the construction of the harbour as they are content with the current situation. Initially, in the PPTA design report, it proposed a harbour 400 m east of the current location, but the local people opposed to a harbour, as their most important landing site would have to be demolished. Even though the harbour is shifted, most of the local people are still not in favor of the project and protests could lead to delays or even cancellation of the project. To reduce the probability, it is suggested to implement the wishes of the local people in the development process and to find an optimal solution in which all parties are content.

The second biggest risk event is "The harbour might not provide enough protection against extreme weather conditions, as the harbour is not designed for tsunamis and cyclones". As nature can not be controlled, it is impossible to reduce the probability. However, the impact should be controlled as much as possible. One manner to reduce the impact is to do additional forecasting in extreme weather scenarios with the use of advanced technology. If extreme weather conditions are known in advance, evacuation measures and damage control actions can be undertaken. The harbour authority should establish an evacuation plan, as well as indicating how to protect vulnerable parts of the harbour.

The third biggest risk event is "The harbour capacity may exceed or be smaller than the fleet size that is currently expected". Due to the recent conflict, the fishery industry in the Northern Province has dropped significantly. Although data before the conflict is available, the design values of the harbour capacity in the future are highly uncertain. Worst case scenario is that there might be no demand for the use of the harbour and the harbour construction will be a total loss. The probability of this risk can be reduced by incorporating an uncertainty for future growth in the design. This can be done by constructing the harbour in several phases so the harbour can adapt to the demand. Another possibility is to reduce uncertainty by undertaking extensive research. By conducting a questionnaire under the local citizens and fishermen, the current demand can be analysed.

Score (scale)	Probability	Time	Cost	Quality
1 (very low)	1-10%	< 3%	< 0,5%	Minor impact on secondary functions
2 (low)	11-30%	3-6%	0,5-1%	Minor impact on overall functionality
3 (medium)	31-50%	6-9%	1-2%	Some impact on key functional areas
4 (high)	51-70%	9-12%	2-3%	Significant impact on overall functionality
5 (very high)	71-99%	> 12%	> 3%	Very significant impact on overall functionality

Table 21: Risk analysis

Nr.	Category	Risk Description			Pre-response Assessment		Risk Owner	Risk Response	Post-Response Assessment		
		Cause	Risk Event	Consequence	Probability	Impact			Probability	Impact	Secondary risk / Residual risk
1	Political	India is currently fishing in Sri Lanka's territorial waters in the Bay of Bengal.	Conflicts might occur between fishermen of both countries due to overfishing.	The harbour is overdesigned because of the decrease in fish production of the fisherman.	3	3	Government of Sri Lanka	Reduce the probability of conflicts by implementing strict laws in the Bay of Bengal.	1	3	The future economic growth of the harbour might be less than predicted.
		The citizens of the Northern Province are Tamils, while the harbour will be constructed by Sinhalese people. As the civil war ended recently the Tamils do not have confidence in the government.	Tamil people may demonstrate and create obstructions that might hinder the construction and operation phase of the harbour.	Delay of construction time and limited harbour operations.	3	2	MFARD	Reduce the probability by involving Tamil people from the beginning of the project and illustration the benefits, like the increase in job opportunities.	2	2	Involving more stakeholders might increase the complexity of the decision making process.
2	Economic	The recent conflict within the country has decreased the fish production significantly in the Northern Province.	The harbour capacity may exceed or be smaller than the fleet size that is currently expected.	Harbour design is not optimal.	5	3	MFARD/ EML	Avoid problems by conducting extensive research on the expected growth of the fishery sector.	2	3	If the extensive research is still insufficient, expensive adjustment may need to be done after the harbour has been built.
		The economy of Sri Lanka is growing.	The inflation might be larger than expected, which increases the costs of future expenses.	The fund is not sufficient to conduct future expansions. Therefore, the harbour will not be able to fulfil the future demand.	2	3	MFARD/ ADB	Avoid by including sufficient margin within the tender/ fund for unexpected events.	1	3	ADB might not want to grant more fund.
		Fish is a homogeneous commodity, meaning that for customers there is no difference between fish from different suppliers.	The price of fish might drop as a result of when the supply of fish increases while the demand of fish is not.	Production cost may exceeds the price of fish.	1	3	Government/ Fisherman	Transfer the problem to the government by temporarily funding local fishermen	1	1	Longer periods of low fish price might exceed funds to local fishermen
3	Social	More fisherman will fish in the same fishing zone because the harbour is also designed for the fisherman in the Jaffna district, instead of solely for the Point Pedro fisherman.	Local people might not be in favor of the non-local fisherman, due to decreased fish catch.	Local fishermen oppose against the project because they are content with the current situation and don't want non-local fisherman around.	2	3	Local fisherman/ MFARD	Reduce disagreements between the fisherman by dividing individual fishing zones for fisherman, corresponding with the current fishing zones.	1	3	There might be less demand to use the harbour of (un)loading purposes.
		Fisherman need to pay harbour fees if they want to make use of the facilities and the resting area in the harbour	Fisherman might be unwilling to pay the harbour fees and might use one of the two current landing sites.	Decrease in the amount of boats in the harbour, reducing the income.	3	2	Harbour authority	Reduce the probability by asking realistic harbour fees that (poor)fisherman are willing to pay	2	2	The income for the harbour might be less than expected.
		The traffic within Point Pedro town will increase.	The current infrastructure might not be able to cope with the increased traffic demand.	Local residents will oppose against the project.	4	2	Government of Sri Lanka/ Local residents	Reduce the impact of the increased traffic by adapting/ improving the current infrastructure to the expected traffic increase	1	2	The income of the harbour might be less than expected.
4	Technical	Over the years the size of vessels is increasing to adapt to future growth.	The harbour might not be able to provide enough manoeuvrability area and quay wall length for the enlarged boat sizes.	Large boats will not be able to enter the harbour and should (un)load and rest in another harbour. Harbour design is not optimal.	2	3	MFARD	Reduce the impact by making an adaptable design that can accommodate large boats in the future.	2	1	Even if the harbour can adapt to the increase in boat size, the capacity might not be sufficient anymore.
		The characteristics of the dredged material are uncertain.	It might be possible that the dredged material will not satisfy the conditions or the amount of material that is needed for the breakwater construction.	Not enough material of sufficient quality is available to construct the breakwater, which causes a delay in construction time.	3	3	MFARD	Reduce the impact by importing material from a quarry.	3	1	Importing from a quarry might cause some unexpected delays and costs.
		Weathered limestone that is found at the project location contains karstic features.	Locations of karst are highly unpredictable and might be present below the quay wall, breakwater and/or jetties.	Damage to the structures can occur, resulting in additional cost and limited harbour operations.	2	4	MFARD	Reduce the probability of karst below structures by doing more extensive soil investigation.	1	4	When extended soil research is provided, the probability of occurring karst will get lower. However, the probability will still exist.
		The soil and reef consist out of heterogeneous materials.	Due to a lack of information, the soil is assumed uniform. However, due to heterogeneity the material might be weaker than the used parameters suggest.	The structures constructed on top can become unstable, which can cause damage.	3	2	MFARD	Avoid by performing extended soil research that provides enough data to acquire a range of values for soil parameters and variability coefficients of the soil.	1	2	Unexpected circumstances might still occur.
		A gravity based quay wall is constructed by stacking concrete blocks which are linked together.	The blocks might be linked improperly.	Failure of the quay wall.	1	2	Construction company	Reduce the impact by designing additional linking measures to increase safety.	1	1	The design of the quay wall might be overestimated and therefore inefficient.
5	Legal	A certain amount of local people are not in favor of the construction of the harbour.	Local people might protest against the government for providing permits for the harbour construction.	Postponing the start of the project or cancellation of the harbour.	4	5	MFARD	Reduce the probability by enhancing to the wishes of the local people and try to find a compromise in the designing stage of the project.	2	5	Negotiations might take a long time, .which can cause a delay in the start of the project.
		Sri Lanka is a democratic republic where the parliament is elected once every six years.	It might be that the parliament will change the policy, certain laws or legal rules, which are not in favor of the project.	Increase in costs and delay of the project.	3	3	Government	Reduce the probability by formulating of a multi year plan to increase the economy of Sri Lanka in which the laws and legal rules during multiple years are stated.	1	3	There might be conflicts between different elected parliaments over the years resulting in even longer delays.
6	Environmental	During and after construction there will be an increase in traffic and waste material, influencing the air quality and water quality.	Due to an increase in pollution, the conditions of the water and air quality might become unfavourable for some species.	Decrease of the biodiversity, flora and fauna and general living conditions.	4	2	Harbour authority	Reduce the impact by formulating rules for waste material disposal and amount of CO2-emission	4	1	There might be an increase in cost for local fisherman as they need to adapt their boats to the new legislation.
		The current ecosystems at the harbour will be damaged during and after construction.	Species might lose their habitat and go extinct in the Jaffna District.	Decrease in biodiversity.	2	4	MFARD	Reduce the impact by adapting to the environmental issues, as stated in Chapter 4.2: *Harbour Impact*, by creating new types of habitats.	2	1	It might be that the nature does not adapt to all the artificial environment measures as expected.
		Due to climate change, the sea level is rising and more storm surges occur.	The height of the breakwater and quay wall might not be sufficient for extreme sea level rise and extreme storm surges.	Damage of the harbour and limited operation.	1	4	MFARD	Reduce the impact by increasing the breakwater height and quay wall height when the increase of sea level rise and storm surges turn out to be higher than the 50-year design values	1	2	The costs for adapting the breakwater and quay wall might be so high it will not fit within budget.
		Sri Lanka is located at a location that is vulnerable for extreme weather scenarios like tsunamis and cyclones.	The harbour might not provide enough protection against extreme weather scenarios, as the harbour is not designed for tsunamis and cyclones	Damage of the harbour and limited operation.	4	5	Government	Reduce the impact by investing in weather forecasting to be able to take evacuation measures in advance when extreme weather is forecasted.	4	4	The harbour might still not be able to withstand extreme weather conditions. Hoverer, the amount of damage can be reduced.

4.2 Harbour impact

An important aspect of the harbour design is the way the harbour fits in its current surroundings. As can be expected, the presence of a harbour this size will have a big impact on the infrastructure that connects the harbour to other parts of the country, as well as on the surrounding flora and fauna. Also, a great emotional impact can be expected, since the presence of a harbour will influence many. These different impacts must be understood and anticipated upon. In this paragraph, the potential problems are presented, as well as possible solutions. Those solutions can be infrastructural, e.g. broadening of the roads, dredging maintenance or management solutions, e.g. stakeholder management, governmental policy.

4.2.1 Infrastructure

First of all, the possible problems which may occur concerning the infrastructure will be evaluated. As the harbour will produce a large amount of fish in the future (see 2.4 Fishery industry on page 18), the traffic will increase at the same rate. This can cause trouble when the current road network cannot accommodate the rise in traffic in the future.

Figure 50 shows the main trade routes currently leading from and to Point Pedro. As shown, the main trade routes will lead in the direction of the Jaffna District, the Western Province, the Central Province and the Eastern Province. Because all the routes originate in Point Pedro, all in- and outgoing traffic will have to use the same few roads present in the Point Pedro town. Currently, the infrastructure is not designed for such an increase in traffic, which means the roads will have to be adjusted and the routes need to be redesigned.

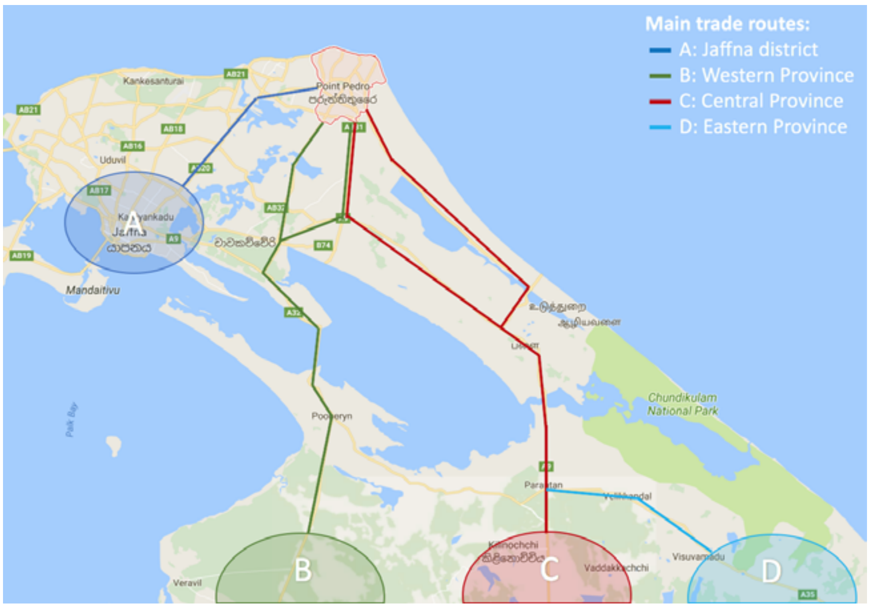


Figure 51: Infrastructure Northern Province scale 1:5000 m (own illustration, derived from Google Maps, 2017)

A more detailed view of the current infrastructure is given in Figure 51. It shows that most trading routes will use the main road that runs straight through Point Pedro town. This is due to the fact the road through town is a well-maintained, smooth and asphalted road, whereas the road which travels along the coastline is bumpy and narrow, which limits the speed of traffic.

A solution for this issue is shown in Figure 52. By expanding and improving the road along the shoreline, trading routes A, C and D can almost be fully redirected. This will result in less traffic having to pass through Point Pedro town, as only traffic towards the Western Province will be obliged to use the road through Point Pedro town. Also, some traffic heading towards the Central and the Eastern Province might use the central road.

Figure 52: Infrastructure Point Pedro district 1:500 m (own illustration, derived from Google Maps, 2017)

Figure 53: Infrastructure Point Pedro district 1:50 m (own illustration, derived from Google Maps, 2017)

This will not solve all problems occurring in Point Pedro town, as still, traffic within town will increase. Therefore, next to expanding and improving the road along the coastline, the road running through town also needs to be widened. This however, is limited to a certain extent due to the houses and public facilities that are built alongside the road.
Figure 52 also shows the main pressure points that will be the result of the presence of the Point Pedro harbour and the expansion of the road network as proposed in the same figure.

These points are displayed by use of numbers and are as follows:

1. The intersection of the main trading routes and the entrance of the harbour need to be redesigned in order to cope with the traffic increase;
2. Increased traffic along the shoreline on the west can create nuisance for the Methodist Girls High School, which is located close to the harbour and along route A;
3. This small road will most likely be used in case of a traffic jam on the central road in Point Pedro and therefore needs to be adjusted to demotivate traders to use the road. However, if the traffic increase continues in the future, this road can be adjusted so it can be used as a bypass of the main route through Point Pedro;
4. Because the main route runs along two sides of the Point Pedro's main square it might become a bottleneck, which creates nuisance for the local residents;
5. Shops and dwellings along the road block further expansion possibilities.

The explanation, attention points and possible solutions to the pressure points listed above, are described in Appendix R.

4.2.2 Flora, fauna and emotional value

Both during and after construction, the harbour will have a big impact on the flora and fauna, as well as on the local residents in the Jaffna region. Most impacts, especially during construction, will be negative. However, some changes might also benefit the flora, fauna or local residents in the area. An overview of all possible impacts are given in Table 22. In the first column, the impacts are categorised in four values, which are: harbour values, environmental values, cultural values and emotional values. The second column provides the actual impact or change, and in the columns three and four, the impact is scored from - - - to + + + compared to the current situation. Below Table 22, the the harbour, environmental, cultural and emotional values are further explained by elaborating on several impacts.

Table 22: Impact of the harbour

	Impact of harbour	During construction	After construction	Explanation
Harbour values	Food provisioning	- -	+ +	Amount of fish that can be caught and brought into the harbour.
	Model for future fishery harbours	+	+ +	The Point Pedro harbour can set an example for future fishery harbours in Sri Lanka on how to manage, build and maintain a modern fishery harbour.
	Education in fishery	- -	+ + +	The possibility to transfer knowledge about modern and sustainable fishing.
Environmental values	Water quality	- -	- -	The disposal of waste (material), fuel leakage, etc.
	Air quality	- - -	- -	Exhaust gasses, dust, removal of trees and plants.
	Sediment transpor-tation	-	0	Erosion and sedimentation of the shoreline.
	Coastal protection	+	+ + +	Providing shelter against incoming waves.
	Ecosystem	- -	0	The changes in the current ecosystem of the coastal region around Point Pedro.
Cultural values	Aesthetics	- -	+	Changes in current coastline for locals.
	Recreation	- - -	-	Change of shoreline, new recreation possibilities.
	Tourism	0	+	The possibility to attract tourism to Point Pedro and its surroundings.
Emotional values	Overall nuisance	- - -	- -	Increase in traffic, people, noise and stray animals.
	Job opportunities	+ +	+ + +	During construction and after increase in demand for shops, maintenance and facilities.

Harbour values

Currently, the ins and outs, skills and knowledge about fishing are passed on from fisherman to fisherman by verbal communication and practical experience. During the construction phase of the harbour however, it will not be possible to use that particular area for fishing education. When the harbour will be in its operational phase, the government plans to teach the local residents on how to fish in a sustainable way and how to increase the amount of fish caught per boat per day. This is described in the PPTA under Output 3 (FGZ ANZDEC & RDC, 2017b). This output describes the plan of the government of Sri Lanka to invest in training, as well as providing easy access to bank loans and to support new businesses. Because there is land allocated to accommodate future expansion within the perimeter of the harbour, it might be possible to build a fishery school inside the harbour. In this school, high quality education about the fishery industry, the impact of fishing on the marine environment and innovative and sustainable fishing methods can be given. This will positively influence the local community in the long term.

Environmental values

The sediment transport will change as the breakwater shape influences the current streams, especially during the north eastern monsoon period. East of the breakwater the shore will erode, while west of the breakwater sedimentation will take place. This change can affect the current landing sites next to the breakwater. East of the harbour the beach will erode, decreasing the resting area for current fishery boats. However, as the main breakwater is located more than 300 meters offshore, this erosion will be very limited near the harbour. On the western side, sedimentation can increase the amount of space at the current west landing site. The positive and negative effect of the change in sediment streams respond to a neutral net-value. However, when dredging maintenance is taking place in the harbour, the dredged material can be used to enlarge the eroding landing site at the eastern breakwater.

Due to the changes in the local environment, habitats and ecosystems will be disturbed. During construction, the coral reef will be removed and dredging activities will take place. The local ecosystems at the current shoreline will be negatively influenced. At the coastline, the beach and trees will be removed as well, which again has a negative impact on the local environment. However, after construction, the rock armour of the breakwater will provide new habitat opportunities for species, creating new ecosystems. Next to that, the harbour will increase the amount of birds, as additional food resources will arise.
To increase the biodiversity even more, salt marshes can form naturally west of the breakwater as sedimentation will occur. Salt marshes can create liveable habitats for species and the sea grasses on top of the marshes reduce wave height. Another artificial way to stimulate the biodiversity is to plant vegetation in the available space between the breakwater and the jetties. Due to the slope of the breakwater, this area will not be suitable as sailing area and will therefore be quite undistorted. The advantage of vegetation inside he harbour is the increase in species it will lead to and as for most species, waste material and algae will serve as food (Slinger & Tas, 2017). Therefore, this results in a higher water quality.

Cultural values

Currently, the coast at Point Pedro consists out of (weathered) landing sites and beaches. The flat coastline creates a large view along the sea. During construction, large cranes and equipment will deteriorate this view immensely. After construction, the view will be partly blocked by the 4 m high breakwater. Local residents are not in favour of the change of view from sea to harbour. However, currently the area is weathered and messy. With the implementation of the new harbour, more facilities are provided, creating more structure. It is suggested that the harbour authority should make a strict plan in consensus with the police about waste disposal, giving fines when not acted accordingly, in order to keep the area clean and neat.

Tourism is hardly existing in the Northern Province, especially at Point Pedro, since not much touristic attractions and facilities are present in the area. The Point Pedro harbour can increase the amount of liveliness in the area, which will also indirectly contribute to tourism. As more people visit Point Pedro, more tourists will get to know the area and may also decide to visit this part of the country. Furthermore, if the government of Sri Lanka decides it would like to invest in tourism in the Northern Province, the Point Pedro harbour can be one of the focus points. The harbour itself can be the starting point of touristic activities on sea, as well as onshore. Examples can be fishing trips, whale spotting tours, a luxury fish restaurant or cooking classes or even a combination of those activities. When tourism increases in the Northern Province, this may also lead to an increase in touristic facilities such as hotels, restaurants and shops.

Emotional values

The relatively 'quiet' Point Pedro area, will change drastically in the field of nuisance. During and after construction, traffic will increase as well as the amount of bustle and noise. Especially during construction heavy trucks and equipment will create a lot of noise, (air) pollution and other nuisance. After construction, the amount of traffic will increase compared to the current situation and as more people will work in and around the harbour, more bustle will take place, especially at the auction halls and the workshop.
In front of the harbour a local authentic girls school is located. This school is not in favour of the new harbour development plan as the classes will be disturbed majorly by the nuisance caused by the harbour. The school is old and very appreciated by the locals. The influence of the local people is taken seriously and can cause large problems, see 2.5 Stakeholder analysis.

Most residents in Point Pedro live from the fishing industry. As the harbour will drastically increase the amount of boats and the amount of fish caught, job opportunities will arise and the unemployment rate in the area will decrease. There are lot of different opportunities local residents can benefit from, both during the construction of the harbour as well as during the operational phase. Also, the harbour can help residents to get higher paid jobs within the harbour compared to staying fisherman, if they would like so.

4.3 Stakeholder engagement plan

In this paragraph, it will be determined which stakeholders need to be engaged and which stakeholders need to be disengaged. As described in 2.5 Stakeholder analysis, the identification of the stakeholder issues is the start of the stakeholder engagement plan. The construction of the harbour comes with three main issues that have to be dealt with. These three issues are; (1) the exact location of the harbour, (2) the design of the harbour and (3) the use of the harbour. All issues can be subdivided in two or more subissues, which form the basis of defining the strengths, weaknesses, opportunities and threats (SWOT) of the project. This SWOT-analysis will then be transformed into a TOWS-analysis in order to create strategies. After the SWOT- and TOWS-analysis have been conducted, the problems and solutions are coupled and a final stakeholder engagement plan is set up, which is the conclusion of the entire stakeholder analysis.

4.3.1 SWOT- and TOWS-analysis

A SWOT-analysis is conducted to find the strengths, weaknesses, opportunities, and threats of the project. The SWOT-analysis can be seen in Table 11. To transform the SWOT-analysis to a situational analysis with clear objectives, a TOWS-analysis is conducted. A TOWS-analysis is used to find measures and mitigations to built on the strengths, eliminate the weaknesses, exploit the opportunities and mitigate the threats. In a TOWS-analysis, you (i) use your opportunities by optimizing strengths, (ii) maximise strengths to minimize threats, (iii) minimize weaknesses to optimize opportunities, and (iv) minimize weaknesses to minimize threats. This analysis can be seen in Table 12.

Table 11: SWOT-analysis

	Helpful	**Harmful**
Internal	Strength 1. Facilities will improve by building the harbour. 2. The infrastructure in Point Pedro will be renewed, which improves the connectivity and accessibility of the town. 3. A new harbour can be used by bigger boats (IIMUL). 4. The consequences of storm surges are reduced because of an optimal breakwater design. 5. The breakwaters protect the fishing boats from waves. 6. The waste of fish will be reduced due to the better facilities on shore. 7. Constructing a new harbour will create job opportunities.	Weakness 1. Fishing communities can counteract the construction of the harbour, since they are not in favor of the project. 2. The harbour will create nuisance to local residents. 3. For the local fishermen and residents, it is unclear where the profits are going. 4. Current IDAY fishermen need to anchor their boats further away from their home. 5. Lack of information of the surroundings could lead to mistakes in the design. 6. Lack of data on the hydraulic, environmental and geological conditions. 7. Two threatened species will have less habitat.
External	Opportunity 1. The harbour in Point Pedro can contribute to the amount of fish caught in Sri Lanka. 2. A new harbour can attract more tourists if touristic facilities are included in the design. 3. Economy growth can create opportunities for minorities in the area. 4. The fish production and revenue at the Point Pedro harbour can increase when the harbour is shared with other fishing communities. 5. The harbour can become a new overseas connection between Sri Lanka and India. 6. The breakwater can provide a new habitat for different kind of species. 7. Additional research in sediment transport, erosion, geology and marine biodiversity could bring new important insights of the project location.	Threat 1. The project might be unsuccessful if the fleet size differs significantly from the 50-year design values. 2. The design of the breakwater will change the water currents, which will cause erosion and sedimentation at different areas. 3. External fishing communities could also make use of the harbour, which could negatively influence the fish caught by local fishermen. 4. The harbour, the boats and the facilities might be damaged or destroyed by an earthquake, tsunami or cyclone. 5. Foundation structures may be placed directly above sinkholes due to insufficient geological research. 6. The new harbour might lead to overfishing in the Bengal Bay. 7. Political issues can occur when Indian fishermen also use the Sri Lankan territorial waters to fish.

Table 12: TOWS-analysis

TOWS	**Opportunity** *(external, positive)*	**Threat** *(external, negative)*
Strength *(internal, positive)*	**(i) Maxi-Maxi strategies (SO)** 1. Tourist facilities, like a seafood restaurant, fishing trips and harbour tours can be included in the design of the harbour. (S1-O2) 2. Reducing the loss of caught fish will decrease the fish that gets thrown away, which can be a leading example to other (planned) fishery harbours in the country. (S6-O1) 3. A bigger harbour provides job opportunities, which will improve the local economy. (S7-O3) 4. Upscaling the harbour size attracts IIMUL boats from other fishing communities, which increases the revenue of the harbour. (S3-O4)	**(ii) Maxi-Mini strategies (ST)** 1. Encourage the local fishermen to use IIMUL boats, in order to increase the chance of a successful harbour. (S3-T1) 2. The design and layout of the breakwater entrance can provide shelter against high waves inside the harbour. (S4-T4) 3. Improving the infrastructure will create (job) opportunities for local residents because more fish will be sold in the Jaffna District. (S2-T4) 4. The political issues between India and Sri Lanka about Indian fishermen using Sri Lankan territorial waters can be reduced by asking different harbour fees. (S3-T8)
Weakness *(internal, negative)*	**(iii) Mini-Maxi strategies (WO)** 1. Show the local fishing communities that their living conditions and economical situation will improve, in order to increase their support towards the project. (W1-O3) 2. Create opportunities for the local fishermen and residents (like entrepreneurial skills), as there is more money to spent in the region due to a better economy. (W3-O3) 3. Provide new habitats in and around the breakwater for different kinds of species, to counteract the negative influence of the change in water currents have on the fauna in the area. (W7-O6) 4. Perform additional research on the hydraulic environmental and geological conditions to get a better understanding of the impact and the risks of the construction of the harbour. (W6-O7)	**(iv) Mini-Mini strategies (WT)** 1. Keep local fishermen involved during the entire process to make use of their knowledge and opinions, which will increase the chance the harbour will become successful. (W1-T1) 2. Minimize the erosion and sedimentation problems by regular dredging, so the ecological nuisance to the local residents will be minimized. (W2-T2) 3. Perform extra geological research to identify ground layers specifically and reduce the chance of emerging sinkholes. (W5-T5) 4. Create a clear plan of where the profit of the harbour will go to, in order to keep the local fishermens on board of the development plan of the harbour of Point Pedro. (W3-T3)

4.3.2 Coupling of problems and solutions

The knowledge gained by the SWOT- and TOWS-analysis can be used to compilate the engagement plan. By scoring and ranking the outcomes of the TOWS-analysis, the opportunities can be prioritised. Then, the TOWS-analysis can be transformed into a policy by coupling problems and solutions in the engagement plan. The coupling of problems and solutions is as follows:

Coupling 1: Upsize the harbour (SO3, SO4, ST1, ST3)

Incorporating a future growth plan in the harbour design, makes it possible for the harbour to adapt to future changes. This is needed because the relatively high uncertainty about the size of the fleet size during the lifetime of the harbour. As in the future more and more IIMUL boats will be used in Sri Lanka, job opportunities in the region increase. A harbour capable of handling IIMUL boats also invites other fishing communities. However, this may lead to conflicts between local and foreign fishermen. By involving the local fishermen in the entire process and making sure their worries are heard, arising problems between local fishermen and foreign fisherman can be prevented.

Coupling 2: Increase local support by economical improvement (SO3, ST3, ST4, WO1, WO2, WT4)

Local fishing communities will not immediately like a new harbour. However, by providing the local community a well working harbour and facilities, the fishing capacity will also increase, which will have a positive economic effect on Point Pedro. To solve the issue between local fishermen and other fishing communities, higher fees can be introduced that apply to foreign fishermen. The extra income generated can partly be used to educate the local community by teaching them entrepreneurial skills. Furthermore, the government could help the fishermen with the transition from IDAY to IMUL and IIMUL boats by providing loans with a beneficial rate.

Coupling 3: Improve the facilities and supply chain within the harbour (SO1, SO2, ST2)

Building new facilities and expanding the current facilities could engage several stakeholders. First of all, better facilities and technologies will reduce the loss of caught fish due to a better supply chain. This will increase the profits of the fishermen and reduce waste. Furthermore, this also keeps the marine ecosystem healthier. Secondly, by expanding the current facilities with touristic facilities like a seafood restaurant and a tourist organization for local activities such as fishing, the MTDCR can be engaged. By making Point Pedro more touristic, the local economy will grow, which will also offer new job opportunities for the local community.

Coupling 4: Increase local support by reducing ecological nuisance: WO3, WT2

Support of local residents and fishery communities can be increased by optimizing natural habitats for fauna and flora by making use of the breakwater as a new habitat. Also, by dredging regularly erosion and sedimentation problems will be minimized, which reduces ecological nuisance. This might change the view of local residents and fishery communities regarding the project in a positive manner.

Coupling 5: Perform additional research (WO4, WT3)

By performing additional research regarding the hydraulic, environmental and geological conditions, new information can be obtained. This will help getting a better understanding of the potential severity of disaster situations such as near shore flooding, storm surges, tsunami inundation and long-term scenarios of coastal erosion and sea level rise. This information could help prevent damages and limit the consequences by implementing this knowledge into the proposed plan.

4.3.3 Stakeholder engagement plan

A stakeholder engagement plan is used to determine how to engage or disengage stakeholders in order to change their interest, power or attitude, if wanted. Engagement can be done by offering them something or by defining the problem in a broader perspective on basis of the outcome of the SWOT- and TOWS-analysis. Disengagement can be done by taking away their concerns or by making them irrelevant to the project. Options for (dis)engaging stakeholders are: 'Inform', 'Consult', 'Involve', 'Collaborate' and 'Empower'.

EML Consultants → Collaborate

EML Consultants' task is to develop a 'Detailed Design', which means they collaborate with the other 'Players' (ADB, MARD, CFHC) in order to make a successful project. As the main consultant, their advice and ideas need to be incorporated as much as possible. Because it is important for EML Consultants to develop a safe and well-performing harbour, it is is important to them that the design contains no mistakes. Therefore, they will back-up coupling 5, and will collaborate with the other parties on coupling 1, 2, and 3.

ADB → Collaborate

ADB is in a special position because they fund the project. All decisions made by MFARD or EML Consultants have to receive approval by ADB. This means that they have a lot of blocking power in the process. The ADB needs to be closely collaborated with to make sure their advice and recommendations are incorporated to the maximum possible extent. In fact, all couplings have to pass the ADB. However, they will be closer involved to coupling 1 and 3, as these are additions to the current scope of the project.

MFARD → Empower

The MFARD acts for the Sri Lankan government and is the client of the project. Because they decide what is implemented, they need to be empowered. They need to be closely involved with all five couplings as they make the final call. This means MFARD has great blocking power and should therefore be constantly involved in every decision.

CFHC → Involve

CFHC is the end user of the harbour and is therefore a 'Player' within the proces. During the development of the harbour, they need to be involved to ensure their ideas and initiatives are considered and reflected in the alternatives considered. This can be done by giving feedback on how, and to what extent, their ideas are reflected in the harbour design. They need to be involved with couplings 1, 2 and 3 since these all have effects on the final harbour design. Even though they are players, their blocking power will be very limited.

Governmental authorities → Consult

The governmental authorities' main focus is to make sure the regulations regarding the environmental impact are maintained. During the development process they need to be consulted in order to keep them informed and to let them provide feedback on the design. As a 'Time Bomb' they are a passive blocker and need to be closely monitored to make sure they do not become active. They will be involved with coupling 1 and 4, as these can have a negative impact on the environment.

MTDCR → Consult

MTDCR's current role within the project is negligible; they are insignificant with no blocking power and are passive. However, they are a backer of the project and can be engaged by involving them in coupling 3. Their interest in the project can increase by widening the scope of the project by adding touristic facilities into the final design, which can attract new investments for the project. Therefore, they need to be consulted during the development process.

Divisional Secretary of Point Pedro → Consult

The Divisional secretary of Point Pedro sees opportunities in the project to develop the Point Pedro area. This makes them an important backer, as they can influence the opinions of the local fishing communities and residents. They mainly need to be consulted with regard to coupling 2 and 4, which both have an influence on the local community. If they form a united front together with the other locals, they can become a blocker of the project. Therefore, it is important to consult them during the project to make sure they are informed and their opinions are considered in the design.

Fishing communities → Involve

The fishing communities are, together with CFHC, the end user of the harbour. Because they are not a backer of the new harbour, it is important to involve them in the development process to ensure their worries are heard and reflected in the proposed alternatives. They are involved in all couplings. Since they will try to block coupling 1, they need to be engaged to make them support the project. This will be done by offering them other assets as described in coupling 2, 3 and 4.

Local residents/landowners → Inform

Just like the fishery communities, the local residents will initially oppose against the project. Alone they will not have any blocking power, but they can form a uniform front with the other local groups against the project. To prevent this, they will be informed during the entire development process. Also, with the help of coupling 2 and 4, their support can be increased.

NGO's → Inform

NGO's are not involved in the project yet, but they still have to be considered in the engagement plan. They can become a blocker of the project when the project has negative impacts on the environment. By complying to the environmental regulations of the ADB and the governmental authorities, the NGO's can be disengaged. However, it is important to keep them informed of the project to prevent any unexpected involvement.

4.4 Implementation plan

In this paragraph a plan is proposed to optimize the harbour efficiency during and after its lifetime. Figure 54 gives an overview of all construction and maintenance activities that are required in the harbour for an optimal use during its lifetime. This planning also consideres the critical risks, which are determined in the risk analysis. Furthermore, a plan has been made on the required construction activities to adjust the 50-year design into a situation that is suitable for a period longer than 50 years.

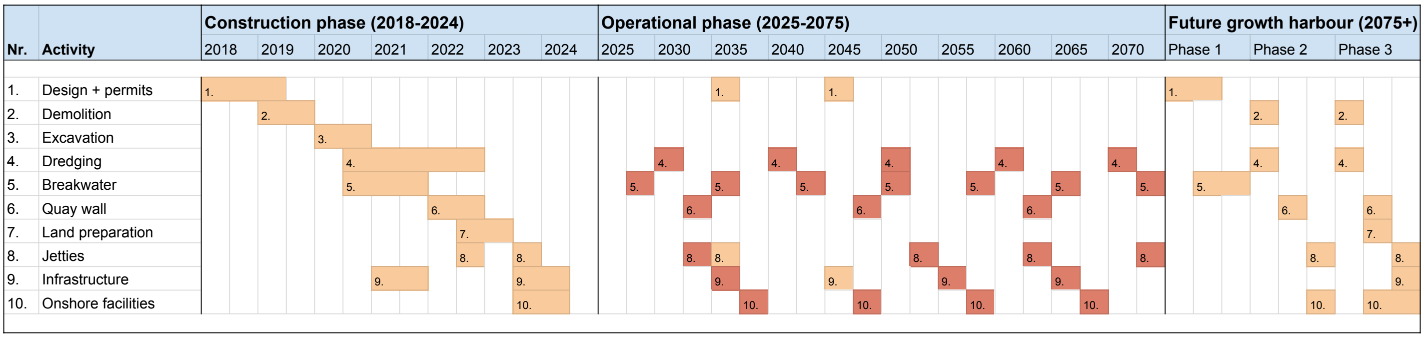


Figure 54: Timeline implementation plan (2018 - 2075+)

As can be observed in Figure 54, the timeline has been divided in three parts; the construction phase, operational phase and the future growth of the harbour. In paragraph 4.4.1 the construction sequence of the Point Pedro harbour has been described. Paragraph 4.4.2 describes the required maintenance and expansion during the lifetime of the harbour. Last, paragraph 4.4.3 describes the construction activities required to make the harbour suitable for a longer lifetime than the currently proposed 50 years.

4.4.1 Construction

Figure 54 shows a planning that is based on minimizing the construction time, taking environmental circumstances into account. It has been assumed that construction inside the harbour is difficult during monsoon time. This is shown by the grey column in every first quarter of a year.

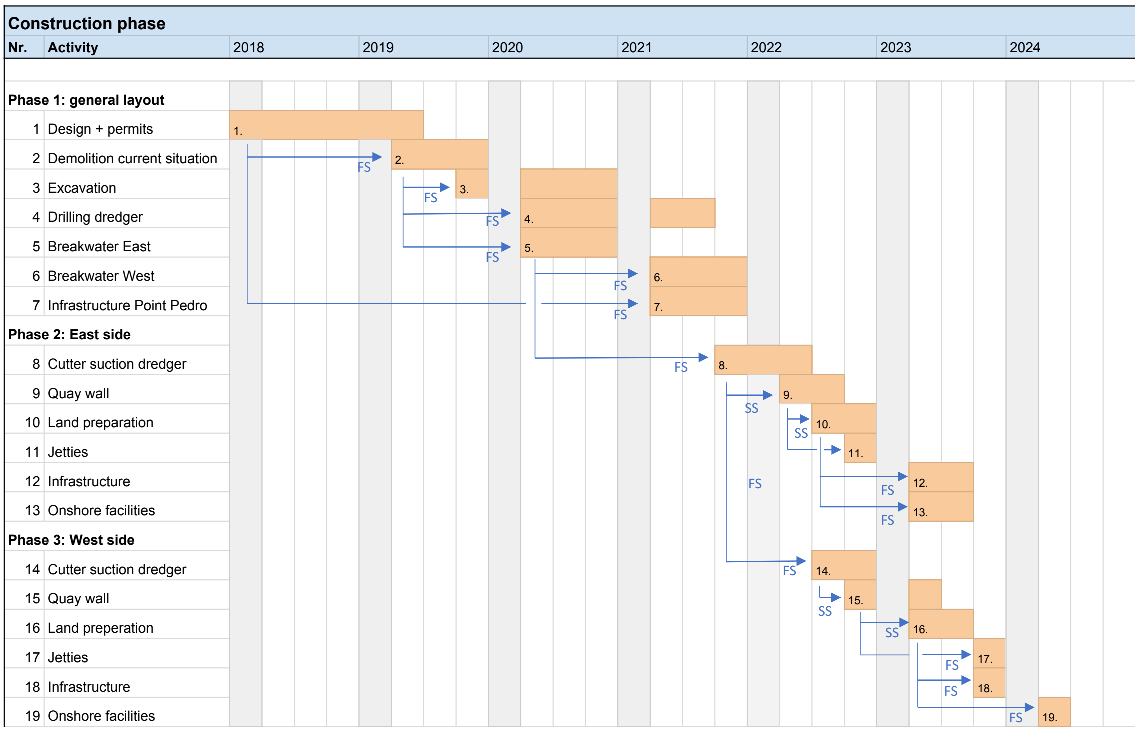


Figure 55: Planning construction phase (2018-2024)

As can be observed in Figure 54, the construction of the harbour consists of roughly three phases; (1) the general layout, (2) east side construction and (3) west side construction. The construction sequence of the harbour is explained using these three stages in the following of this paragraph.

Phase 1: General layout

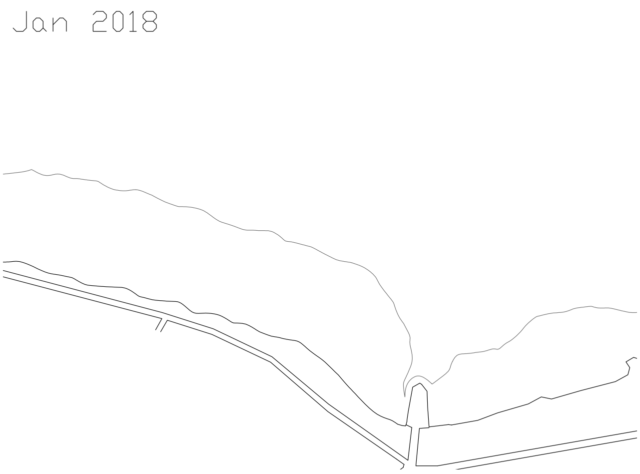


Figure 56: Harbour implementation phase 1A

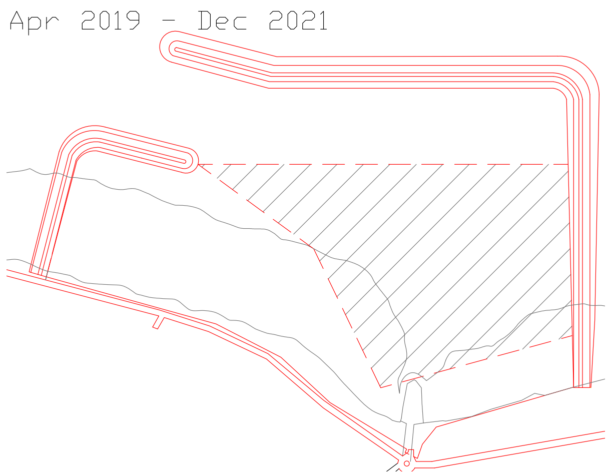


Figure 57: Harbour implementation phase 1B

In this phase the general outline of the harbour will be constructed, meaning that the harbour breakwaters and the surrounding infrastructure will be made (Figure 56). The phase is started by developing an extensive structural design and obtaining the required permits for the harbour. The real construction works start in 2019 by deconstructing the current coastal infrastructure (Figure 56). After the largest part of the deconstruction works is finished, excavating and dredging activities will be started. Dredging activities will take place in the hatched area in Figure 56, while the highly weathered top layer of the reef will be excavated. Also, the construction the east breakwater starts at this time. Boulders recovered from excavating and dredging can immediately be used as core and toe material of the breakwater. After the east breakwater is constructed, the construction of the west breakwater will start. Both breakwaters will be constructed during quiet weather conditions. It has been calculated that the amount of limestone recovered during excavation and dredging in phase 1 is sufficient for completion of both breakwaters. The second important activity in phase 1 is the construction and replacement of the infrastructure in Point Pedro. By replacing the infrastructure before the other phases start, construction traffic can already make use of the new infrastructure and nuisance for locals during construction will be reduced.

Phase 2: East side construction

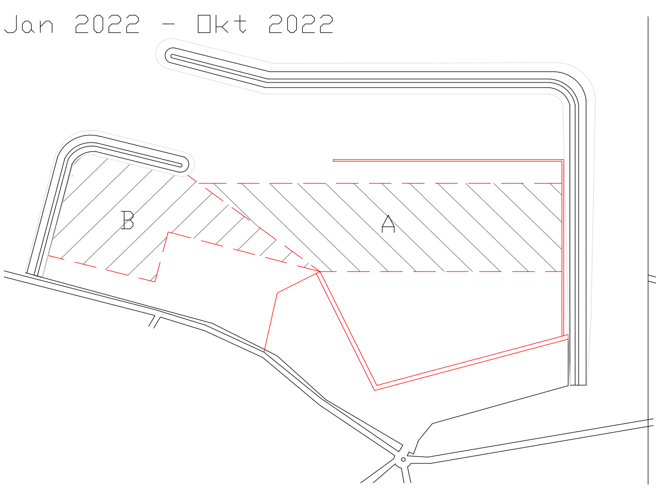


Figure 58: Harbour implementation phase 2A

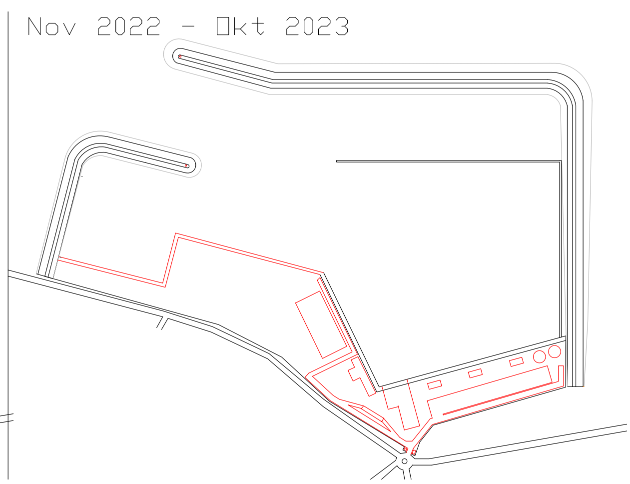


Figure 59: Harbour implementation phase 2B

The second construction phase is mainly focussing on getting the east side of the Point Pedro harbour operable as soon as possible. This phase starts with reclamation of the land on the east of the harbour (Figure 57). The material required for this land reclamation is obtained from dredging activities in area A (Figure 57). This material can be dredged using a cutter suction dredger, for example. When the dredging activities in the east of the harbour are finished, the cutter suction dredger can go to the west side of the harbour to dredge area B. Dredging in area A starts at the east breakwater, slowly travelling towards the west. The dredged sand will be dumped onshore and can later be used for the land reclamation behind the quay wall. After some lag, the construction of the quay wall will be started, proceeding from the east towards the west. When the quay wall has been (partly) constructed, the hinterland can be filled and the land can be prepared for onshore construction activities. The land preparation starts at the east breakwater at the same time dredging takes place and the quay wall will be construction. The proposed construction sequence optimizes the time, without making the construction process more complex. The onshore construction can be started after the land preparation is finished. When the onshore construction and infrastructure are finished, the east side of the harbour is ready for use. The harbour will be partly operable from November 2023. During finalizing the eastern part of the harbour, construction activities will start in the western part. When area A in Figure 59 is completely dredged, the dredging equipment will move towards area B and recovered sediment from this area will be used for the land reclamation on the west.

Phase 3: West side construction

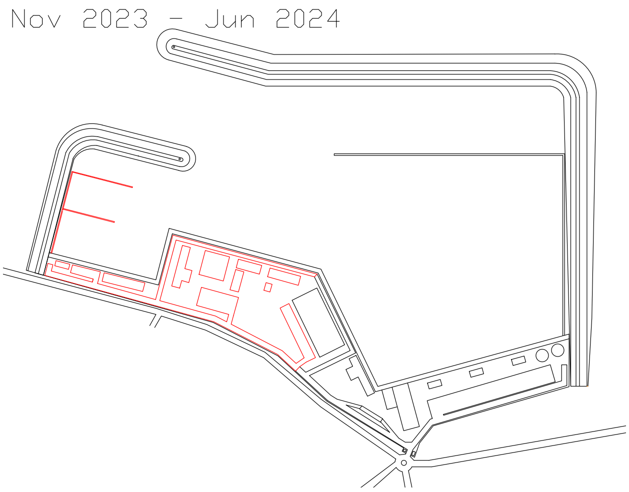


Figure 60: Harbour implementation phase 3A

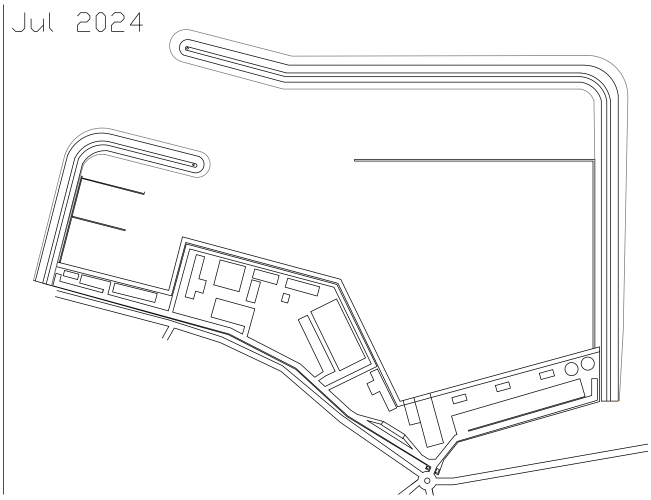


Figure 61: Harbour implementation phase 3B

The east side of the harbour is already in use during a part of phase 3. In the meantime, construction works in the west of the harbour will be continued (Figure 59). After obtaining the required basin depth, the quay wall will be constructed. When the quay wall is partly finished, the land preparation will be started. Just like in phase 2, this sequence of activities will propagate towards the east. After finishing all land preparations, the construction of the infrastructure and jetties in the west side of the harbour will be started. The construction of the jetties is expected to be finished before 2024 monsoon, which allows IDAY boats to shelter during this monsoon. The onshore facilities however, are not build at that time yet. These construction works will start after the monsoon period, leading to an expected completion date in June 2024. The harbour will be fully operational from July 2024 (Figure 60).

4.4.2 Operational phase

After the construction of the harbour is completed, the harbour will be fully operational in 2025. The operational phase stretches out from 2025 until 2075, a period that is equal to the required lifetime of the harbour. The planning of this phase is shown in Figure 61.

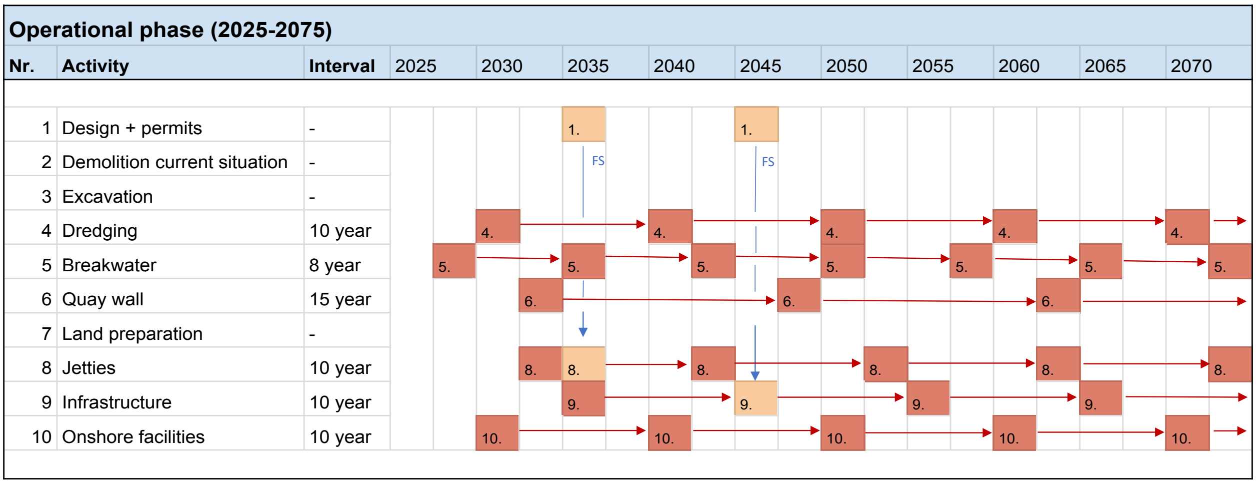


Figure 62: Planning operational phase (2025-2075)

Even though this phase mainly contains maintenance work, it also contains two construction activities that will take place in 2035 and 2045. These activities are shown in orange in Figure 63. In 2035, the jetties will be expanded in order to meet the increasing demand of the harbour. This jetty will be built at the east side of the harbour and will accommodate IMUL boats. The activity in 2045 is the adjustment of a bypass-road on the main trading route through Point Pedro town. This adjustment will be needed to prevent traffic jams in the town centre and will be the responsibility of the local authorities.

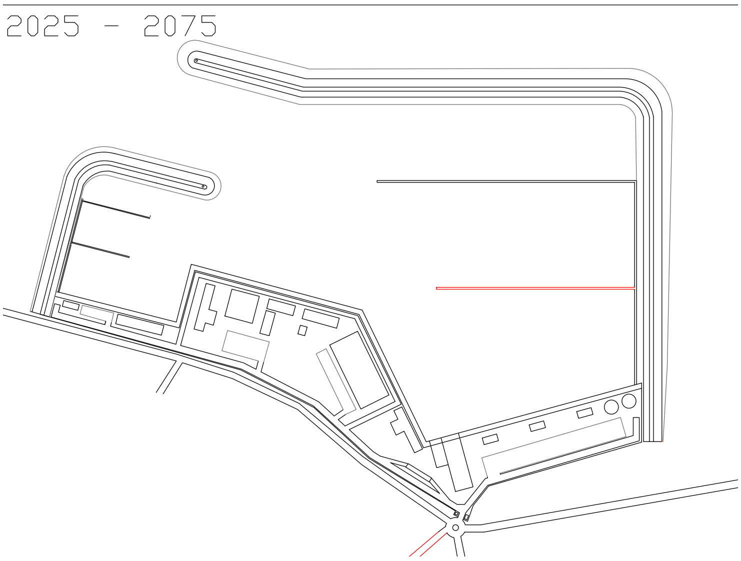


Figure 63: Construction activities during the operational phase

During these 50 years, all constructions need maintenance in order to prevent structural damages. It is proposed to do dredging maintenance every ten years, to remove inflowing sentiment and to keep the harbour basin at a sufficient depth. For the breakwater, maintenance mainly consists of monitoring erosion every eight years. If erosion takes place, the toe of the breakwater needs to be supplemented with small boulders. The quay wall needs to be monitored and checked on erosion every fifteen years. Also, visual inspection on the concrete quay wall is needed every fifteen year. Not only do the jetties need to be expanded in 2035, they also need maintenance every ten years for painting works and the replacement of rotten and damaged parts. The infrastructure within the harbour also needs maintenance every ten years, to repair cracks in the pavements and to fill holes in the road. Finally, the onshore facilities need to be maintained every ten years to make sure they withstand the rough sea conditions for at least the lifetime of the harbour.

Besides these two construction activities and the yearly maintenance, several additions can be made to the design which are concluded from paragraph 4.2 Harbour impact and 4.3 Stakeholder engagement plan. Not only is it better to construct the harbour in several phases to stay in line with the demand, also some additional buildings can be constructed to engage stakeholders in a positive way. A first addition that can be made during the operational phase is to design and construct a fishery school, where fishermen can share their knowledge and new and innovative fishing techniques can be taught to improve the quality and quantity of caught fish. A second addition is the construction of a seafood restaurant, a fishing tour organisation and a guided tour through the harbour. By the help of these facilities, tourism can improve in the area when the harbour is fully operational and the economy in the region is already increasing. These facilities could be located in Point Pedro town or in area C (as can be seen in Figure 64), designated for future growth of the harbour.

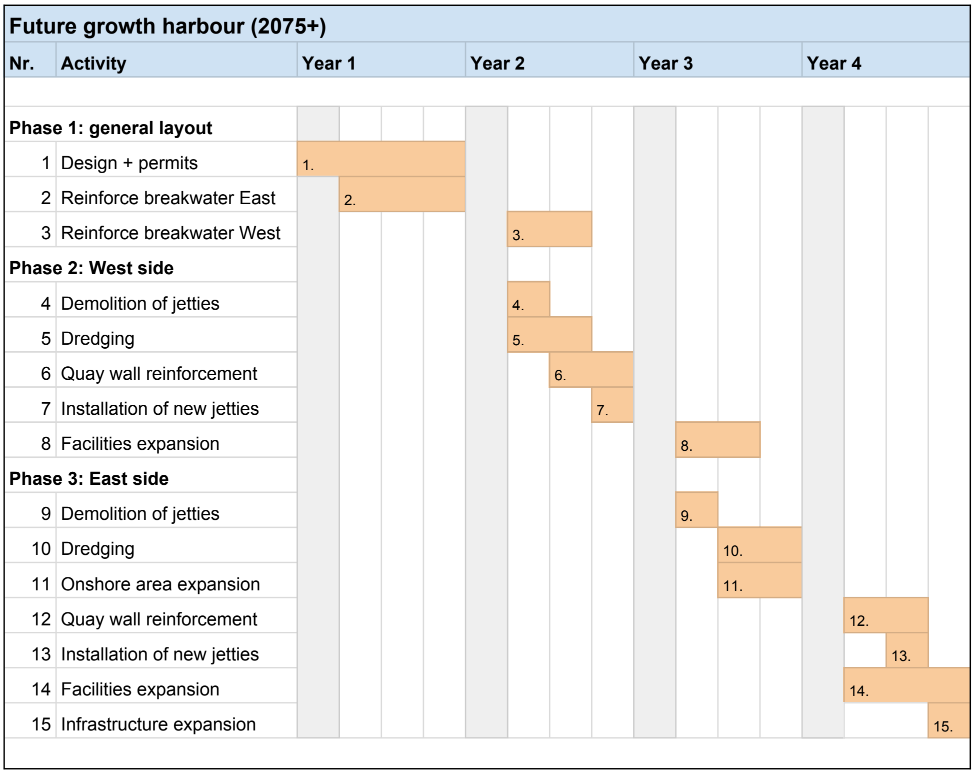


Figure 64: Planning future growth of the harbour (2075+)

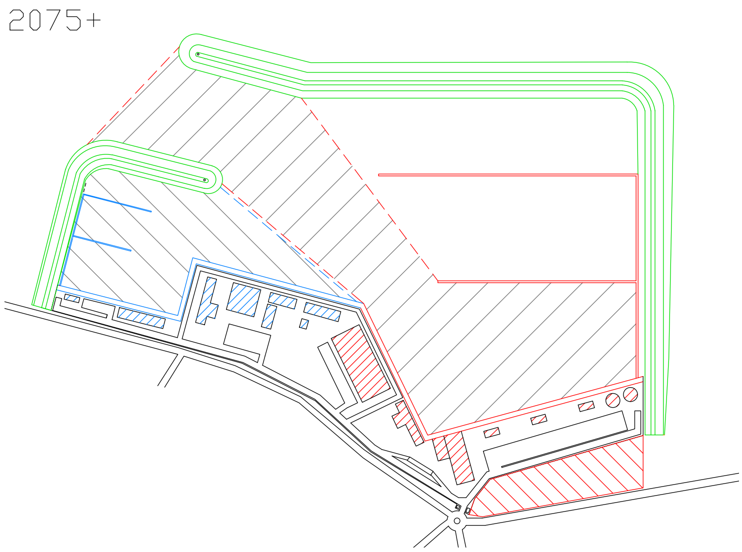


Figure 65: Three different phases for future growth of the harbour

4.4.3 Future growth

In 2075, both the construction and operational phase have passed, which means the harbour is at the end of its current design lifetime. From this moment on, the 50-year design values do not longer apply on the harbour. Obviously, the harbour will continue operating beyond 2075, and therefore the future growth of the harbour has also been accumulated for in this implementation plan. The first issue covered is climate change, which causes further sea level rise and an increase storm intensity. Harbour elements are currently not designed for this scenario, resulting in structural safety problems. The second issue is that vessels are constantly increasing in size. In order to accommodate these vessels in the harbour, several structures (harbour entrance, quay wall and jetties) might need to be adjusted.
As shown in Figure 63, the future growth activities have been split up into three phases: (1) general layout, (2) west side and (3) east side. These three phases are further elaborated on in Figure 64, which displays phase 1 in green, phase 2 in blue and phase 3 in red.

Phase 1 consists out of the adjustment of the general layout of the harbour. First, the design has to be made and permits have to be retrieved for all three construction phases. Then, both the breakwaters on the east and west side will be reinforced to be able to meet increased safety requirements. Also, the entrance between the breakwaters will be widened in order for larger vessels to make use of the harbour. The construction of this phase starts with the east breakwater, in order to give immediate shelter for vessels in case of an increase in intensity of the storms during the northeast monsoon.

Phase 2 will start directly after the reinforcement of the breakwater on the east side is finished. In this way, the harbour will always be partly operational: the west side will be fully operational during phase 1, while the east side is only partly operational during phase 1 and fully operational during phase 2. During the reinforcement works of the breakwater on the west side, the old jetties will also be deconstructed, as the harbour basin needs to be dredged to a depth of 6 m in hatched area B. This is done because the harbour basin at that area might need to be able to accommodate both IMUL and IIMUL boats if the growth of the fleet size is continuing after 2075. After dredging has taken place, the quay wall can be adjusted to meet the future requirements. Also, the slab on top of the quay wall will be heightened from 30 cm to 80 cm in order to adapt to future sea level rise. During the reconstruction of the quay wall, the jetties will be newly built to be able to accommodate larger vessels. Finally, the facilities at the west side of the harbour will be rebuilt and adjusted to meet higher capacity demands.

Phase 3 will start after the jetties at the west side are constructed. Just like phase 2, the jetties will be deconstructed first, followed by the increase in depth of the harbour basin by dredging area B, which allows larger vessels to make use of the harbour. The dredged material will be used for land reclamation of the onshore area expansion at the south-east side of the harbour (area C). This onshore area may be needed for expansion of the onshore facilities in order to facilitate the increased fish production. After dredging and land reclamation is finished, the quay walls will be constructed, followed by the installation of new jetties. At this point, the type of jetties could be changed in order to allow more activities on the jetties. Finally, the facilities at the east-side will be rebuilt and adjusted.

Since the fishing industry in Sri Lanka is growing fast, growth numbers are difficult to predict. Besides that, it is also difficult to make prognosis about the effects of climate change. Due to the large uncertainty in these issues it is important that the implementation of the future growth plan is independent of time. When safety problems inside the harbour occur in the lifetime of the harbour, the construction of this plan can be started immediately.

4.5 Conclusion

The outcome of this chapter is the final design of the Point Pedro harbour. It consists of the master plan, expected harbour impact, stakeholder engagement plan and implementation plan. With the use of the requirements following from the MCA analysis in chapter 3, the master plan has been determined. The master plan makes use of the concept design 'building on the reef', while incorporating several aspects of the other alternatives. In this way, dredging operations and changes to the natural shape of the coastline are limited, while at the same time optimizing the harbour layout. The result of the master plan can be seen in Figure 65.

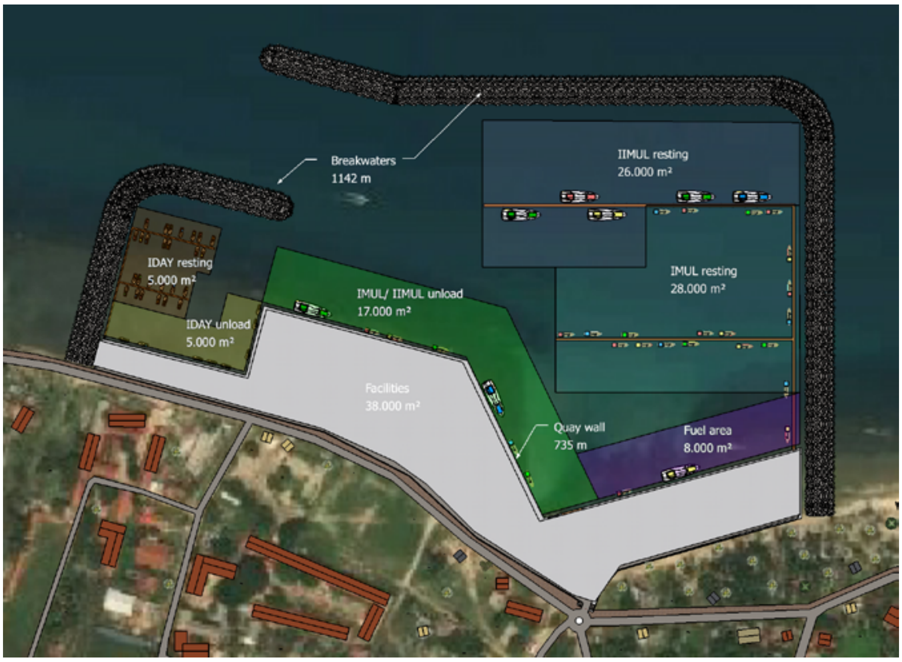


Figure 66: Top view of final layout

The position of the entrance channel is located central-west, providing shelter against incoming wind and waves while at the same time minimizing the sailing route. The capacity of the harbour is based on the 50-year design values of the fleet size. The east side of the basin will provide resting places and unloading facilities for the IMUL and IIMUL vessels. The west basin will be occupied by IDAY vessels and therefore will only be excavated to -2 meters MSL to minimize the required amount of dredging. Most facilities are located in the center of the harbour to optimize the supply chain within the harbour. The proposed jetties for IDAY boats have a total length of 130 meters, whereas the total jetty length of the IMUL and IIMUL boats together is 555 meter. The IMUL and IIMUL boats use the principle of stacking boats during monsoon times to minimize jetty length. However, during the fishing season these boats can berth parallel and stacking will not be required.

A cost estimation has been made for the construction of the harbour, which resulted in the approximated cost of €45.5 million. This price includes the purchase of the (imported) material, transportation costs, placement costs, overhead costs and labour costs.

Furthermore, a risk analysis is provided by making use of the PESTLE-method to indicate possible threats. The three largest risks found are; opposition of local communities, extreme weather conditions and uncertainty in fleet size. These risks can be mitigated by implementing the wishes of the local people during the development process, investing in better weather forecasting during extreme weather conditions, and by constructing the harbour in several phases to make sure the harbour is not over designed.

The impact on the infrastructure due to the presence of the new harbour is analysed on both a local scale as well as for the entire Northern Province. This analysis resulted in a list of five possible pressure points, such as the main square of Point Pedro and the the Methodist Girls High School, and also suggests adjustments to the present infrastructure to solve the problems regarding those pressure points. Next to the impact on local infrastructure, the impact of the harbour on the environment and the cultural and emotional values are discussed for both situations during and after construction. To improve these values, a fishery school can be implemented in a future growth plan, dredging will have to be carried out structurally and tourism can be exploited.

Conclusions can be drawn from the stakeholder analysis by conducting the SWOT- and TOWS-analysis. These analyses resulted in multiple strategies, which are then coupled as: (1) upsize the harbour, (2) increase local support by economical improvement, (3) improve the facilities and supply chain within the harbour, (4) increase local support by reducing ecological nuisance, and (5) perform additional research. The engagement plan described how all important stakeholders need to be (dis)engaged during the development process when implementing these strategies.

The implementation plan provides a timeline elaborating on the construction sequence and the operational phase. The most important conclusion from the construction planning is that the east side of the harbour can be operational one year before the west part of the harbour will be opened. In this way locals can observe the advantages of using the harbour instead of landing sites. During the operational phase, required maintenance and construction activities are described. Most important is that an extra jetty should be constructed after using the harbour for ten years to accommodate the increasing demand.

5. CONCLUSION

The last chapter of this report gives the final conclusions of this project. This will contain the overall conclusions and the limitations and recommendations. This conclusion also gives the answers to both the research question and subquestions.

Source: own picture, taken at Point Pedro

5.1 Conclusion

Finally, all information provided in the report can be combined into a final conclusion, on which this chapter will elaborate. To determine the optimal design of the new harbour at Point Pedro, the main research question will be answered. This question is as follows:

"How can safety, economic efficiency and environmental impact be combined optimally in a harbour design for Point Pedro in the Jaffna District?"

Figure 67: 3D-overview of the final harbour design

5.1.1 Subquestions

In order to answer this research question properly, it has been divided into five subquestions. These subquestions will be elaborated below, followed by the answer on the main research question.

The first subquestion 'What are the critical environmental conditions which have to be taken into account when designing a harbour at Point Pedro?' has been elaborated on in the analysis. This chapter described that Point Pedro is located in a sheltered shallow sea environment, protected by a coral reef parallel to the shore. Furthermore, monsoon winds define wet and dry seasons with different hydraulic characteristics, resulting in normative conditions during the northeastern monsoon period. In addition, it is expected that due to climate change, the sea level will rise and storm surges will occur more often and with an increase in magnitude, these conditions have to be accounted for in the final design. Just outside the coral reef the sediment transport is highest and sediment transport only occurs from east to west direction. The geology of the project location indicates the presence of a limestone base below the coral reef with expected occurrence of karst.

The second subquestion 'What is the optimal harbour design at the project location?' is based on requirements which are derived from the analysis. By comparing multiple alternative designs, in which the requirements are processed, characteristics are set for a most optimal design of the Point Pedro harbour. This optimal harbour design can be seen in Figure 66. The most important characteristics are: (1) a minimal sailing route, (2) a safe working environment, (3) optimal quay wall usage and (4) optimized dredging operations and (5) optimal harbour size. The sailing route is minimized by constructing the entrance in the center west of the harbour. It was not possible to have the entrance in the middle, because wave intrusion could harm the safety inside the harbour. By designing the entrance directed towards the west, normative wave directions are blocked and cannot intrude. Safety is also accounted for in the location of the fuelling quay wall, which is located in the west side of the harbour far away from the main facilities. Optimal quay wall usage is obtained by constructing the quay wall for IIMUL and IMUL boats in the center of the harbour. This quay wall is located close to the most important fish handling facilities. The IDAY boats are located in the west of the harbour and specific IDAY facilities will be located at this quay wall. By constructing the IDAY quay wall and IDAY resting places in the west of the harbour, the required dredging depth in this area is limited to two meters. The required harbour depth in the rest of the basin has to be equal to a depth of six meters, because this area will accommodate for IMUL and IIMUL resting in the northeast, and unloading and fuelling in the south of the harbour. Dredging operations are further minimized by designing land reclamation on top of the reef and having a sediment budget which is almost zero. Two basin depths are determined within the harbour, a shallow basin west and a deeper basin east. The harbour breakwater in the west is constructed in shallow water to minimize the construction costs and provides shelter for IDAY boats. The eastern breakwater is constructed to shelter IMUL and IIMUL boats.

The third subquestion 'What will be the impact of the harbour?' is answered based on the designed master plan. It is found that during and after construction, the amount of traffic will increase significantly, resulting in noise disturbance and air pollution. Also, the infrastructure needs to be improved to be able to cope with the increased traffic. The harbour itself will provide an economic impulse for the people of the surrounding villages. However, the local citizens will experience an increase in nuisance and a change of coastline view. Additionally, the construction of the harbour will also damage some habitats of several different species, due to the change in water currents and the demolition of a small strip of land close to shore. However, the breakwaters also provide a new living habitat for different kinds of species.

The answer to the fourth subquestion 'How should the most important stakeholders be engaged during the development process?' follows from the stakeholder analysis and the engagement plan. The five most important stakeholders are the Ministry of Fishery and Aquatic Resources Development (MFARD), the Asian Development Bank (ADB), EML Consultants, Ceylon Fishery Harbours Corporation (CFHC) and the local fishing communities. Multiple solution and problem strategies were conducted from the SWOT- and TOWS-analysis in order couple issues between these stakeholders. Five couplings were determined: (1) upsize the harbour, (2) increase local support by economical improvement, (3) improve the facilities and supply chain within the harbour, (4) increase local support by reducing ecological nuisance, and (5) perform additional research. The engagement plan is based on the implementation of these couplings into the development process. Because MFARD is the initiator of the project and executes the NPSFDP for the Sri Lankan government, they need to be empowered. The ADB funds the project, and therefore, all decisions made by CFHC and EML Consultants need their approval. Because of this position, they have a lot of blocking power. EML Consultants' task is to develop a detailed design, which means they collaborate with the other 'Players' (ADB, MFARD, CFHC) in order to make a successful project. As the main consultant, their advice and ideas need to be incorporated as much as possible. CFHC will operate the harbour after construction and for this reason their vision needs to be involved. The local fishing communities also need to be involved since they will be the end users in combination with the CFHC. If their opinion is not taking into account during the development process, they can become an important blocker against the project.

The fifth and final subquestion 'How can the master plan be implemented optimally?' is answered by proposing an implementation plan. This plan consists of a construction sequence, the operational phase and the future growth of the harbour. The construction phase (2018-2024) is divided in three phases; first the breakwater will be constructed to give shelter during the construction phase, then the construction works in the east side of the harbour will be started, and lastly, the construction in the west side will started. Constructing in several phases has three advantages; (1) the construction time and labour will be optimized, (2) there will be a sheltered and safe working environment after the breakwaters have been constructed and, (3) the east side of the harbour will be operational in an early stage. Fishermen will already be able to use the eastern part of the harbour, while the western part of the harbour is still under construction. Initially, the harbour is not able to accommodate the 50-year design values, this is done because there is a large uncertainty in the expected fleet size. During the operational phase (2025-2075), two construction activities are required to accommodate the design values; (1) constructing an extra jetty and (2) improving the infrastructure in Point Pedro. Also, a plan has been developed to accommodate for future growth after the lifetime of the harbour (2075+). Since a 50-year forecast is highly uncertain, a plan on the construction of harbour expansions and reinforcement is made, while keeping the harbour operable.

5.1.2 Research question

By combining all subquestions, the research question is answered. The determined optimal combination between safety, economic efficiency and environmental impact is implemented in the final design. Because these three criteria are conflicting, they can not be individually optimized in the final design. In order to solve this conflict, the three criteria are prioritized as follows: (1) safety, (2) economic efficiency and (3) environmental impact.

Safety is regarded as most important criteria, because a safe working environment has to be created. This is accounted for by applying the Dutch safety standards for the harbour design. During the design phase no compromise is made on incorporating these standards. Safety is provided by constructing breakwaters around the harbour. The breakwaters provide sheltered water conditions in the harbour basin. Also, the harbour entrance is constructed so that monsoon waves can not directly intrude into the basin. In addition, all facilities are located on shore and will not be hindered by overtopping waves during storm surges. And last, fuelling facilities are located away from the fish handling facilities and repair shops.

Economic efficiency is the second most influencing criteria and is best when construction costs are minimal and returns are maximal. The returns of the harbour will be highest when the harbour layout is optimal. In the final design this is accounted for by constructing the quay wall of IDAY, IMUL and IIMUL boats close to the central located fish processing facilities. This optimizes the supply chain, resulting in a smaller loss (compared to the current situation) in the fish production. Economic efficiency is also established by expansion possibilities in the harbour design to accommodate future growth. A costs minimization has been obtained by finding the minimum required material for the land reclamation and construction of the breakwater. Furthermore, the implementation plan provides an efficient planning to minimize construction time and costs. The location of the harbour entrance is minimizing the sailing routes as much as possible. However, it is not optimal as from a safety point of view a harbour entrance with an opening directed towards the west is required.

The last criteria is environmental impact as the influence on the final design is smallest, compared to the other criteria. A way of limiting the environmental impact will be involving local fishermen and residents during the entire development process. Other negative impacts of the harbour can be either mitigated or minimized. For instance, negative environmental effects can be mitigated by adding new vegetation around the harbour to increase biodiversity. Cultural values can be enhanced by implementing tourism within the implementation plan and harbour values can be improved by implementing facilities for educational purposes. However, as the environmental impact is the last criteria, not every issue can be solved. For instance, the problem regarding the Methodist Girls High School cannot be resolved, because the landing sites are valued to be more important than the school. If the landing sites would be demolished, more objection from local fishermen will be faced and the harbour construction may be endangered.

To conclude, the proposed master plan is found to be the optimal combination of safety, economic efficiency and environmental impact. Implementing this plan at Point Pedro gives best possibilities for stimulation of fishery at Point Pedro. Which could result in an economic impulse for the Jaffna District and the Northern Province.

5.2 Recommendations and Limitations

This paragraph describes the recommendations and limitations of the report, which are both based on the conclusions made in paragraph 5.1. First, recommendations are formulated for EML Consultants on how to proceed with the Point Pedro project. Secondly, the limitations of the performed design study are discussed.

5.2.1 Recommendations

As concluded, the design as shown in Figure 66 is considered to be the most optimal combination for the harbour design of Point Pedro, regarding the criteria of safety, economic efficiency and environmental impact. It is recommended to EML Consultants that applying this design, or at least implement certain characteristics, into their design of the Point Pedro harbour will be beneficial. It is recommended to definitely implement the following characteristics of the proposed final design masterplan in the Point Pedro harbour project:

- Apply the 'building on the reef' concept (alternative 2), because it reduces the amount of dredging of the limestone reef compared to the other alternatives;
- Cluster the fish processing activities as close as possible to the unloading quay walls is found to be a strong point of the design and therefore it is advised to implement it in their design;
- Construct jetties for IMUL and IIMUL boats in the same shape as described in the proposed design. Implementation of the jetties in this shape has two big advantages: firstly, during the fishing season the jetties will provide sufficient length for parallel berthing, creating easy navigation in the resting areas; and secondly, during the monsoon time all boats can berth at the jetties. In this case the boats will berth side-by-side, stacked six to nine times.

Other recommendations are obtained by conducting a risk analysis, a harbour impact study, determining a stakeholder engagement plan and implementation plan. These recommendations are not directly included into the masterplan of the final design. However, they do contain aspects that improve the safety, economic efficiency and environmental impact of the design. Not only during the development process, but also during the construction and operational phases. These recommendations are as follows:

- Involve local fishermen in the harbour development process to use their knowledge and to make them willing to use the harbour after construction, as this is essential to the success of the fishery harbour;
- Expand the current facilities with touristic facilities like a seafood restaurant and a tourist organization for local activities such as fishing. By making Point Pedro more touristic, the economy will grow, which will also offer new job opportunities for the local community;
- Expand the infrastructure in Point Pedro town to prevent traffic jams, which cause nuisance for local residents;
- Construct the design in several phases in order to make the east side of the harbour operational in an early stage;
- Incorporate a future growth plan in the harbour design to cope with the uncertainty in the future fleet size;
- The government should help the fishermen with the transition from IDAY to IMUL or IIMUL boats by providing loans with beneficial rates;
- Solve the issue between local fishermen and other fishing communities by introducing higher fees that apply to foreign fishermen. The extra income generated can partly be used to educate the local community by teaching them entrepreneurial skills;
- The harbour authority should establish an evacuation plan, as well as indicating how to protect vulnerable parts of the harbour. If extreme weather scenarios are known in advance, evacuation measures and damage control actions can be undertaken;
- Improve values regarding the harbour impact by implementing a fishery school in a future growth plan, carry out dredging activities structurally, and exploit tourism.

5.2.2 Limitations

Besides all the recommendations, this design study also contains some limitations. These limitations are not directly visible in the final design. However, they do need to be taken into consideration when continuing with the design. The known limitations that are present within this design are:

- Limited data was available on several topics within the analysis phase. For instance, it was not possible to conduct a reliable wave analysis because not enough measurements were available, resulting in an unreliable breakwater design. Also, for the geological analysis, insufficient data was available; only one borehole inside the harbour domain was known. Consequently, variability is missing in order to make a reliable geological risk assessment. The expected fleet size used for the harbour design is also uncertain, as it is only based on average numbers of the whole country. Besides that, specific data for the Northern Province including the Jaffna district was not available;
- The precise calculations and data of the PPTA design were not available. Data of the PPTA report is assumed to be correct in our research. However, much of this data is not elaborated in their report. Therefore, our research might not correspond to the data assumptions provided by FCG ANZDEC and RDC;
- The cost estimation also has a limitation, as it is only based on the largest construction works. The additional costs resulted by delays, permits, infrastructure changes and unforeseen expenses are neglected in this price estimation, resulting in a relatively low final price estimation for this harbour design. Additional expenses might also include changes in facilities and investments in harbour equipment.
- The breakwater outline of the harbour might influence the sedimentation and erosion of the nearby landing sites, but the effects are difficult to predict. What is missing is a 2- or 3-dimensional water systems model, for example Delft3D, which predicts the effects of the implementation of the harbour on the landing sites and the coastline near Point Pedro;
- A water circulation model inside the harbour is missing, which gives insight in the effects of the current breakwater position. Due to the shallow water in the west basin and the sheltered setting due to the reclaimed land, there might be a water circulation problem. Wastewater and waste material will naturally be retained in this part of the basin, decreasing the water quality and increasing maintenance activities;
- No safety assessment has been made on the harbour entrance location. It has been assumed that the harbour entrance located central-west would lead to safety problems, because of wave intrusion. This estimation has not been grounded by any water systems model;
- It was not possible to conduct field research and interviews during our site visit to Point Pedro because we were asked not to talk to any locals, due to a conflict between MFARD and the local residents/fishermen at that time. Therefore, important information that could have been obtained from a questionnaire is missing;
- The material used in the core and toe of the breakwater is all excavated or dredged at the project site. It is assumed that this material is suitable for the breakwater design, but more information on the soil characteristics is required to find if limestone reef can be used as breakwater material. Also, the applied dredging methods are not extensively evaluated on its applicability for this specific project;
- Resource management, in which suitable areas to dispose waste material and material import locations are determined, is not conducted. Because regulations in Sri Lanka prohibit import of material and equipment out of specific countries and areas, it is important to sort this issue before it becomes a problem during the construction phase.

Most of these limitations can be resolved by doing additional qualitative and quantitative research, such as numerical modelling, geological research, economical feasibility and questionnaires. It is critical to conduct this additional research before this, or any other, harbour design is constructed at Point Pedro. If no further research is performed, surprises in the construction and operating phase of the harbour could lead to large unexpected costs, loss in quality and major delays. These consequences could harm the safety, economic efficiency and environmental impact of the harbour design.

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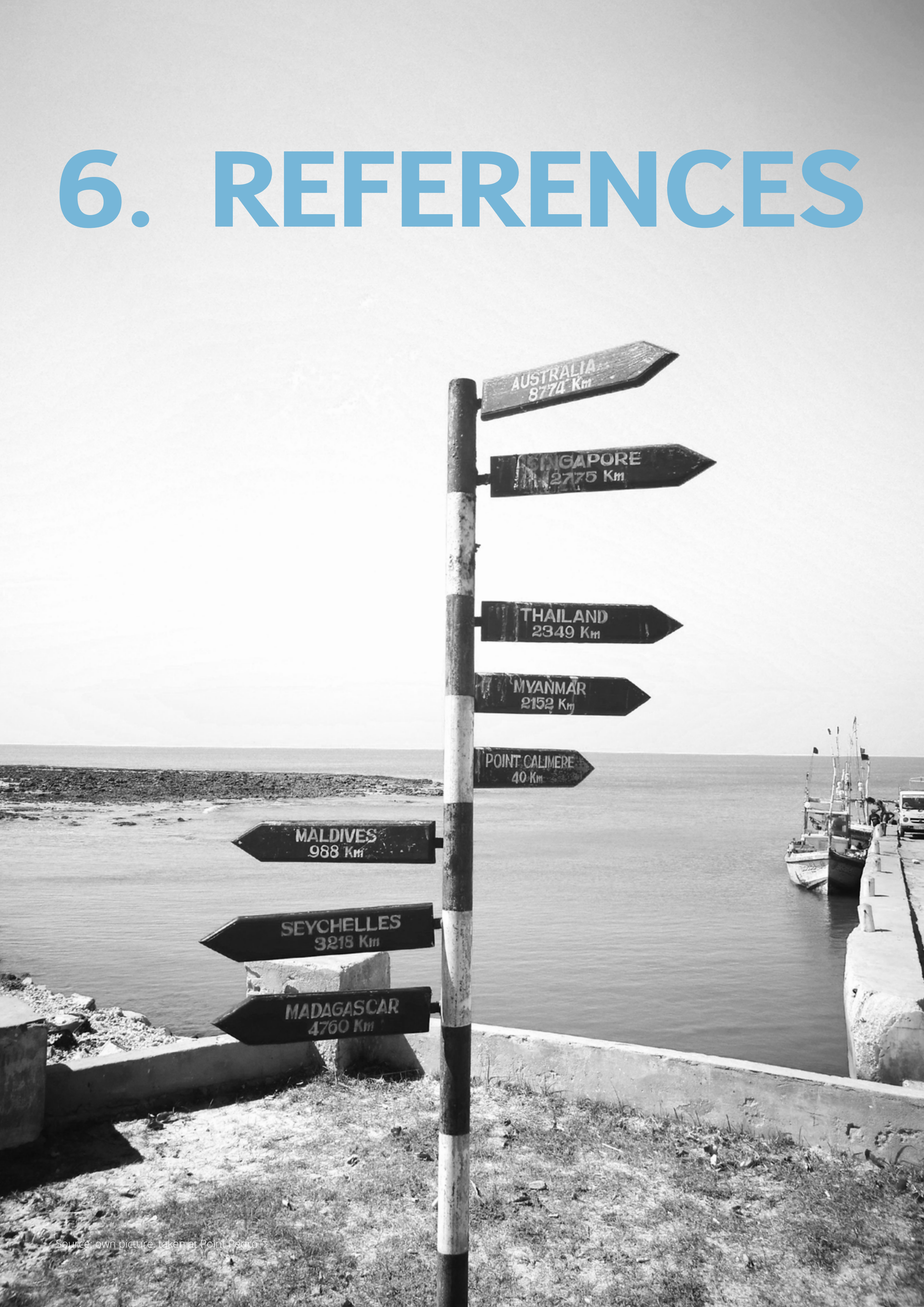

Source: own picture, taken at Point Pedro

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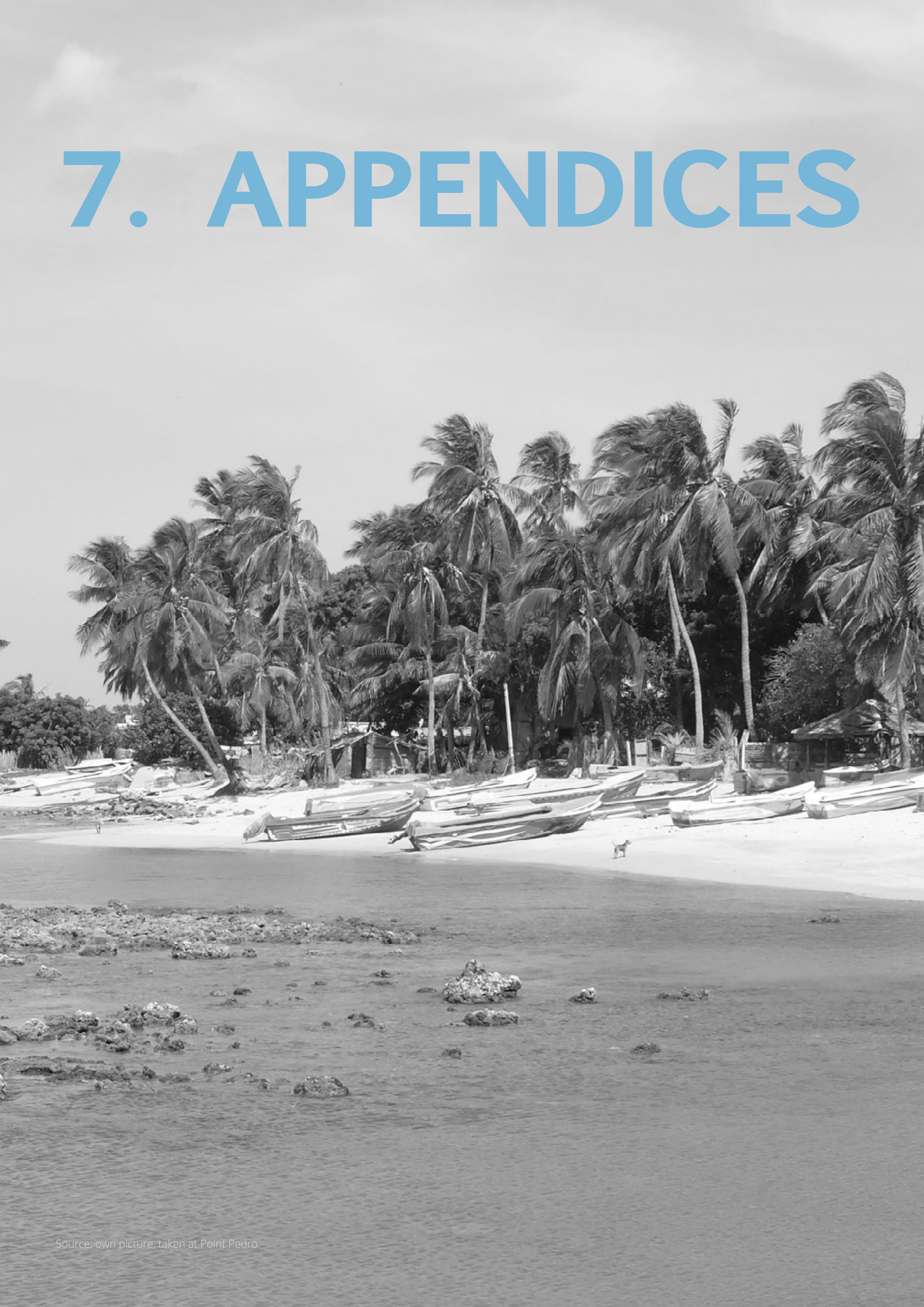
7. APPENDICES



Source: own picture, taken at Point Pedro

Appendix A: Form factor

In order to determine the tidal behaviour a form factor calculation is required. The calculation uses tidal measurements of UNESCO-IHE (2016b) shown in Table A-1.

Table A-1: Tidal data at Point Pedro for one month (UNESCO-IHE, 2016-1)

	Amplitude [m]	**Phase [degree]**
M2	0.213	82.59
S2	0.094	105
K2	0.024	104.55
N2	0.079	75.58
K1	0.052	245.27
O1	0.009	286.31
P1	0.018	245.73

With the known tidal components the tidal form factor can be calculated, using the following formula:

$$F = \frac{(K1 + O1)}{(M2 + S2)} = \frac{0.061}{0.307} = 0.199 \qquad \text{Eq. 1}$$

This form factor (Eq. 1) gives an indication of the influence of the diurnal and the semidiurnal components to the total tide. In Table A-2 is shown how the form factor (F) is translated into a characterization of the tidal behaviour.

Table A-2: Values F for determining tidal character (Bosboom and Stive, 2015)

Value F	0.00 - 0.25	0.25 - 1.50	1.50 - 3.00	> 3.00
Tidal character	Semidiurnal	Mixed, mainly semidiurnal	Mixed, mainly diurnal	Diurnal

Appendix B: Total geological history approach models

In this appendix the characteristics of the tectonic, geological and geomorphological models which have been selected are presented schematically. In Figure A-1 the cratons tectonic model is represented. In Figure A-2 the platform sediments and basins tectonic model is shown. In Figure A-3 the geological model shelf carbonates and evaporites is represented. In Figure A-4 the geological model gneisses and migmatites is shown. In Figure A-5 the coastal geomorphological model is presented.

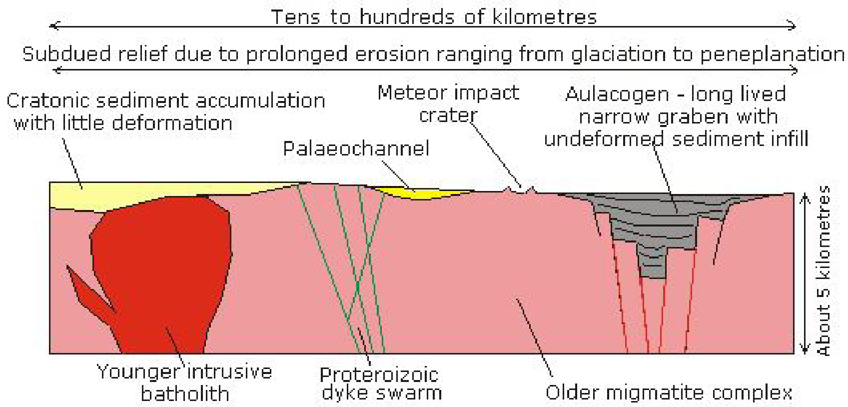


Figure A-1: Cratons tectonic model characteristics (Fookes, 2000)

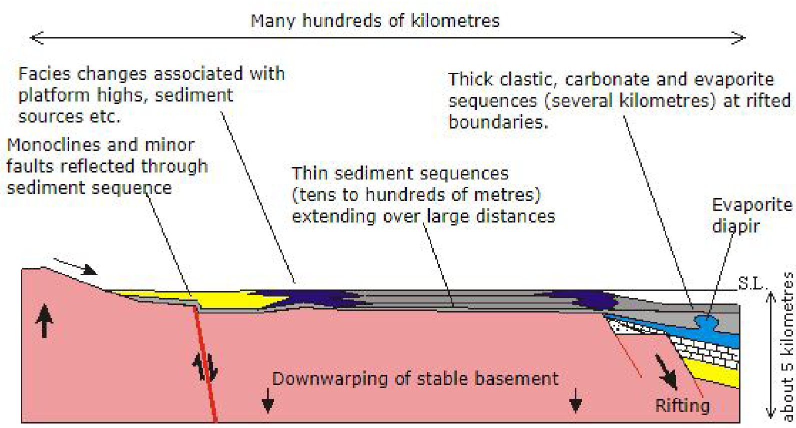


Figure A-2: Platform sediments and basins tectonic model characteristics (Fookes, 2000)

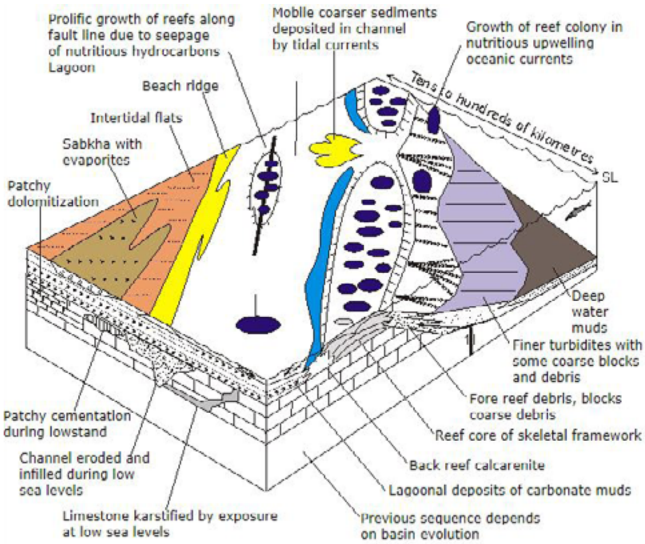


Figure A-3: Shelf carbonates and evaporites geological model characteristics (Fookes, 2000)

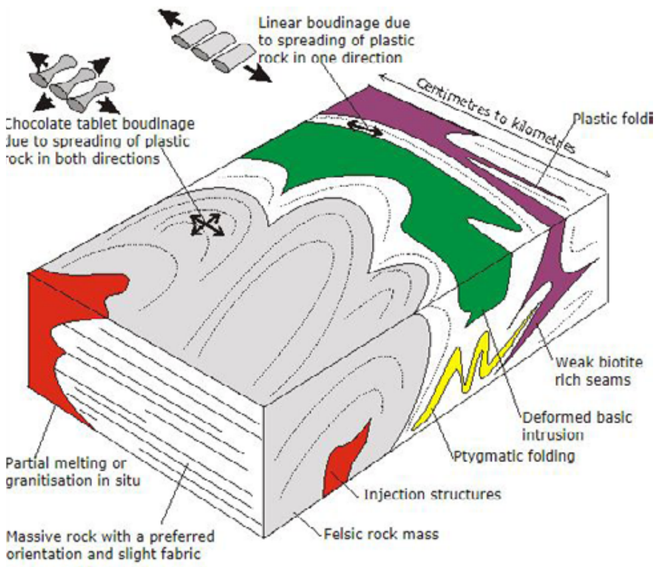


Figure A-4: Gneisses and migmatites geological model characteristics (Fookes, 2000)

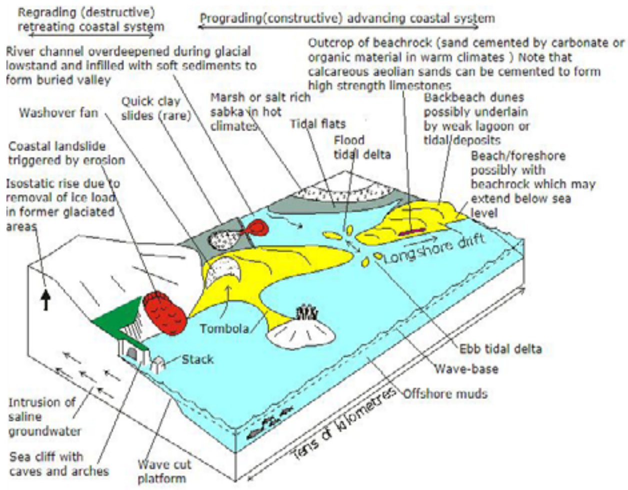


Figure A-5: Coastal geomorphological model characteristics (Fookes, 2000)

Appendix C: Site visit

On the 21st of September the project team visited the project location in the Jaffna District. During this site visit a clear image of the geology, the current infrastructure and the current fishery industry of Point Pedro was established. In this appendix, the geology of the site area is considered.

An important observation of the geology was that the reef is completely exposed during low tide and looks like a typical fringing reef. Further investigation showed that most of the reef was mechanically weathered, Figure A-6. The exposed broken coral particles have an average diameter of 5 to 15 centimeters. Near the end of the reef, the particle diameter increases of 0.35 to 1 meter. In addition to the diameter sizes, a conversation with local citizens and fisherman resulted in the fact that the edge of the reef is very unstable due to weathering and erosion. However, it is expected that beneath the weathered layer of reef, a strong limestone base is situated. The available borehole log confirms the suggestion of a strong, unweathered base beneath this weathered zone (FCG ANZDEC, 2016). For this reason, the limestone base beneath the weathered layer is assumed to be suitable as foundation for harbour elements.

Figure A-6: Top of the reef

Appendix D: Fleet forecast

In order to be able to predict the fleet size, first the contribution of the different boat types to the total production of the Jaffna District needs to be found. In order to find this composition the number of boats per category is multiplied by the mean production per boat type, this is also done for Point Pedro. Result are shown in Table A-3.

Table A-3: Composition of boat types in Jaffna District and Point Pedro in 2016 (Source: University of Moratuwa, 2016b)

Boat type	Production (MT/y)	Number of boats in Jaffna District	Number of boats in Point Pedro	Production Jaffna District (MT/y)	Production Point Pedro (MT/y)
NBSB	11	-	90	-	-
NTRB	1.5	2904	349	4,356	524
MTRB	6.1	558	47	3,404	287
OFRB	5.6	3412	961	19,107	5,382
IDAY	20.4	82	29	1,672	592
IMUL	43.4	58	25	2,517	1,085
IIMUL	73.8[1]	0	0	0	0
Total		**7,014**	**1,501**	**31,057**	**7868**

The boat types described in Table A-3 can be divided in three types of boats: (1) coastal boats, (2) offshore boats and (3) deep sea boats. The Sri Lankan government divides the fishery industry in three sectors: (1) inland fishery, (2) coastal fishery and, (3) offshore and deep sea fishery. The estimates of the fleet size in the new Point Pedro harbour are based on the national distribution between the fishery sectors. Since only marine fishery industry is located in the Jaffna District, only this data of the country is used. In Table A-4 the division between coastal fishery and offshore and deep sea fishery is shown for Sri Lanka, the Jaffna District and Point Pedro.

Table A-4: Composition of marine fishery in Sri Lanka, Jaffna District and, Point Pedro

	Sri Lanka	Jaffna District	Point Pedro
Coastal fishery (boat types: NTRB, MTRB, OFRB)	40.2%	86.5%	78.7%
Offshore & Deep sea fishery (boat types: IDAY, IMUL, IIMUL)	59.8%	13.5%	21.3%

Optimistic forecast

In the optimistic forecast it is assumed that constructing the harbour at Point Pedro leads to a large increase in offshore and deep sea fishing in the Jaffna District. It is assumed that after the construction the offshore and deep sea industry has a 40% contribution to the total fish production of the Jaffna District. This number is chosen since it is equal to the share of the deep sea and offshore fishery in the marine fishery industry of Sri Lanka. This results in an extra production of fish in the Jaffna District, shown in Table A-5.

1 This number is an assumption. The average length of IIMUL vessel are 30m, IMUL vessel are 15m on average. Because no further information is available it is assumed that IIMUL produces 1.7 time the production of IMUL.

Pessimistic forecast

In the pessimistic forecast it is assumed that the harbour is not contributing to the deep sea and offshore fishery in the complete Jaffna District, but only in the Point Pedro area. It is assumed that the new harbour leads to a 40% contribution of the marine fishery industry in the Point Pedro area only. This result in an extra production in the Point Pedro area, given in Table A-5.

Table A-5: Forecast scenarios

	Optimistic forecast	**Pessimistic forecast**
Harbour production (MT)	19,209	4,168
IDAY No.	102	22
IMUL No.	307	67
IIMUL No.	51	11

The division between the number of IDAY, IMUL and IIMUL is based on the feasibility study conducted by FCG ANZDEC and RDC (2017b). In this study a forecast for the Point Pedro harbour was made, this forecast scenario is taken as the realistic fleet forecast in the report. In their forecast they found a distribution between IDAY, IMUL and, IIMUL of 50, 150 and, 25 boats. This distribution is also used in this forecast, since there was no additional data available.

Appendix E: Channel dimensions

Channel width

In the channel three zones can be distinguished: the ship clearance zone, the manoeuvring zone and the bank clearance zone, Figure A-7. Table A-6 indicates the channel width for different types of boat sizes in factors of the beam of the largest vessel (B_s). The manoeuvring zone in the inner channel is two times the beam, while the outer channel is estimated as 3 times the beam (Ligteringen and Veslink, 2014).

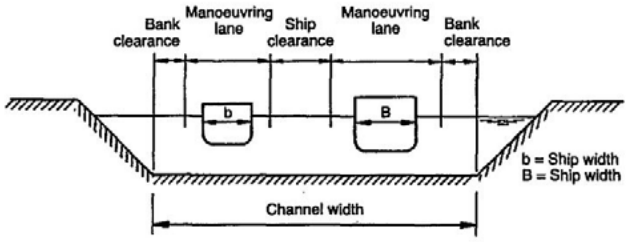


Figure A-7: Required channel width, two-way channel (Thoresen, 2013)

Table A-6: Required channel width (Ligteringen and Veslink, 2014)

Zone Types	Needed width	One-way	Two-way
Manoeuvring zone	2-3 • B_s	1 • 2-3 B_s	2 • 2-3 B_s
Bank clearance zone	1.5 • B_s	2 • 1.5 B_s	3 • B_s
Ship clearance zone	B_s	-	B_s
Total			8-10 • B_s

The normative wind velocity during the northeastern monsoon is 3-12 m/s and small currents of 0.7 m/s are present, see chapter 2.2 Site conditions. Combining these relatively low values with the fact that extra margins should be taken as breakwater in the harbour is desirable, a safety factor of 1.2 is assumed. This results in 6 - 7.2 B_s and 9.6 - 12 B_s for respectively the inner and the outer channel width.

Channel depth

The following factors are used for determining the minimum entrance channel depth:

- maximum draught vessel = 0.9 - 5 m
- variation in water level due to tides and winds = 0.6 m (spring)
- minimum keel clearance = 0.2 m
- channel bottom topography = 0.1 m
- ship motion due to waves = 0.1 m
- sinkage of vessel due to squat = 0.0 m

These factors lead to a minimum channel depth of the maximum draught vessel plus an additional meter.

Assumptions are made for the keel clearance, bottom topography, ship motion and sinkage of small fishery boats in a sheltered harbour environment. Squat is unlikely to occur as the length of the fishery boats is limited, as well as the speed and the wave climate are moderate (Ligteringen and Veslink, 2014).

Appendix F: Quay wall dimensions

First estimates for required quay length are based on a formula derived from Ligteringen and Veslink (2014), see Eq. 2:

$$L_q = \frac{\widehat{c_d} \cdot (\overline{L} + s) \cdot f_r}{c_{s/h} \cdot n_{hd}} \qquad \text{Eq. 2}$$

Table A-7 describes the parameters used for determining the required quay length.

Table A-7: Parameters for determining quay length

Parameter	Description	IDAY	IMUL	IIMUL
$\hat{C}_d$ [kg/day]	Total peak daily discharge	O: 9,180 R: 4,500 P: 1,980	O: 360,360 R: 180,180 P: 81,900	O: 74,144 R: 37,072 P: 37,072
L+s [m]	Required space at quay wall	9 x 1.15	15 x 1.15	30 x1.15
f_r [-]	Irregularity factor	1.5	1.5	1.5
$c_{s/h}$ [kg/hour]	Mean unloading rate per vessel per hour	180	2,730	3,707
n_{hd} [hours]	Number of unloading hours per day	3	10	10

O: Optimistic scenario
R: Realistic scenario
P: Pessimistic scenario

Total peak daily discharge
For calculation of the total peak daily discharge, first it is important to determine the amount of fishing days in a year. It is assumed that during the northeastern monsoon fishery is not possible (3 months) and that fishers are working 6 days a week on average. Applying this assumptions leads to 234 days of fishing per year.

From Table A-3 it can be derived that the mean yearly production of an IDAY boat is equal to 20.4 MT/year. Leading to a mean production of 90 kg/day/boat. By using the forecast scenarios for the amount of IDAY boats it can be determined what the peak daily discharge is (given in).

Table A-8: Calculation of total daily production		
	IMUL	**IIMUL**
Yearly production [MT/year]	43.4	73.8
Daily production [kg/day]	195	331
Minimum time required for obtaining the production [days]	14	21
Mean time per fishing trip [days]	21	28
Mean production per trip [kg]	195 x 21 = 4,095	331 x 28 = 9,268
Arriving boats per day **(=Amount of boats / minimum time required on sea)**	O: 307 / 14= 22 R: 150 / 14= 11 P: 67 / 14 = 5	O: 51 / 21= 2 R: 25 / 21= 1 P: 11 / 21= 1
Total daily peak discharge **(=arriving boats per day x mean production per trip x peak factor)** **[kg/day]**	O: 360,360 R: 180,180 P: 81,900	O: 74,144 R: 37,072 P: 37,072

Calculating the peak daily discharge is more complicated. The calculation is provided in Table A-8. The yearly production is retrieved from table Table A-3. Dividing the yearly production by the number of fishing days (234) leads to the average daily production. According to Eng. P.C. Fernando the mean time of a IMUL boat trip is 21 days and of a IIMUL boat trip is 28 days, leading to a mean production per trip (Table A-8). He also noted that the minimum time for obtaining the average trip production is 14 days for IMUL and 21 days for IIMUL (during good fishing conditions). This time is used for calculating the berthing capacity, since this is the normative event in the harbour. Also a large peak factor is applied, since the returning of these multiday trips is dependent on weather conditions. Therefore, a peak factor of 4 is assumed.

The number of arriving boats per day has a minimum of one, otherwise the obtained quay length will be less than the required quay length per boat. Using these values gives the total daily peak discharges.

Required space at quay wall

The required space at the quay wall is calculated using the assumption that "parallel to the quay"-type of berthing is used. This gives that the required space to moor will be 1.15 times the length of the vessel.

Irregularity factor

The irregularity factor for the vessel can range between one and two. One is indicating that it is perfectly known when boats are arriving and two indicates that is unknown how boats arrive. For the Point Pedro harbour it is assumed that a factor of 1.5 is sufficient, since there is much information about the different types of boats, but not much known about their arrival frequency.

Mean unloading rate per vessel

The mean unloading rate per boat is not equal for IDAY, IMUL and IIMUL boats. IDAY operate with less people than the others, therefore it can be assumed that their unloading rate is assumed to be lowest (90 kg/hour). IMUL boats have more equipment and crew on board, therefore it is expected that unloading will go a lot faster. It is assumed that the mean production of an IMUL boat can be unloaded within 1.5 hours, leading to a unloading rate of 2,730 kg/hour. For IIMUL it is assumed that there is even more crew and equipment on board, it is assumed that an IIMUL boat can be unloaded within 2.5 hours. This means that the unloading rate per hour is equal to 3,707 kg/hour.

Number of unloading hours per day

For the number of unloading hours per day it is assumed that IDAY boats will all arrive within a 3 hour time slot after a fishing day. For IMUL and IIMUL days it assumed that they will be arriving within a time slot of 10 hours (a normal working day), because they will return to the harbour when their storage space is full, which is not restricted to time.

Total area of resting quay

In this part the calculations for the area required for the resting quay are set out. The estimate is based on the amount of boats using the harbour and the average amount of space needed per boat. The space required is based on an average of the space usage of the resting types of berthing arrangements, which is 1.1 for both the length and the width. This results in a multiplication factor of $(1.1)^2$ which is used in the formula:

Area = (number of boats) • (multiplication factor) • (length of boat) • (width of boat)

For the IDAY boats this results in the following scenarios:

- Optimistic: $A = 102 \cdot (1.1)^2 \cdot 9 \cdot 3 = 3{,}332\ m^2$
- Realistic: $A = 50 \cdot (1.1)^2 \cdot 9 \cdot 3 = 1{,}634\ m^2$
- Pessimistic: $A = 22 \cdot (1.1)^2 \cdot 9 \cdot 3 = 719\ m^2$

For the IMUL boats this results in the following scenarios:

- Optimistic: $A = 307 \cdot (1.1)^2 \cdot 15 \cdot 4.5 = 25{,}074\ m^2$
- Realistic: $A = 150 \cdot (1.1)^2 \cdot 15 \cdot 4.5 =12{,}251\ m^2$
- Pessimistic: $A = 67 \cdot (1.1)^2 \cdot 15\ x \cdot 4.5 = 5{,}472\ m^2$

For the IIMUL boats this results in the following scenarios:

- Optimistic: $A = 51 \cdot (1.1)^2 \cdot 30 \cdot 5 = 9{,}075\ m^2$
- Realistic: $A = 25 \cdot (1.1)^2 \cdot 30 \cdot 5 = 4{,}538\ m^2$
- Pessimistic: $A = 11 \cdot (1.1)^2 \cdot 30 \cdot 5 = 1{,}997\ m^2$

Appendix G: Required habour dimensions

To find design values for the water surface area inside the harbour, the design fleet size should be known. A harbour has different functions like unloading, refuelling and resting areas. In this chapter the design fleet size is estimated first. Afterwards, the minimum design values for the typical harbour areas are found.

Design fleet size

Currently, three scenarios (optimistic, realistic and pessimistic) are used for forecasting the fleet size in the Point Pedro harbour. To be able to design the harbour properly, one design value forecast should be given. The calculation for the design fleet size is based on a combination of the three scenarios made during the analysis phase.

For every boat type a normal distribution is assumed on the expected amount of boats. The average and standard deviation of the distribution are obtained by using the "Delphi Technique" (Nicholas & Steyn, 2011). This technique assumes that an optimistic scenario will only be exceeded in 10% of the time. For the pessimistic scenario it is assumed that this value will be exceeded in 90% of the time. In order to retrieve a mean and standard deviation for the normal distribution Nicholas & Steyn (2011) proposes to combine the optimistic and pessimistic scenario with a most likely value (in our case the realistic scenario) using a Beta Distribution. This results in the values given in Table A-9.

Table A-9: 5-year boat values

	Estimate	Optimistic	Most likely	Pessimistic	Average	Standard deviation
IDAY	50	102	50	22	54.00	13.33
IMUL	150	307	150	67	162.33	40.00
IIMUL	25	51	25	11	27.00	6.67

The average and standard deviations per boat types are used to determine a design value for the harbour in the first five years after the construction. For the designs, it is assumed that the initial harbour infrastructure should be sufficient for the first five years with a certainty of 80%. The 80% value is chosen, because this reduces the chance of an immediate scarcity of mooring places after the harbour has been constructed. On the other hand, the 80% does not lead to large over dimensioning of the harbour infrastructure during the first five operating years of the harbour.

After the first five years it has been assumed that the fleet size will still be growing. The growth of the harbour over its lifetime is assumed to be inverse exponential. In order to take this growth into account, growth factors are applied to compare the 50-year growth with the 5-year growth. It is assumed that every boat type has an independent growth factor and the values of these factors are approximated based on government policies.

Since the government is promoting deep sea fishing it is most likely that the amount of IMUL and IIMUL boats will grow in the future. The IIMUL boat is the newest type of fishery boat in Sri Lanka. Because it is expected that this boat type will grow fastest, a growth factor of 2 is applied. For IMUL a growth factor of 1.5 is applied. The IDAY growth factor will be 1, since the government does not allow to build new IDAY boats anymore (P.C. Fernando, personal communication, 04/10/2017). Leading to the design values for the harbour given in Table A-10.

Table A-10: Design forecasts			
	5-year design value (P80 value)	**Growth factor**	**50-year design values**
IDAY	65	1	65
IMUL	196	1.5	294
IIMUL	33	2	66
Total	294		425

For the design phase, it has been assumed that the harbour breakwater will be constructed at once. Therefore, the harbour basin should have sufficient size in order to accommodate the design forecast over 50 years. Since it is uncertain how the harbour will perform after construction, it has been assumed that it is better to expand the infrastructure within the harbour step by step. Initially, the basin infrastructure will be designed on the 5-year forecast with a 80% certainty.

Design harbour dimensions

An approximation for the required harbour dimensions can be made by using the design fleet size. Table A-11 gives the required quay wall length and resting areas for the harbour.

Table A-11: 5-year forecast: design values for resting area and quay wall length				
	IDAY	**IMUL**	**IIMUL**	**Total**
Boats	65	196	33	
Mean production (kg/day)	90	195	331	
Peak factor	1	4	4	
Trip time	1	14	21	
Mean production per trip	90	2,730	6,951	
Arriving boats per day	65	14	2	
Total daily discharge	5,850	152,880	43,692	
Required space	10	17	35	
Irregularity factor	2	2	2	
Mean unloading rate per vessel per hour	180	2,730	3,707	
Number of unloading hours per day	3	10	10	
Boat width	3	4,5	5	
Boat length	9	15	30	
Space factor width	1.1	1.1	1.1	
Space factor length	1.1	1.1	1.1	
Resting area	2,124	16,008	5,990	
Channel width	29	43	48	
Total channel area	1,872	8,467	1,584	
Jetty area	429	1,940	363	
Quay wall area	5,129	6,972	4,512	
Total resting area (m^2)	**4,425**	**26,416**	**7,937**	**38,777**
Quay wall length (m)	**168**	**145**	**61**	**374**

The calculation for the quay wall length and resting area are similar to the calculation as made in Appendix F. Therefore, clarification about used certain values can be found in this appendix. The same calculation has also been made for the 50-year design lifetime of the harbour. Resulting in the quay wall length and resting areas as shown in Table A-12.

Table A-12: 50-year forecast: design values for resting area and quay wall length

	IDAY	IMUL	IIMUL	Total
Boats	65	294	66	
Mean production (kg/day)	90	195	331	
Peak factor	1	4	4	
Trip time	1	14	21	
Mean production per trip	90	2,730	6,951	
Arriving boats per day	65	21	3	
Total daily discharge	5,850	229,320	87,384	
Required space	10	17	35	
Irregularity factor	2	2	2	
Mean unloading rate per vessel per hour	180	2,730	3,707	
Number of unloading hours per day	3	10	10	
Boat width	3	4.5	5	
Boat length	9	15	30	
Space factor width	1.1	1.1	1.1	
Space factor length	1,1	1.1	1.1	
Resting area	2,124	24,012	11,979	38,115
Channel width	29	43	48	
Total channel area	1,872	12,701	3,168	
Jetty area	429	2911	726	
Quay wall area	5,129	10,102	7,439	
Total resting area	**4,425**	**39,624**	**15,873**	**59,921**
Quay wall length (m)	**168**	**217**	**122**	**508**

Refuelling quay

Besides the resting area and the quay wall length, space is also required for refuelling of vessels. The refuelling area consists of a quay wall, a mooring place with manoeuvring space and a waiting area. The length of the quay is calculated with a formula derived from Ligteringen and Veslink (2014), see Eq. 3:

$$L_q = \frac{\widehat{c_d} \cdot (\overline{L} + s) \cdot f_r}{c_{s/h} \cdot n_{hd}} \qquad \text{Eq. 3}$$

Since this formula was designed for calculating unloading quays, some adjustments were made in order to make the formula applicable for refuelling quays. These adjustments are clarified below. Furthermore, Table A-13 shows the input parameters and the resulting quay wall lengths.

Table A-13: Quay wall length for refuelling					
Parameter	**Unit**	**Description**	**IDAY**	**IMUL**	**IIMUL**
$\hat{C}_d$ (5-year)	[boats/day]	Total peak daily discharge for 5-year forecast	37	56	6
$\hat{C}_d$ (lifetime)	[boats/day]	Total peak daily discharge for lifetime forecast	37	84	1
L+s	[m]	Required space at quay wall	10	17	35
f_r	[-]	Irregularity factor	1.5	1.5	1.5
$c_{s/h}$	[boats/ hour]	Mean fuelling rate per vessel per hour	4	2	1.33
n_{hd}	[hours]	Number of unloading hours per day	10	10	10
L_q (5-year)	[m]	Quay length 5-year forecast	14	69	23
LQ (5-year)	[m]	Quay length lifetime forecast	14	104	47

Total peak daily discharge
The amount of refuelling boats per day is based on the average trip length. It is assumed that IMUL and IIMUL boats have to refuel after each trip. However, for IDAY boats it has been assumed that they have to refuel once a week. Because it is logical to refuel before leaving for the next trip or after arriving from last trip, also a peak factor should be applied. Also weather conditions play an important role on the refuelling amount of boats per day, and therefore, increase the peak factor even more. A peak factor of four is supposed to be sufficient. Table A-14 shows the input parameters and the resulting total daily discharge for the 5-year and 50-year forecast.

Table A-14: Total daily discharge calculation			
	IDAY	**IMUL**	**IIMUL**
Peak factor	4	4	4
Fuelling boats per day (5-year)	9.3	14.0	1.5
Fuelling boats per day (50-year)	9.3	21.0	3
Total daily discharge (5-year)	37	56	6
Total daily discharge (50-year)	37	84	13

Required space at quay wall
The required space at the quay wall is calculated using the assumption that "parallel to the quay"-type of berthing is used. Table 14 (2.6.2 Berthing possibilities on page 36) gives that the required space for mooring will be equal to 1.15 times the length a boat.

Irregularity factor
The range of the irregularity factor for a boat is '1-2'. A factor of 1 is indicating that it is perfectly known when boats are refuelling, and a factor of 2 indicates that it is unknown when boats are refuelling. For the Point Pedro harbour, it is assumed that a factor of 1.5 is sufficient.

Mean fuelling rate per vessel
For the mean fuelling rate per boat it is assumed that an IDAY boat needs 15 minutes for refuelling. For IMUL it is assumed that 30 minutes is needed and for IIMUL a time of 45 minutes is assumed. Assumptions are made based on the boat sizes and their average fishing trip lengths. The assumption of refuelling times are transferred into a mean fuelling rate per boat per hour.

Number of unloading hours per day

Regarding the number of unloading hours per day, it is assumed that all boats will refuel on a working day of 10 hours. The peak factor applied on the total daily discharge already takes into account that more boats will be arriving on certain times.

Sufficient space is required to ensure easy manoeuvring near the refuelling quay wall. It has been assumed that an inner channel width of 48 m is sufficient. This is equal to the width of an inner channel for IIMUL boats. For easy operations of the quay wall also a waiting area near the quay is desired. Because there could be a queue for the refuelling quay, the waiting area size is assumed to be equal to a resting area size for the average amount of fuelling boats per day. In this way, enough space is guaranteed.

5-Year forecast

- IDAY: $A = 9.3 \cdot (1.1)^2 \cdot 9 \cdot 3 = 303\ m^2$
- IMUL: $A = 14 \cdot (1.1)^2 \cdot 15 \cdot 4.5 = 1{,}143\ m^2$
- IIMUL: $A = 1.5 \cdot (1.1)^2 \cdot 30 \cdot 5 = 285\ m^2$
- Total = 1,732 m^2

50-Year forecast

- IDAY: $A = 9.3 \cdot (1.1)^2 \cdot 9 \cdot 3 = 303\ m^2$
- IMUL: $A = 21 \cdot (1.1)^2 \cdot 15 \cdot 4.5 = 1{,}715\ m^2$
- IIMUL: $A = 3 \cdot (1.1)^2 \cdot 30 \cdot 5 = 570\ m^2$
- Total = 2,589 m^2

Harbour dimensions

This paragraph gives an overview on all required surface areas for determination of the harbour basin. In Table A-15 the outcomes of the calculation of the required areas for the 5-year scenario are given.

Table A-15: Required surface area inside the harbour for the 5-year forecast

	IDAY	IMUL	IIMUL	Total
Boats	65	196	33	294
Unloading quay length [m]	168	145	61	374
Refuelling quay length [m]	14	69	23	106
Unloading quay area [m^2]	5,100	7,000	4,500	16,600
Refuelling quay area [m^2]	530	4,100	1,900	6,600
Resting place area [m^2]	2,100	16,000	6,000	24,000
Total required area [m^2]	10,400	38,700	14,600	63,700

The dimensions shown in Table A-15 are the values which should be implemented in the harbour during the first construction phase. During this construction phase, the harbour outer infrastructure should be sufficient for the complete lifetime. The space requirement for the lifetime is given in Table A-16.

Table A-16: Required surface area inside the harbour for the lifetime forecast				
	IDAY	**IMUL**	**IIMUL**	**Total**
Boats	65	294	66	425
Unloading quay length [m]	168	217	122	508
Refuelling quay length [m]	14	104	47	164
Unloading quay area [m^2]	5,100	10,100	7,400	16,600
Refuelling quay area [m^2]	530	6,200	3,800	10,500
Resting place area [m^2]	4,400	39,600	15,900	59,900
Total required area [m^2]	10,400	57,600	27,700	95,700

The sum of all spaces together gives a required surface area of 9.6 ha. Since all the space has a specific function in the 9.6 ha, also an additional manoeuvring area between this functions should be taken into account. It is assumed that an additional 20% space is required for manoeuvring in the harbour. This results in a space of 11.5 ha that should be enclosed by the harbour breakwaters.

Appendix H: Harbour facilities

Table A-17: harbour facilities needed in Point Pedro harbour

Facility	**Amount**	**Dimensions (m x m)**	**Surface area (m^2)**	**Location in harbour**
Net Mending Hall	1	40 x 8	320 m^2	Close to IDAY and IMUL quay wall/jetties.
Auction Hall	2	40 x 8	320 m^2	One near IDAY and IMUL quay wall/jetties, one near deep sea fishing quay wall.
Loading area for trucks attached to Auction Hall	2	7 x 9	63 m^2	One near IDAY and IMUL quay wall/jetties, one near deep sea fishing quay wall.
Off-Loading Building	1	60 x 25	1,500 m^2	Right next to the quay wall of the deep sea fishing quay wall.
Facility for SL Navy and Coast Guard	1	30 x 8	24 m^2	Approximately in the middle of the harbour to provide fast and easy navigation through the entire harbour.
Community Hall and Canteen	1	0 X 0	n/a	These facilities will be part of the 2 storied building where the facilities for SL Navy and Coast Guard are also provided (ground floor).
Radio Room and Fisheries Inspector's Office	1	0 x 0	n/a	These facilities will be part of the 2 storied building where the facilities for SL Navy and Coast Guard are also provided (ground floor).
Sales Outlets	1	0 x 0	n/a	These facilities will be part of the 2 storied building where the facilities for SL Navy and Coast Guard are also provided.
CFHC Administrative Office	1	25 x 8	200 m^2	The CFHC Administrative Office needs at least 2 cubicles with a harbour side view for the harbour manager and the assistant harbour manager, thus the facility needs a location which can fulfill this need.
Accommodation Facility and CFHC Storage	1	20 x 8	160 m^2	As this facility also provides accommodation facilities for the harbour manager, the building must be located close to the CFHC Administrative Office.
Toilet and shower facilities	1	9 x 4.5 m	40.5 m^2	Located next to the 2 storied building where the facilities for SL Navy and Coast Guard are provided.
Security Facilities	1	4 x 2	8 m^2	Located next to the entrance of the harbour.
Wastewater Treatment Facilities	1	10 x 10	100 m^2	No specific location is needed.
Water Supply	1	10 x 10	100 m^2	No specific location is needed.
Weighbridge and Control Room	1	3 x 20	60 m^2	As the trucks loaded with fish from deep sea fishing vessels need to be weighed, the weighbridge needs to be located next to the road which leads from the deep sea fishing quay wall to the exit of the harbour.

Table A-17: harbour facilities needed in Point Pedro harbour				
Ice Plant	1	+- 25 x 25	700 m^2	As the ice storage is only needed for the IDAY and IMUL boats, the ice plant needs to be located close to the quay walls of those boats.
Ice/Cold Storage	1	0 x 0	n/a	The ice storage facility will be located inside the Ice Plant.
Fuelling Facility	3	3 x 3 3 x 3 2 x 3	24 m^2	2 Diesel tanks of 36,000 L provided on either side of the harbour, as well as one Kerosine tank of 18,000 L, near the deep sea fishing vessels.
Boat Lifting and Mechanical Repair Workshop	1	40 x 15 (inside workshop) 20 x 10 (repair yard)	800 m^2	As this facility is only meant for IDAY and IMUL boats, it needs to be located near the of/onloading area of those boats.
Beacon Lights, Leading Light and Marker Buoys	2	1 x 1	2 m^2	Located at each side of the entrance of the harbour to ensure safety.
Access road	1	6 x 750	4,500 m^2	The road needs to run along the full length of the harbour for easy navigation.
Pedestrian way	1	1 x 750	750 m^2	The pedestrian way will run along the full length of the access road.
Land allocated for Future Development	1	n/a	n/a	A considerable amount of land area needs to be reserved for future growth of the harbour. This land can be allocated anywhere in the harbour.
Parking facilities	3			Several parking facilities in different parts of the habrour are needed. At least a parking lot near the auction halls and the different resting places are needed.
Total area of land facilities			9,671.5 m^2 (0.96715 ha)	This number does not take into account any future development or space around the facilities in order to move around. Therefore, a much bigger area than this 0.96715 ha is needed within the perimeter of the harbour.

Appendix I: Ice production and storage

Because of the monsoon, during three months of the year, it is impossible to fish at sea. Therefore, all fish caught in one year will be caught in the nine remaining months. It is assumed that the fishermen will head to sea six out of the seven days in a week. This results in 234 fishing days per year.

$$365 \cdot \frac{9}{12} \cdot \frac{6}{7} = 234.64$$ days per year of fishing

As the production of fish forecast is set to 12,256 MT/y (P80 value of expected fish production), the amount of fish that is expected to be caught in one day is 48.1 MT.

$$\frac{12256}{234} = 48.10$$ MT of fish per day

This calculated amount of fish which will be caught during one day needs to be stored in a so-called chill room, to prevent deterioration of the fish. The amount of floor space required for the cold storage of the fish is between 0.5 and 1.5 m^2/MT (Ligteringen and Veslink, 2014).
It is assumed the storage in the fishery harbour in Point Pedro will not be optimally used since local fishermen do not have experience with a harbour of this size. Therefore, 1.5 m^2 floor space per metric ton of fish is assumed. The total amount of floor space needed to store all fish caught during a day is thus 72.15 m^2.

$$48.10 \cdot 1.5 = 72.15$$ m^2 needed floor space

As the ice produced also needs to be stored before being used to cool the fish, an additional storage facility is needed. As one tonne of fish needs one tonne of ice to be cooled, 48.1 tonnes of ice needs to be stored during the day. As flakes of ice are most suitable to cool down fish (P.C. Fernando, personal communication, 29/09/2017), this type of ice will be produced and stored in the Point Pedro Harbour. Ice flakes, also called small-ice, requires a storage floor area of 0.5 to 1.0 m^2/t. As again, efficiency is assumed to be fairly low, the maximum amount of floor space is assumed, thus 1.0 m^2/t. This results in a total floor space needed to store the ice of 48.10 m^2 (Ligteringen and Veslink, 2014).
Right now, fish is not cooled during the time the boats are on the water to catch fish. It is however wanted to cool offshore as well, since this will lower the amount of fish which will go to waste due to lack of cooling offshore. Therefore, space needs to be allocated onshore to cool this ice as well. As IIMUL boats make use of freezing facilities on the boat itself, ice is only needed to cool fish on board of IDAY and IMUL. The yearly production of IDAY and IMUL boats are 20.4 and 43.4 MT, respectively. Together with the forecast of the fleet, the daily production of fish on these boats can be calculated. The fish production per day of both the IDAY and the IMUL boats comes down to 32.18 MT.

$$\frac{(20.4 \cdot 50)}{234} = 4.36$$ MT per day

$$\frac{43.4 \cdot 150}{234} = 27.82$$ MT per day

$$4.36 + 27.82 = 32.18$$ MT per day

Again, one tonne of ice needs one square meter of storage, so, to store the ice needed for offshore cooling, 32.18 m^2 is needed.

Next, space needs to be allocated to produce the ice in a ice factory. Small-ice production needs one to six meter squared per tonne of ice per day capacity. To be on the safe side, 5 m^2/MT per day capacity is assumed to be needed to produce all the ice needed in the factory. As both the onshore as well as the offshore cooling ice will have to be produced in this factory, this results in a factory floor area of 401.4 m^2 (Ligteringen and Veslink, 2014).

$$5 \cdot (48.10 + 32.18) = 401.4 \quad \text{m}^2 \text{ floor area in ice factory}$$

The total floor area needed to store ice, cool fish and produce ice is therefore 553.83 m^2.

$$48.10 + 32.18 + 72.15 + 401.4 = 533.83 \quad \text{m}^2 \text{ floor area}$$

All calculations above are made using the average production of fish per day. Of course, the amount of fish caught in one day will never be the exact average. Therefore, a safety factor of 1.25 is used to account for these daily differences (Sciortino & Ravikumar, 1999). Therefore, the total space which needs to be allocated for ice will be approximately 700 m^2.

$$533.83 \cdot 1.25 = 692.29 \quad \text{m}^2 \text{ floor area}$$

Appendix J: MCA criteria

The criteria taken into account in the multi criteria analysis are explained in this appendix. There are three main criteria; costs, technical characteristics and living environment. Those main criteria are divided in three subcriteria. In this appendix it is explained how all criteria have to be interpreted while grading the different design alternatives.

Costs

1. Construction costs

'Construction costs' contain the sum of the costs for the construction of the breakwater, the quay wall and the amount of dredging. Only these aspects are considered as these aspects are relatively costly and vary most between the alternatives. Lowest cost will result in the highest score.

2. Maintenance costs

'Maintenance costs' are the costs for maintaining the harbour. This includes dredging of incoming sediment, maintenance of the breakwater and quay walls and maintaining of the facilities. Lowest estimated costs will result in the highest score.

3. Disposal costs

'Disposal costs' are the costs for the removal of the old anchorage point, nearby houses/ buildings, the reef and left-over dredging material. Lowest cost will result in the highest score.

Technical characteristics

4. Harbour layout

The most optimal 'Harbour layout' will be chosen by looking at the infrastructure within the harbour and the general usability. Also, the harbour logistics will be of great influence. In this matter, the harbour layout will be scored on the location of the several areas within the harbour, like facilities, resting places and quay walls.

5. Technical complexity

The 'Technical complexity' aspect will be scored by looking at the interfaces, fragmentation and risks of the design. All these subaspects increase the technical complexity of the harbour during construction. Lower complexity will result in higher scores.

6. Adaptability

This aspect assesses the 'Adaptability' of a design to changing circumstances. The main possible change of circumstance is the uncertainty of the fleet size in 50 years. The harbour design should be able to adapt to the capacity calculated with the 50-year design values, but should also be possible to adapt to a negative growth.

Living environment

7. Safety

'Safety' concerns the probability and consequences of events that can cause damage to the harbour or can cause human injuries. Also the safety of the design against the monsoon waves and winds will be considered.

8. Flora and fauna

The 'Flora and fauna' aspect will be scored based on the environmental impact of the designs. For instance, subaspects that have influence on this score are the impact on the reef, animals and water quality. Larger impact on the 'Flora and fauna' will result in a lower score.

9. Emotional value: usage of land, local fisherman

The 'Emotional value' concerns the inhabitants and users of the surrounding area. When the harbour will be built, the area will change drastically, which will dissatisfy many local residents and fishermen. Another factor that has influence on this aspect is the usage of land, which is currently owned by local residents.

Appendix K: Cost analysis MCA

Computing the first estimate of the total costs will be done in two steps. First the specific harbour characteristics, like length of the quay wall and proposed amount of dredging, are estimated. Secondly, in the paragraph cost estimation, unit prices are determined.

Specific alternative design statistics

To determine the main dimensions of each alternative a lot of assumption are necessary. Table A-18 presents the result of the calculations, additional explanation about the calculations will be provided in the following alineas. An important notice is that these values are first estimates, in the final design a more precise price will be determined.

Table A-18: Characteristics different harbour alternatives

	Alternative 1	**Alternative 2**	**Alternative 3**	**Alternative 4**
	PPTA	Filling of reef	Breakwater on reef	Artificial Island
Dredged material [m³]	222,038	209,281	188,800	230,824
Land reclamation [m³]	189,362	76,211	109,689	302,600
Sediment disposal [m³]	32,675	133,070	79,111	-71,777
Breakwater length [m]	1,244	972	1,141	1,068
Average breakwater depth [m - MSL]	6.51	5.01	4.71	7.06
Breakwater construction material [m³]	253,000	138,000	165,000	279,000
Quay wall length [m]	715	519	593	880

Dredged material

To indicate the amount of dredged material the bathymetry lines and the alternative design templates are imported in Google Earth. With the use of the 'linial-function' areas are indicated and measured with the same depth. Additionally, the required harbour depth differs for different parts of the harbour. Assumed is that all dredged material is equal, there will be no distinction between reef and sand in the first cost estimation.

Land reclamation

The land reclamation is calculated in the same manner as the amount of dredged material, with the use of Google Earth. Assumed is that the current ground profile provides enough support and no ground improvement is needed. Another assumption is that all the reclaimed land will be elevated to +2 m above MSL.

Sediment disposal
The sediment disposal is the difference between the dredged volume and the land reclamation. It is assumed that all dredged material is of such quality that everything can be used for land reclamation.

Breakwater
The breakwater dimensions are separated in the breakwater length, the average breakwater depth and the amount of material that is needed for construction. The length and average depth are provided to get a clear image of the different designs. The amount of material is based on the specific depth, the use of a road and the use of the reef. Assumed is that the breakwater height will be uniform as +4 m MSL. Additional no division is made in different types of construction material.

Cost estimation

To compare the alternative designs a first outline of the construction costs is obligatory. The costs are depended on the prices for the amount of material (m^3). The different cost-factors are explained and given in the next alineas. It is assumed that all the site facilities will be equal for each design. The main variable factors for each alternative are the amount of dredged material, the different size of the breakwater and the length of the quay wall.
The estimations are based on the currency exchange rate between the Euro and Sri Lanka Rupees as on 3rd of October 2017.

Valuta rate 3 October 2017:
€ 1,00 = SLRs 180.00
SLRs 1,00 = € 0.0055

Dredged material
The ground profile consists mainly out of limestone from the coral reef. At the end of the reef the ground slope decreases steeply till -4.5 m, after this the soil profile consists out of coarse sand. Therefore, most of material that needs to be dredged is hard limestone, this requires more power (kW) in comparison with dredging sand.

To determine the most suitable method to remove limestone, the rippability of the rock is determined using the discontinuity spacing index and point load strength (Verhoef, 2015). The limestone has an average point load strength over the dredged depth of 2.43 MPa and an average discontinuity spacing of 0.25 meter (FCG ANZDEC, 2016). As can be determined out of Figure A-8, the limestone requires difficult ripping. The blue dot gives the position of the limestone in the diagram.

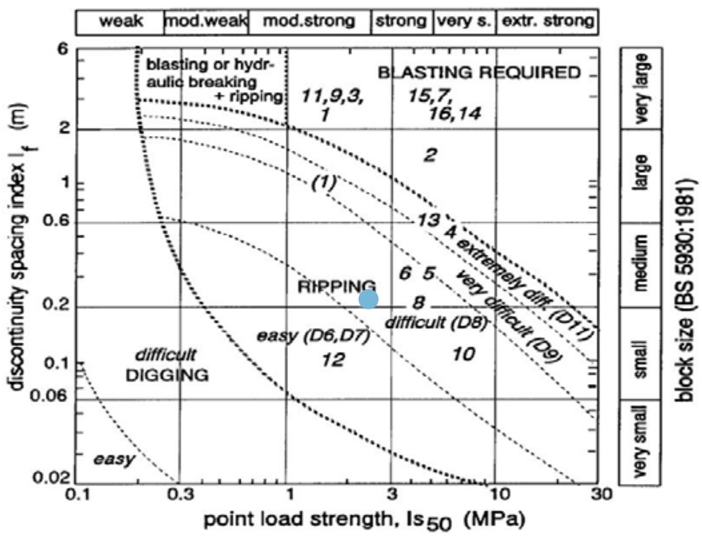


Figure A-8: Rock rippability diagram (Verhoef, 2015).

To dredge the limestone it is assumed that a cutter suction dredger (CSD) will be sufficient. This type of dredger has a rotating cutter system which is able to cut hard rocks. For a first estimation an average size CSD is selected. It is assumed that the rent of a CSD will be €400,000 per week with an average cost of site management placement of €45,000. The production rate is 1250 m^3 per operational hour with a maximum of 120 operational hours in one week. Assuming that the dredger will be operating continuously this results in a production of 120 hours • 1,250 m^3/hour = 150.000 m^3 per week (van Koningsveld, 2017).

This estimation is based on a 100% efficient dredger, generally the efficiency for dredging is estimated at 70%. However, as the limestone is very hard rock and the precise properties of the reef are unknown, lot of delay and inefficiency is expected. The production rate and the rock mass quality have an inverse relationship, if the rock mass quality is high the resulting production rate is low. As the RQD of the limestone is varying around the 70%, this results in a relatively low production rate. The production rate is assumed at 20%.

Applying these two adjustment factors to the optimal production of the CSD, the estimated actual production is determined: 150,000 m^3/week • 0.70 • 0.20 = 21,000 m^3/week. With the implementation of the production per week and the costs per week, the cost per cubic meter of dredged material is determined: 445,000/21,000 = €21.19 per m^3. Concluding that the cost of dredging a cubic meter of limestone is €21.19.

Breakwater

As the total amount of cubic meters breakwater is estimated, one total price tag will be applied. Meaning that no division is made between the different types of material, like the core material, the different sizes of rock armour, geotextile on top of the breakwater, road construction, back filling and the casting and placing costs. Is is assumed that the transportation costs from the quarry to the offshore location are uniform for all the designs.

As main material for the breakwater 0.5 - 1.0 tonnes rock armour stones are selected, this is due to the price class range. As the report of FCG ANZDEC and RDC (2017b), investigated the quarry from Wickremasinghe Metal Quarry Suppliers in the Anuradhapura District will be suitable for supplying the breakwater materials. This quarry is located 200 km from the project location. The final cost estimations for the breakwater materials are provided in Table A-19.

Table A-19: Cost estimation for breakwater material per m^3 (Source: FCG ANZDEC and RDC, 2017a)

	Unit	**Unit cost**
Transport costs	200 km/m^3	€ 0.083
Average armour rock price at quarry	m^3	€ 12.78
Total costs	**m^3**	**€ 12.86**

Land reclamation

The land that will be reclaimed to provide enough space for the site facilities will be mainly constructed with the dredged material. As the dredged material will be a mix of coarse sand and limestone, the sediment mix will be suitable to use as filling material. If a design requires more filling material, this material needs to be exported from an external area or dredged from a nearby location. However, in the final design the use of dredged sediment and land reclamation will be optimized, to minimize total costs. For this reason, additional land reclamation costs are neglected.

Disposal costs

Disposal costs will consist out of multiple independent cost factors. The major disposal elements are:

1. Preparation of the site area: removal of (old) buildings and constructions
2. Disposal of the waste material of the construction site
3. Disposal of the residual dredged sediment

As in the final design disposal costs will be minimized by making most efficient use of the materials, the disposal costs of 2 and 3 are assumed equal for each alternative. The changes made along the current coastline will be graded separately in the MCA (living environment) and are therefore not individually indicated as additional costs.

Quay wall construction

Quay walls can be constructed in different types and methods, in general quay wall placement is expensive. In deep water the use of caissons might be more suitable to simplify construction methods, while near the shore L-walls can be more sufficient.

For a cost estimation of the designs, the L-wall type quay wall is considered, since an open caisson can be constructed out of three L-walls. It is assumed that no additional dredging for foundation will be necessary and that all the quay walls will rise up to +2 m MSL. The majority of the quay walls is located at 6 m depth, however in each alternative area's with less depth are present. On average the quay wall depth will be at -5 m MSL.

To determine the price the amount of concrete in a L-type quay wall is calculated, Table A-20. It is assumed that the bottom slab of the L-wall will be 0.5 times the height of the quay wall. The slabs is assumed as an uniform slab with a thickness of one meter. The price of concrete in the Northern Province of Sri Lanka is 100,000 SLRs, or €555.56 per m^3. Resulting in €555.56 x 10.5 = €5,833.38 per meter.

Table A-20: Estimation of concrete quay wall

	Rule of thumb [m^3/m]	**Amount of concrete [m^3/m]**
Vertical slab	H x 1 m	7
Bottom slab	0.5 H x 1m	3.5
Total		**10.5**

Final costs estimation

To determine the final costs for each alternative the amount of dredging, breakwater material and quay wall length are multiplied with their cost factors. Table A-21 provides the outcome of the first price estimation.

Table A-21: Cost estimation per alternative

	Dredging	**Breakwater**	**Quay wall**	**Total**
Unit costs	€ 21.19 / m^3	€ 12.86 / m^3	€ 5,833.38 / m	
Alternative 1 PPTA	€ 4,704,985.22	€ 3,253,580.-	€ 4,170,866.70	**€ 12,129,000**
Alternative 2 Building of reef	€ 4,434,664.39	€ 1,774,690.-	€ 3,027,524.22	**€ 9,237,000**
Alternative 3 Large pier	€ 4,000,672.-	€ 2,121,900.-	€ 3,459,194.34	**€ 9,582,000**
Alternative 4 Artificial island	€ 4,891,160.56	€ 3,587,940.-	€ 4,666,704.56	**€ 13,146,000**

Appendix L: Design master plan

Figure A-9: Final design view 1
Figure A-10: Final design view 2
Figure A-11: Final design view 3

Figure A-12: Final design view 4
Figure A-13: Final design view 5
Figure A-14: Final design view 6

Appendix M: Final costs harbour design

In this appendix, the price of the major harbour elements and the facilities are indicated. In this price the material costs at the quarry in Anuradhapura, transportation costs and labour costs are all included. The prices are converted from Sri Lankan Rupees (SLRs) to Euro (€) based on the currency exchange rate between the Euro and Sri Lanka Rupees as on 3rd of October 2017.

Valuta rate 3 October 2017:

€ 1,00 = SLRs 180.00
SLRs 1,00 = € 00055

Dredging

In Table A-23, the cost estimation of the dredging works are provided. The top layer of the reef consists of small grained limestone as well as boulders. This layer will be dredged using a clamshell dredger. The boulders are used as core and toe material of the breakwater, whereas the small granular material is used for land reclamation. As this top layer does not provide enough boulders, a part of the core and toe material needs to be retrieved from the underlying layer. This layer cannot be immediately dredged, as this is a solid layer. Therefore, a drilling dredger must first loosen the solid layer, whereafter the clamshell dredger can retrieve the boulders from the reef. The remainder of the reef that must be dredged to reach the needed depths within the harbour basin will be dredged using a cutter suction dredger. The price of the clamshell dredger and the support vessels are taken from the PPTA (FCG ANZDEC and RDC, 2017b). The cost per unit of the cutter suction dredger is taken from Appendix K: Cost analysis MCA. As found in Abrahams (1974), the costs of drilling and blasting rocks under water can vary between €3.40 and €22.60 per m^3. To account for low productivity and to be on the safe side, it is assumed in Sri Lanka, the drilling and blasting of rocks will cost €20.00 per m^3. FCG ANZDEC and RDC (2017b) states that 30% of the subtotal needs to be added to account for profits and overhead cost. Combining all the costs of the different machines used for dredging, drilling and blasting as well as the overhead costs, the total dredging costs will come down to approximately 8.9 million euros.

Table A-22: Estimated price of dredging work

	Amount	Unit	Cost/unit	Price
Clamshell dredger	195,000	m^3	€6.82	€1,330,000
Support vessels	195,000	m^3	€12.89	€2,514,000
Drilling and blasting	73,000	m^3	€20.00	€1,460,000
Cutter suction dredger	72,000	m^3	€21.19	€1,526,000
Subtotal				€6,864,000
Profits & overhead costs	30%			€2,059,000
Total				€8,923,000

Breakwater

The breakwater design is determined in Appendix N. Figure A-15 presents the breakwater cross-section. The breakwater consists out of three different types of material: rock armour layer, core material and toe material. To determine the amount of material needed, the shape of the breakwater as well as the depth need to be taken into account. The amount of material is calculated by determining formulas for the area (m^2) for each type of material with the depth as variable. This area is multiplied by the length of the breakwater at that specific depth, resulting in the amount of material per type of rock (m^3) for that specific depth. The total sum of the amount of material (m^3) per depth indicates the necessary amount of rock for that type of material. The results of this calculation can be found in Table A-23.

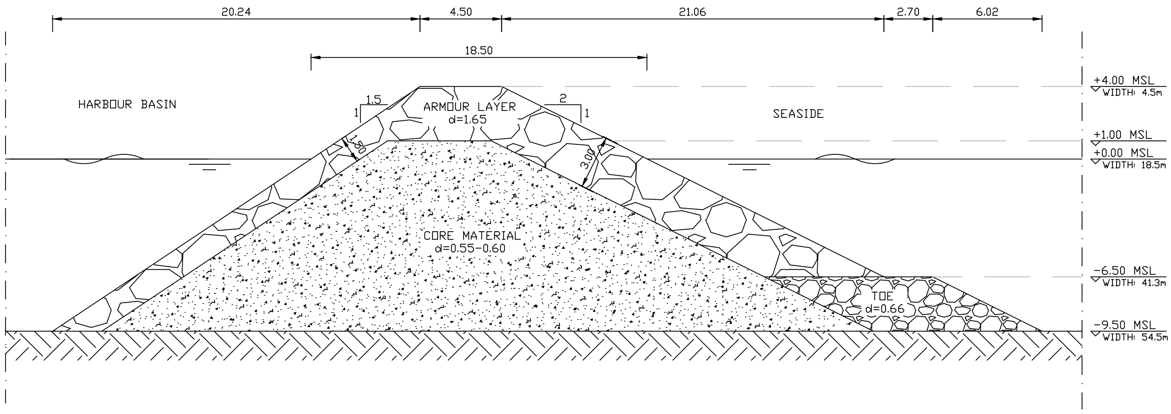


Figure A-15: Cross-section breakwater

The rock armour that will be used is around 5.8 tonnes per boulder. Assuming that the same quarry of the feasibility study of FCG ANZDEC and RDC (2017b) will be used, the price of the armour rocks including the transport, labour and placement costs will be €46.11 per m^3. The excavated limestone from the reef inside the harbour will be used as the core and the toe of the breakwater. As the material comes directly from the site, the costs are relatively low. The costs only include transportation costs from onshore to offshore, placement and labour costs. All costs combined form the total costs of the breakwater, which comes down to €5,751,000. In all costs the labour and overhead costs are included in this price, as they are part of the cost/unit. The full calculation can be found in Table A-23.

Table A-23: Estimated price breakwater

	Amount	**Unit**	**Cost/unit**	**Price**
Rock armour	112,000	m^3	€46.11	€5,164,000
Core material	143,000	m^3	€3.62	€518,000
Toe material	13,000	m^3	€5.27	€69,000
Subtotal	268,000	m^3		€5,751,000

Quay wall

To indicate the price of the materials the feasibility study of FCG ANZDEC and RDC (2017b) is used. FCG ANZDEC and RDC (2017b) estimated that the construction cost, the pouring of the concrete elements and placement of all the material (labour), is equal to 80% of the total amount of the material cost. Table A-24 provides the outcome of the cost analysis of the quay wall. The total costs of the quay wall comes down to approximately 23.5 million euros.

Table A-24: Estimated price of quay wall				
	Amount	**Unit**	**Cost/unit**	**Price**
Concrete block wall	21,663	m^3	€556	€12,045,000
Concrete working platform	1,071	m^3	€556	€595,000
Gravel foundation	8,925	m^3	€44.5	€397,000
Geotextile	5,855	m^2	€4.17	€24,000
Subtotal				**€13,061,000**
Labour				€10,449,000
Total				€23,500,000

Jetties
Two type of jetty structures are considered, the jetty for the IDAY boats and the jetties for the IMUL and IIMUL boats. The unit cost for jetties is based on the rate of the Fisheries Department of Sri Lanka of current Jetty Projects (FCG ANZDEC and RDC, 2017b), resulting in a unit cost of 1,000,000 SLRs per meter jetty (€5,555.55 / m). The length of the jetties is the sum of the length of the double finger jetties and the length of the jetty parallel to the breakwater. This lengths are taken from the 50-year design values. However, it might be possible to construct only a part of the jetty in the beginning years. The total price of the construction of the jetties (50-year design values) can be found in Table A-25.

Table A-25: Price estimation of the jetties				
	Length	**Unit**	**Cost/unit**	**Price**
IDAY, IMUL and IIMUL jetties	888	m	€5,556	€4,934,000

Harbour facilities
For the harbour facilities again the price estimations from the FCG ANZDEC and RDC (2017b) are used, as they have taken their estimations based on similar recently completed local projects. FCG ANZDEC and RDC (2017b) uses the same type of raft foundations; the area of the structures itself with a thickness of 0.3 meter. The cost of the foundation is included in the price. The specific costs per facility can be found in Table A-26, as well as the total approximate costs, which is €2,434,000.

Table A-26: Estimated price of harbour facilities		
Type of facility	**Area**	**Price**
Net mending hall	40 x 8m	€89,000
Auction hall	40 x 8m	€110,000
Loading area for trucks (attached to auction hall)	7 x 9m	€13,000
Off-loading building and ice-cold storage	60 x 25m	€274,000
2 storey building: facility for SL Navy and Coast guard	30 x 8m	€152,000
2 storey building: CFHC administrative office	25 x 8m	€128,000

Table A-26: Estimated price of harbour facilities		
3 storey building: Accommodation facility and CFHC storage	20 x 8m	€182,000
Toilet and shower facilities	9 x 4.5m	€14,000
Security facilities	-	€3,000
Wastewater treatments facilities	10 x 10m	€21,000
Water supply	10 x 10m	€21,000
Weighbridge and control room	3 x 20m	€13,000
Ice production plant	25 x 25m	€132,000
Fuelling facility	6 x 4m	€5,000
Boat lifting and mechanical repair workshop	20 x 40m	€169,000
Access road	6 x 750m	€950,000
Pedestrian way	1 x 750m	€158,000
Total		**€2,434,000**

Appendix N: Technical details; Breakwater

In order to design a breakwater a few design requirements have been set. The requirements have two functions; guaranteeing a structural integer breakwater and guaranteeing safety behind the breakwaters. Table A-27 shows the requirements set for this breakwater, with a short explanation on why a certain requirement is needed.

	Requirement	Explanation
1	The probability of failure of the breakwater structure during its lifetime (50-year) is 10%.	According to Verhagen, d'Angremond and Roode (2012) normally a probability between 5 and 20% is chosen during the design of a breakwater. For the design of the Point Pedro breakwater it is assumed that a probability of failure of 10% is sufficient.
2	The 50-year design storm, may not lead to sinking or severe damage to small fishery boats inside the harbour.	One of the main functions of the harbour is to give shelter to fishery boats during the northeast monsoon. If a storm causes severe damage to fishery boats it is not fulfilling this function.
3	The annual downtime of the harbour may not exceed 5%.	Severe storm surges may cause an amount of overtopping or wave transmission that makes it impossible for the harbour to keep operating.
4	During the construction phase the breakwater should be able to resist a 2-month design storm (non-monsoon tide).	During the construction of the breakwater it is required that all used materials in the breakwater can resist a 2-month storm. Otherwise it is difficult to construct a reliable breakwater. It is assumed that the breakwater is built during quiet wave conditions (May to October).

In the following of this appendix the design calculations are explained, concluded by a proposed breakwater design.

Wave characteristics

To determine the characteristic of the breakwater, first the applicable significant wave characteristics for the breakwater should be found. The available wave data is very limited, therefore the resulting wave characteristics found during the analysis are unreliable. Since a breakwater design cannot be made without knowing certain wave characteristics, assumptions are made when determining the wave characteristics.

From the analysis can be retrieved that the significant wave height with a return period of 50 years is equal to 3.0 m. Further, only wave measurements of January, May and June 2017 are available.

The significant wave height with a return period of two months during quiet conditions is found by using the wave data of May and June. Since these two months are not during the northeast monsoon it can be assumed that there will be quiet wave conditions in this period. Measurements of these two months consists of significant wave heights and the corresponding peak period every three hours. Significant wave height in a storm event with a return period of two months is taken as the largest significant wave height measured in this time. The result is a 2-month significant wave height of 0.7 m, with a corresponding peak period of 4.7 s.

Also the significant wave height with a return period of 475 years needs to be determined. The probability of failure from requirement 1 is translated into a return frequency by applying the following formula (Verhagen et al., 2012).

$$f = \frac{1}{t_L}\ln(1-p) = \frac{1}{50}\ln(1-0.1) = 2.1e-3\ s^{-1} \qquad \text{Eq. 4}$$

The found return frequency is equal to a return period of 475 years. In order to find the significant wave height for this return period it has been assumed that a Rayleigh (logarithmic) distribution describes the relation between the significant wave height and return period. Since only the significant wave height with a return period of 50 years is currently known, at least one other value has to be determined. It has been assumed that the highest measured significant wave height in January is the significant wave height with a return period of 1 year. This approximation is based on the fact that the month January is in the middle of the northeast monsoon. By extrapolating the Rayleigh distribution (based on the 1-year and 50-year significant wave heights) a significant wave height for the 475-year return period is found to be 4.2 m (Figure A-16).

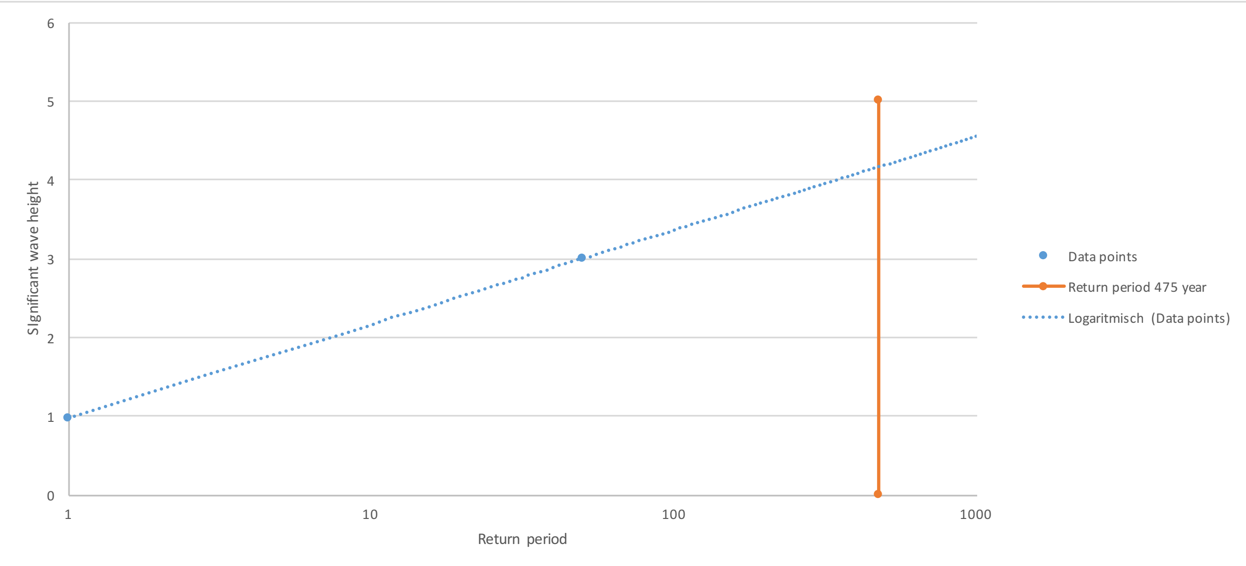


Figure A-16: Determination of the corresponding wave height of a 475-year return period

Composition of the breakwater

It is assumed that a rubble mound breakwater is designed in combination with an armour layer of rocks. This design choice has been made, because it is expected that it is the cheapest solution for the Point Pedro harbour due to the large availability of limestone in the Northern Province and on the proposed harbour location. This assumption is the basis of the complete breakwater design.

Crest height

First the crest height is determined. Requirement 2 and requirement 3 have influence on the required crest height of the breakwater. The crest freeboard required for satisfying requirement 2 is calculated using the wave overtopping formula proposed in Verhagen et al. (2012) with the input parameters shown in Table A-28. The resulting crest freeboard (R_c) is found to be 3.0 m.

$$\frac{q}{\sqrt{gH_{m0}^3}} = 0.2e^{-2.3\cdot\frac{R_c}{H_{m0}\gamma_F\gamma_B}} \qquad \text{Eq. 5}$$

Table A-27: Input parameters as result of requirement 2 (retrieved from Verhagen et al., 2012)			
	Parameter	**Value**	**Explanation**
q	Mean overtopping discharge [m³/s/m]	10	This value gives the design value preventing sinking of small boats set at 5 to 10m from the breakwater.
g	Gravitation constant [m/s²]	9.8	
H_{m0}	Significant wave height at breakwater [m]	3.0	The significant wave height with a return period of 50 years.
γ_f	Roughness factor [-]	0.4	The roughness factor determined for an armour layer consisting of rocks.
γ_B	Berm factor [-]	1	No berm will be used in this breakwater, because it is assumed that more material is required in that case.

To find if the crest freeboard (Rc) of 3.0 m is also sufficient to meet requirement 3, equation 5 is performed again. Table A-29 describes the current input parameters.

Table A-28: Input parameters to check requirement 3 (retrieved from Verhagen et al., 2012)			
	Parameter	**Value**	**Explanation**
q	Mean overtopping discharge [m³/s/m]	0.01	This value gives the design value for aware pedestrians on the breakwater.
g	Gravitation constant [m/s²]	9.8	
R_c	Crest freeboard [m]	3.0	Calculated crest height.
γ_f	Roughness factor [-]	0.4	The roughness factor determined for an armour layer consisting of rocks.
γ_B	Berm factor [-]	1	No berm will be used in this breakwater, because it is assumed that more material is required in that case.

It is found that the resulting significant wave height is equal to 1.8 m. According to Figure A-16 this value corresponds to a return period of five years.

Another event that can cause downtime in the harbour is wave transmission. According to Verhagen et al. (2012) the maximum wave height in fishery harbour is 0.4 m. Since there is no yearly overtopping also wave transmission due to overtopping in the harbour will not be a problem. Applying wave transmission formulas proposed by Verhagen et al. (2012) give negative outcomes for wave transmission, which is not realistic. It can be concluded that requirement 3 (downtime of the harbour) will be met for a crest freeboard of 3.0 m.

The crest height is equal to mean sea level (MSL) plus expected sea level rise plus mean high water spring plus the crest freeboard. In the analysis phase it has been determined that the expected sea level rise 0.4 m and the mean high water spring tide is 0.6 m. The resulting crest height is 4.0 m.

Armour layer

The armour material that will be used in the breakwater design is limestone rock. To determine the required armour layer grainsize the Van der Meer formula for plunging waves is used (Verhagen et al., 2012).

$$\frac{H_s}{\Delta d_{n50}} = c_{pl} p^{0.18} (\frac{S}{\sqrt{N}})^{0.2} \xi_m^{-0.5} \qquad \text{Eq. 6}$$

The values in Table A-29 are used as input parameters. The resulting nominal average grainsize of the armour layer has to be equal to 1.65 m. Assuming a density of limestone of 2,500 kg/m³ results in average armour rock weight of 5.8 ton.

Table A-29: Armour layer grainsize input parameters (retrieved from Verhagen et al., 2012)

	Parameter	**Value**	**Explanation**
H_s	Significant wave height [m]	4.2	The significant wave height with a return period of 475 years. This return period is required to reduce the probability of failure of the armour layer during the lifetime of the harbour to 10% (requirement 1).
Δ	Relative density [-]	1.5	The relative density is the density of limestone (2500 kg/m³) relative to the density of water (1500 kg/m³).
c_{pl}	Design value [-]	5.5	A c_{pl} value of 5.5 should be taken into account during the design phase.
P	Permeability factor [-]	0.5	The permeability factor for a breakwater with an armour layer on the core is 0.5.
S	Damage factor [-]	3.0	This value indicates some damages to the armour layer, but the armour layer does not fail.
N	Number of waves during design storm [-]	3,600	This is the number of waves occurring in a storm event of 8 hours, when the wave period is equal to 8 seconds (equal to the found peak period).
tan α	Breakwater slope [-]	0.5	A slope of 1:2 is assumed on the outer breakwater.
T	Period [s]	8	This is the assumed period, based on the 50-year peak period. Another value cannot be found due to lack of information.
ξ_m	Iribarren number [-]	2.4	Indicates plunging wave breaking. This has been calculated by the following formula: $$\xi_m = \frac{\tan\alpha}{\sqrt{\frac{2\pi}{g}\cdot\frac{H_s}{T^2}}}$$

It is chosen that the armour layer will have two layers on the sea side of the breakwater on a slope of 1:2. The layer thickness can be calculated using the equation 7.

$$t_f = n \cdot k_t \cdot d_{n50} = 2 \cdot 0.92 \cdot 1.65 = 3.0m \qquad \text{Eq. 7}$$

The k_t value is retrieved from Verhagen et al. (2012) for a random shaped rock armour layer. It chosen to have a leeside slope of 1:1.5 with an armour layer thickness of 1. It is found that the layer thickness is 1.50 m. The leeside slope is chosen to be steeper since less forces act on this part of the breakwater and it safes a lot of material.

Crest width

A design rule for the crest width is that the crest width should at least consist of three times the width of armour material (Verhagen et al., 2012). Using equation 3 again results in a minimum crest width of 4.5 m. This crest width is assumed to be sufficient for the breakwater since it does not facilitate other activities than wave sheltering.

Core material

During the site visit it was remarked that the reef at the Point Pedro harbour consist of large rocks, it is estimated that the sizes of the block range between 0.35 m and 1.0 m (Appendix C). For constructing the quay walls and onshore area a large part of these blocks needs to be excavated. In order to reduce the disposal costs of the project this material will be used as core material of the breakwater. It has been required that stability of the breakwater should be sufficient to resist a 2-month design storm. In order to calculate if this is sufficient equation 8 is used (retrieved from Verhagen et al., 2012).

$$d_{n50} = \frac{1}{(c_{pl} \cdot P^{0.18} (\frac{S}{\sqrt{N}})(S_{m-1.0})^{0.25} \sqrt{\cot\alpha} \cdot \frac{\Delta}{H_{2\%}}} \qquad \text{Eq. 8}$$

The required grainsize during construction is 0.3 m, based on the input values given in Table A-30. It is found that the excavated material can used as core material of the breakwater.

Table A-30: Input parameter for core calculations (retrieved from Verhagen et al., 2012)

	Parameter	Value	Explanation
$H_{2\%}$	Wave height with probability of exceedance of 2% [m]	0.98	It is found that the 2-month significant wave height is equal to 0.7 m. This translated to $H_{2\%}$ by multiplying H_s by 1.4.
Δ	Relative density [-]	1.5	From analysis it is retrieved that the project site consists of limestone only.
c_{pl}	Design value [-]	6.2	A c_{pl} value of 6.2 is sufficient during construction phase.
P	Permeability factor [-]	0.6	The permeability factor for a breakwater with a core only is 0.6.
S	Damage factor [-]	5.0	This value indicates failure of the core.
N	Number of waves during design storm [-]	6,809	This is the number of waves occurring in a storm event of 8 hours, when the wave period is equal to 4.2 seconds (0.9 • T_p = 0.9 • 4.7). The peak period has been measured together with 2-month significant wave height.
tan α	Breakwater slope [-]	2	A slope of 1:2 is assumed on the outer breakwater.
$s_{m-1.0}$	Wave steepness [-]	0.04	Wave steepness has been determined using the following formula: $s_{m-1.0} = \frac{2\pi \cdot H_{2\%}}{g \cdot T_{m-1.0}} = \frac{2\pi \cdot 0.98}{9.8 \cdot 4.2} = 0.04$

According to Verhagen et al. (2012) it is required to have a sufficient grainsize in the core to ensure stability of the armour layer. The minimum required weight of the core material should be equal to weight of the armour material divided by 25. This results in a minimum weight of the core material of 300 kg. If the weight is calculated into a grainsize, the grainsize would be 0.3 m. It is found that the core material is sufficiently large to guaranty a safe structure during and after construction of the breakwater.

Breakwater toe

The breakwater toe is designed to ensure the structural integrity of the armour layer. According the Verhagen et al. (2012) no heavy armour is needed in water depths lower than 1.5 times the significant wave height. This book also proposes a formula to determine the grainsize required in the toe (Eq. 9).

$$\frac{H_s}{\Delta d_{n50}} = (6.2(\frac{h_t}{h})^{2.7} + 2)N_{od}^{0.15} \qquad \text{Eq. 9}$$

Equation 5 can be used since the water depth is 8.5 m and the water level on top of the toe is 6.5 m. It is found that the required grainsize in the toe will 0.66 m. A description of the input values is given in table Table A-31.

Table A-31: Input parameters for toe calculation			
	Parameter	Value	Explanation
$\mathbf{H_s}$	Significant wave height [m]	4.2	This is the significant wave height with a return period of 475 years. This value is chosen to meet requirement 1.
	Relative density [-]	1.5	From analysis it is retrieved that the project site consists of limestone only.
$\mathbf{h_t}$	Water level above toe [-]	6.5	Assumed height of the toe is 4 m.
h	Water depth [-]	9.5	Water depth at the breakwater.
$\mathbf{N_{od}}$	Damage factor [-]	1.0	This indicates no damage is allowed.

According to Verhagen et al. (2012) the width of the toe is approximately four times the grainsize used inside the toe. For this situation it would mean that the width of the toe is 2.7 m. Since the toe material has a nominal grain size of less than a meter, also this material can be retrieved from the project site when sufficient material is available. Large blocks should be sieved out of the recovered material in this case.

Appendix O: Technical details; Quay wall

The most likely quay wall types are gravity walls as the rockhead is close to the bottom surface of the harbour basin. For this reason, sheet pile walls are not a viable option as they cannot be driven or vibrated into place. The remaining possible types of gravity walls are block walls and T- and L- shaped walls. The T- and L- shaped walls are not possible to construct, as next to the base of the quay wall, the limestone slope is present. Due to this limestone slope these quay wall types cannot be embedded. The most viable option is therefore the block type gravity wall.

It is assumed that BH03 from the Geotechnical study performed by FCG ANZDEC & RDC is applicable to the entire length of the quay wall. To apply the borehole to the deeper location of the quay wall the upper three meters are disregarded. Meaning that the stratigraphy is expected to start at three meters in the borehole, which is equal to six meters below mean sea level. The borehole can be found in Figure A-17. As can be seen from the data in the borehole, the upper half meter of limestone is weak and highly weathered.

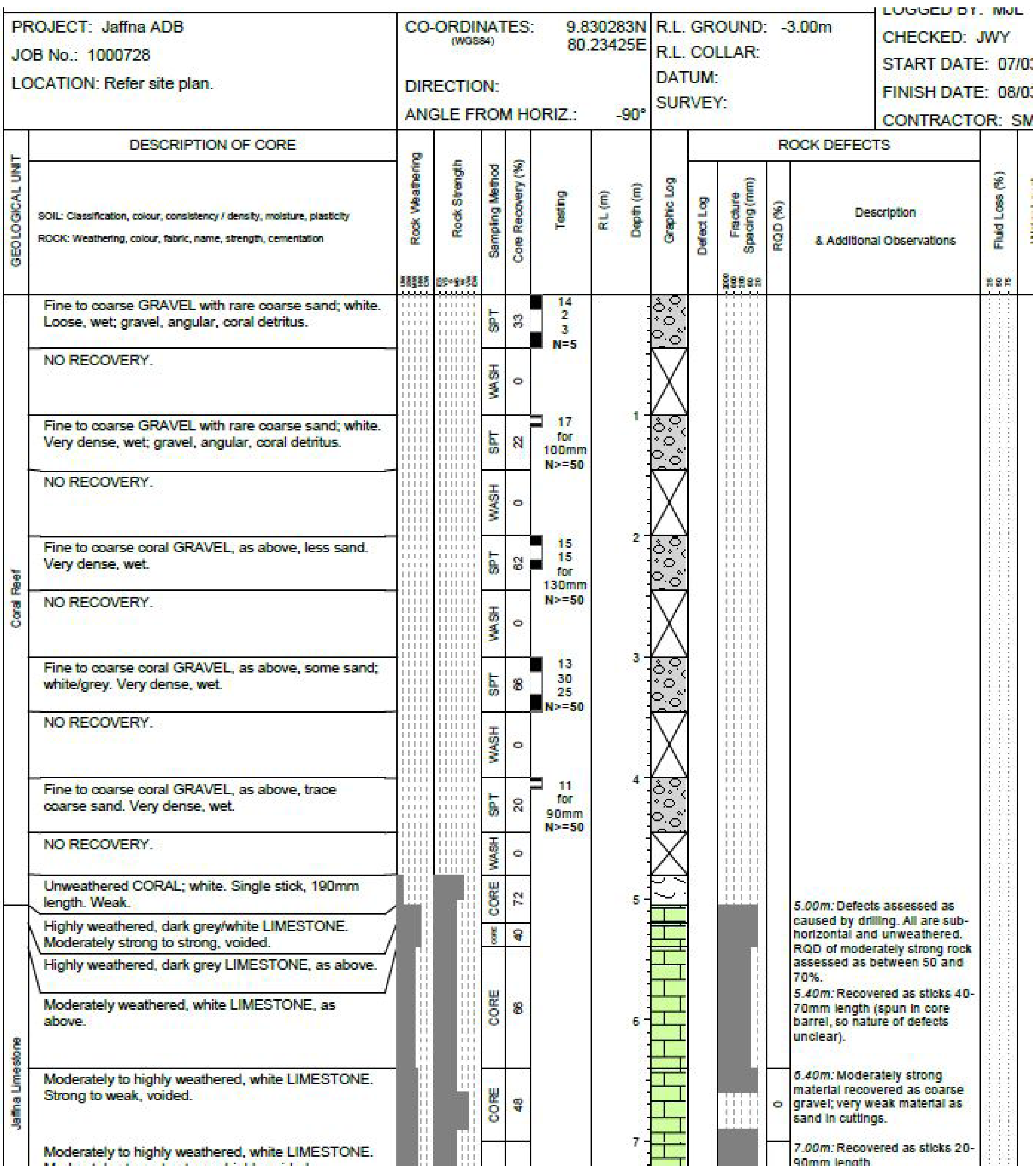


Figure A-17: BH03 (FCG ANZDEC, 2016)

To create a safe quay wall in general a gravel backfill foundation with thickness of 1.0 m is assumed to be sufficient. However, as this would leave only 1.0 meter of dense coarse coral gravel in place above the highly weathered limestone, it was opted to remove these extra 1.5 meters of highly weathered limestone and place a gravel backfill of 2.5 meters below the structure to serve as foundation. Behind the quay wall the slope of limestone is covered with a backfill of homogeneous sand.

Design calculations

The safety of the design of the quay wall is tested for sliding failure and overturning as these two failure mechanisms are most likely to occur at the project location. Bearing and slip failure are not included in the analysis as the foundation of the structure is placed on rock, both these failure mechanisms are related to foundations on soil. In Table A-32 the material properties which are used in these calculations are shown. It is assumed that for the friction angle below the quay wall the following formula can be applied (Eq. 10):

$$\delta = \frac{2}{3} \cdot \phi \qquad \text{Eq. 10}$$

It is also assumed that the porosity of the quay wall is 0.25 and the coefficient of active earth pressure (Eq. 11) and passive earth pressure (Eq. 12) are respectively calculated by:

$$K_a = \frac{1-\sin\phi}{1+\sin\phi} = 0.24 \quad \text{and} \quad K_p = \frac{1+\sin\phi}{1-\sin\phi} = 4.2 \qquad \text{Eq. 11 \& Eq. 12}$$

Table A-32: Material properties

Material properties	Symbol	Value
Density concrete[1]	γ_c	23.5 kN/m³
Density dry sand[2]	γ_{sd}	15.7 kN/m³
Density wet sand[3]	γ_{sw}	19.0 kN/m³
Density seawater	γ_w	10.25 kN/m³
Friction angle sand[4]	φ	38°
Friction angle below quay wall	δ	25.3°
Quay wall porosity	n	0.25
Coefficient of active earth pressure	K_a	0.24
Coefficient of passive earth pressure	K_p	4.2

[1] - Dorf (1996)
[2] - AVCalc LLC (2017)
[3] - FCG ANZDEC (2016)
[4] - Geotechdata (2013)

The geometry which is used in the calculations is set out in Table A-34. It is assumed that the quay wall will function as one structure and will not fail itself. If the block wall is constructed properly this assumption is valid. The width as given in Table A-34 is the result of several iterations varying the width until an optimum value was found. The calculations as performed for the optimal situation are shown.

Table A-33: Geometry of the quay wall		
Geometry	**Symbol**	**Value**
Total height quay wall	H	8.2 m
Width quay wall	B	3.7 m
Embedded depth quay wall	h_3	1.0 m
Groundwater level	h_2	7.0 m
Lowest seawater level	LSL	6.6 m
Construction height above MSL	h_1	1.2 m
Thickness concrete slab	T	0.8 m
Total height backfill	-	2.5 m

There are three additional loads acting on the quay wall, these are given in Table A-35. The load of the concrete slab is determined for the initial case (0.3 meters) and the ultimate case (0.8 meters). The quay wall will be heightened to the ultimate case if this is necessary to keep it serviceable.

The load which is imposed due to the largest IIMUL boat is calculated by taking the tidal difference, +0.6 to -0.4 meter, which has a maximum of 1 meter. Multiplying this by the area of the IIMUL boat gives $30 \cdot 5 \cdot 1 = 150$ m^3 of water. This volume is multiplied with the specific weight of the seawater, resulting in 1,537.5 kN of load. Assuming the boat is attached to two docking points an additional point load facing down of 769 kN is taken into account.

Table A-34: Loads acting on quay wall		
Loads per meter quay wall	**Value**	**Amount**
Vertical design load	F_d	70 kN/m
Concrete slab load initial case	$F_{c,i}$	24.7 kN/m
Concrete slab load ultimate case	$F_{c,u}$	65.8 kN/m
Load due to berthing of boats		769 kN

Safety factors

Partial safety factors need to be applied, they are given in Table A-36 and Table A-37 (Normcommissie 351 006 Geotechniek, 2012). Table A-36 shows the partial safety factors for loading, these are applied to the overturning failure. Table A-37 gives the partial safety factors for resistance of soil retaining structures, these are applied to the sliding failure.

Table A-35: Partial safety factors for loading (Normcommissie 351 006 Geotechniek, 2012)		
Belasting	**Symbool**	**Waarde**
Blijvend Ongunstig[a] Gunstig[b]	 $\gamma_{G;dst}$ $\gamma_{G;stb}$	 1.1 0.9
Veranderlijk Ongunstig[a] Gunstig[b]	 $\gamma_{G;dst}$ $\gamma_{G;stb}$	 1.5 0

Table A-36: Partial safety factors for resistance of soil retaining structures (Normcommissie 351 006 Geotechniek, 2012)

Weerstand	**Symbool**	**Verzameling**		
		R1	R2	R3
Draagkracht	$\gamma_{R;v}$	1.0	1.4	1.0
Horizontaal glijden	$\gamma_{R;h}$	1.0	1.1	1.0
Grondweerstand	$\gamma_{R;e}$	1.0	1.4	1.0

Sliding failure

Sliding occurs when the net horizontal force is larger than the friction force. The net horizontal force is calculated by active force minus by the passive force. These forces acting on the quay wall are schematically shown in Figure A-18.

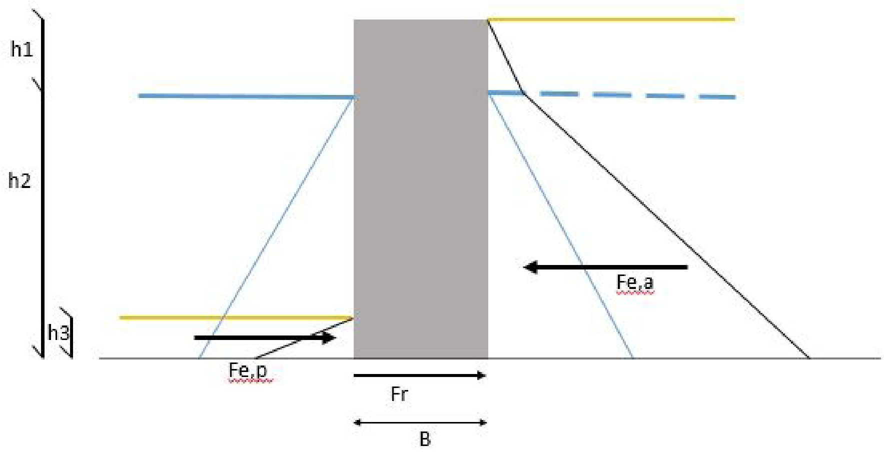


Figure A-18: Sliding forces quay wall (own illustration)

The active force is calculated by the following formula:

$$Q_a = K_a \cdot (0.5 \cdot \gamma_{sd} \cdot h_1^2 + \gamma_{sd} \cdot h_1 \cdot h_2 + 0.5(\gamma_{sw} - \gamma_w) \cdot h_2^2) = 85.8kN \quad \text{Eq. 13}$$

And the passive force is calculated by the following formula:

$$Q_p = K_p \cdot (0.5 \cdot h_3^2 \cdot (\gamma_{sw} - \gamma_w)) = 18.4kN \quad \text{Eq. 14}$$

As drainage is designed to be good to prevent surcharges and to reduce the possibility of piping, it is assumed that both water pressures are not of influence. This results in a net horizontal force, the driving force, on the quay wall of 85.8 - 18.4 = 67.4 kN.

The resisting force is the friction force due to the weight of the quay wall and the loads which act on the quay wall. The partially submerged weight of the quay wall is added to the load of the concrete slab in the initial case. The initial case gives the least amount of friction as the weight is the smallest. The other loads are disregarded as they would benefit to the resisting forces and thus would not give the most critical case. The blocks are assumed to consist out of massive concrete. This results in the following formula:

$$F_r = \tan(\delta) \cdot (H \cdot B \cdot \gamma_c - h_2 \cdot B \cdot \gamma_w \cdot (1-n) + F_{c,i}) = 255.0kN \quad \text{Eq. 15}$$

The driving force is multiplied by a partial safety factor of 1.1 and the resisting force is divided by a partial safety factor of 1.1 as given in Table A-36. The factor of safety against sliding results in:

$$FoS = \frac{231.8}{74.1} = 3.13 \quad \text{Eq. 16}$$

Overturning failure

Overturning failure can occur when a structure experiences a large difference in horizontal forces. Failure occurs when the eccentricity is larger as $^1/_6$ of the width of the structure.

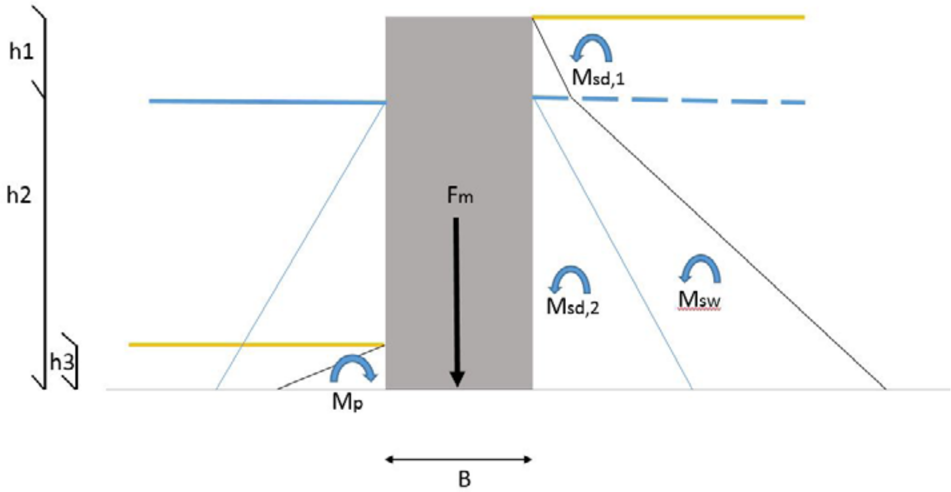


Figure A-19: Moments working on the quay wall (own illustration)

As can be seen in Figure A-19, there are four moments acting on the quay wall, one negative moment due to the passive earth pressure and three positive moments due to the active soil load. The sum of the moments is divided by the force due to the mass of the structure. When determining the moments, the loads that increase with depth act on $^1/_3$ of the height over which they apply. The loads which are constant over depth act on $^1/_2$ of the height over which they apply.

The load due to the dry sand above the water table increases with depth and thus acts on $^1/_3$ of the h1. This moment is calculated by:

$$M_{sd,1} = (K_a \cdot 0.5 \cdot h_1^2 \cdot \gamma_{sd}) \cdot (h_2 + \frac{1}{3} \cdot h_1) = 20.1kNm \quad \text{Eq. 17}$$

The load due to the dry sand below the water table is constant over depth and thus acts at $^1/_2$ of h2. This moment is calculated by:

$$M_{sd,2} = (K_a \cdot h_1 \cdot h_2 \cdot \gamma_{sd}) \cdot (\frac{1}{2} \cdot h_2) = 110.8kNm \quad \text{Eq. 18}$$

The load due to the wet sand increases with depth and thus acts on $^1/_3$ of the h2. This moment is calculated by:

$$M_{sw} = (K_a \cdot 0.5 \cdot h_2^2 \cdot (\gamma_{sw} - \gamma_w)) \cdot (\frac{1}{3} \cdot h_2) = 120.1kNm \quad \text{Eq. 19}$$

The passive load resulting in a moment counteracting overturning increases with depth as well, therefore this acts on $^1/_3$ of h_3. This is calculated by:

$$M_p = -(K_p \cdot 0.5 \cdot h_3^2 \cdot (\gamma_{sw} - \gamma_w)) \cdot (\frac{1}{3} \cdot h_3) = -6.1kNm \qquad \text{Eq. 20}$$

The sum of moments acting on the quay wall is 244.9 kNm. The resisting force against overturning is the mass of the quay wall, this mass is calculated with the following formula:

$$W_q = H \cdot B \cdot \gamma_c - h_2 \cdot B \cdot \gamma_w \cdot (1-n) + F_{c,i} = 538.6kN \qquad \text{Eq. 21}$$

According to Table A-36 the partial safety factor for the driving force is 1.1, and the partial safety factor for the resisting force is 0.9. The eccentricity is then determined using:

$$e = \frac{1.1 \cdot \Sigma M}{0.9 \cdot \Sigma W_q} = 0.56m \qquad \text{Eq. 22}$$

As the entire foundation is in compression the eccentricity needs to be within $^1/_6$ of the width, which is 0.62 m. As in the case of a foundation width of 3.7 meters thus the structure is safe against overturning.

Thus if the quay wall has dimensions as set out in Table A-34 (width of 3.7 m, 1.0 m embedding and a total height of 8.2 m) the structure is safe.

Appendix P: Technical details; Jetties

Jetties

Resting of the vessels will be done with the use of jetties. Chapter 2.6 Harbour dimensions describes the possible berthing arrangements for resting areas. For resting, five types of jetties are possible, it depends on the type of vessel which berthing arrangement will be the most suitable.

First, the IDAY boats are considered. The amount of IDAY boats will not increase during the 50-year lifetime as the production of this type of boats is now prohibited. In total 65 boats need to be able to rest in the harbour every day. The resting area for IDAY is located west in the shallow basin area. As the IDAY boats need daily berthing a berthing type with easy manoeuvring possibilities is chosen. The boats will berth perpendicular to the jetty, on two sides of the jetty. As for perpendicular berthing the width of the berthing area will be 3.9 m, see 2.6 Harbour dimensions, the minimal required length of the jetty will be 65 • 3.9 = 253.5 m. With the use of finger jetties, berthing on two sides is possible, decreasing the jetty length with a factor two: 253.5/2=126.75m.
As the available basin width is 120 m, at least two jetties are required. One jetty of 70 m and one jetty of 60 meters will be considered to provide a jetty length of 130 meters. The spacing between these jetties is divided in three different parts, see Figure A-20: Dimensions jetty area IDAY, the spacing between the breakwater and the longest jetty, the spacing between the two jetties and the spacing between the quay wall and the jetty. It is assumed that the channel between the jetties needs to be wide enough for two-way traffic. However, as the vessels are only 3 meter wide, the smallest inner channel width is chosen, $8 \cdot B_s = 8 \cdot 3 = 24$ m (appendix 2.6).The length of the boats during perpendicular berthing is 9 m (Table 14 in 2.6 Harbour dimensions). The width of the jetties will be one meter. Figure A-20 gives an overview of the desired spacing.

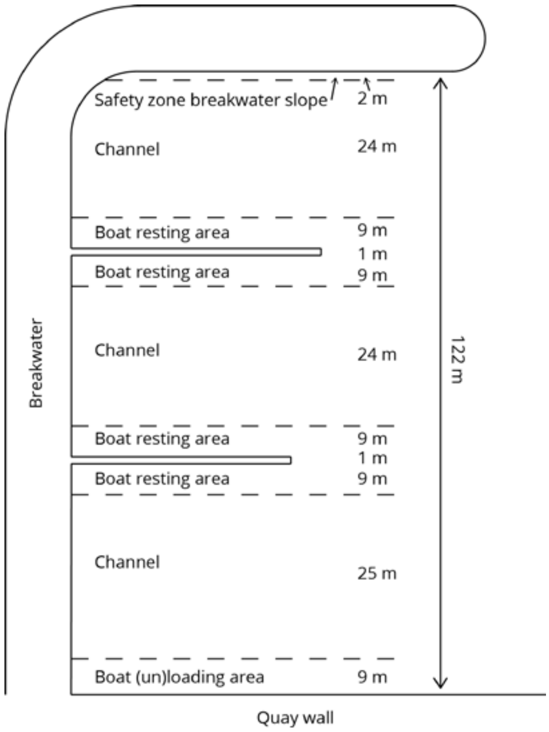


Figure A-20: Dimensions jetty area IDAY

The jetties for the IIMUL and IIMUL vessels will be designed to provide shelter for all the boats of the 50-year design values. In total that will be 66 IIMUL boats and 294 IMUL boats. As both type of vessels are large, parallel berthing will be more sufficient. It is assumed that during season parallel berthing to the jetty is possible and during monsoon period boats will lay parallel side-by-side (stacked) of the jetty.

The IMUL boats are sailing at sea for two weeks. Once in every two weeks they will enter the harbour to unload their catch. In general, these boats stay in the harbour for one day. As it is irregular when the vessels will enter, it is assumed that during peak time two times the daily amount of vessels will enter simultaneously. The IIMUL boats are at sea for three weeks. Also due to their irregular arrival, it is assumed that the peak flow of IIMUL boats during the fishery season will be three times the average daily amount. Table A-38 provides the required capacity and jetty length for the 50-year design values.

Table A-37: 50-year scenario IMUL and IIMUL		
	IMUL	**IIMUL**
Inner channel width	27 m	45 m
Amount of boats	294 boats / 14 days	66 boats / 21 days
Amount of boats during peak time in season	294 / 14 x 2 = 42 boats	66 / 21 x 3 = 10 boats
Resting capacity monsoon	294 boats	66 boats
Resting amount of boats during season	42 boats	10 boats
Required jetty length per boat Parallel berthing during season	17.3 m / boat	34.5 m /boat
Required jetty length Parallel berthing during monsoon	16.5 m / boat	33 m / boat
Required jetty length Parallel berthing during season	17.3 x 42 = 727 m	34.5 x 10 = 345 m

For a first estimation a jetty of 260 m and a jetty of 200 m are assumed, as these lengths will be suitable in the design. To indicate the spacing between the jetties the monsoon period is considered. It is assumed that IIMUL boats can berth six times side-by-side. A jetty length of 363 m is required: 66 / 6 = 11 boats, 11 • 33 = 363 m.

For the IMUL boats, (260 • 2 + 200 • 2) - 363 = 557 m can be used. For normal side-by-side resting IMUL boats need 16.5 m length, meaning that 557 / 16.5 = 34 boats can lay parallel to the jetty. As 294 boats need to berth, this means that the IMUL boats need to lay, 294/34= 8.65, nine boats thick. This is considered possible according to Ligteringen and Veslink (2014).

During the monsoon period a one-way entrance channel is assumed to be sufficient for manoeuvring. IIMUL boats are resting with six boats side-by-side, resulting in 6 • 5 + 45 (inner channel) = 75 m. This spacing is between the jetty and the breakwater, as the breakwater slope, 1:1.5, influences the depth, an additional 6 • 1.5=9 m will be necessary for enough manoeuvring area. This results in: 75+9=84 m.
The IMUL boats are resting with nine boats side-by-side, resulting in 9 • 4 + 5 • 2(two jetty sides) + 27(inner channel) = 108 m spacing, see Figure 47.

Table A-38 shows that in total during season 727 + 345 = 1,072 m of jetty is required. During the season no side-by-side resting places are considered, giving the opportunity to make use of the jetty length between the main jetties. The length of the usable jetty area will be 240 • 2 + 220 • 2 + 108-10 (two times the width of the IMUL) = 1,018 m. An additional 54 m of resting can be found between the first finger jetty and the tanking area.

Concluding that two jetties, one of 260 m and one of 200 m, will be sufficient for the 50-year lifetime during fishing season and monsoon season. The spacing between the breakwater and the 240 m jetty will be 60 m and the spacing between the two jetties will be 108 m. The jetties will have a width of 2 m.

For easy berthing and convenient construction floating jetties are considered. This type of jetty can be constructed with pile placement where the jetty can be attached. The advantage of a floating jetty is the possibility to adapt to the water level variation. Currently the jetties will not be used for loading and unloading purposes, meaning that no (small) vehicles are allowed to drive on the jetty. In the future, the jetty can be constructed as a solid pier, able to transfer loads with cars, to expand the amount of quay wall.

Appendix Q: Technical details; Onshore facilities

In the design of the onshore constructions there are two possible types of foundations, a piled or a raft foundation. The soil on which the structures are to be placed is a backfilled homogeneous sand layer, which has an average thickness of 2.5 meters. As a sand layer is a strong soil and since the material is homogeneous no differential settlement is expected. Because of this, the most viable option is to construct on a raft foundation. The actual foundations of the onshore facilities are not designed in detail in this report.

To determine if the strength of the backfilled sand is sufficient for bearing of the raft foundation of the harbour facilities a first estimate is given by using the Brinch-Hansen formula. The Brinch-Hansen formula is given by:

$$p = i_c \cdot s_c \cdot c \cdot N_c + i_q \cdot s_q \cdot q \cdot N_q + i_\gamma \cdot s_\gamma \cdot \frac{1}{2} \cdot \gamma \cdot B \cdot N_\gamma \qquad \text{Eq. 23}$$

In the formula, p indicates the ultimate acceptable foundation pressure. In this case the facilities will be constructed on sand, therefore the cohesion is zero. As the load is expected to be perpendicular to the foundation the inclination factors are one. Additionally it is assumed that no additional surcharge is placed on the soil surrounding the foundation. This reduces the formula to:

$$p = s_\gamma \cdot \frac{1}{2} \cdot \gamma \cdot B \cdot \gamma \cdot N_\gamma \qquad \text{Eq. 24}$$

It is assumed that the load is distributed homogeneous and that this load is applied to a square footing of one meter by one meter. The unit weight of the sand is taken at 15.7 kN/m^3. This is the same value as used for the dry sand in the calculations of the quay wall. The N_γ is taken at 74.899 (Verruijt, 2001) and the s_γ is taken at 0.7 (Verruijt, 2001), this results in a ultimate bearing pressure of the soil is therefore 412 kN/m^2 (Verruijt, 2001). This is relatively high and therefore it is assumed that this is sufficient bearing strength. Concluding that a raft with the same area as the structure is already sufficient.

Appendix R: Harbour impact; Infrastructure

In this appendix, the five main infrastructural pressure points are explained. The five pressure points correspond to the five numbers in Figure 52 on page 73 in chapter 4.2 Harbour impact.

1. Intersection of the main trading routes and the entrance of the harbour.
The entrance of the harbour will be the main junction connecting the harbour to all infrastructure outside the harbour. Therefore, traffic using this junction will increase significantly. If the traffic is not regulated at this pressure point, traffic will have difficulty passing this point and traffic jams will occur. To overcome this problem, a roundabout is proposed right before the entrance of the harbour. As five roads join at this junction, a roundabout seems the best solution to handle the increase in traffic. Also, the road along the coastline as well as the road leading to the centre of town will be widened and improved.

2. Girls high school close to the harbour and along route A.
The Methodist Girls High School located at point 2 is one of the oldest schools in Sri Lanka, as it was founded in 1823 (Steve, 2017). Therefore, this school has a lot of emotional value to the inhabitants of Point Pedro and surrounding villages. It is very important to the divisional secretary of Point Pedro the school will experience little to no nuisance from the existing harbour. As the harbour stretches beyond the school, the school will look out over the harbour. However, as the IDAY boats are located at the west side of the harbour, the view from the school will not be negatively influenced by the presence of large multiday boats right in front of the school. Also, as the road that runs in front of the school will be improved, the school will benefit from this as well.

3. Small bypass-road that will most likely be used in case of a traffic jam.
In case the main road running through town will become too busy, drivers might use the road running almost parallel to the main road. This road is however much narrower than the main road, and will get congested easily, which will cause nuisance for inhabitants. To prevent this, traders need to be discouraged to use this road. This pressure point might become a problem in the farther future if the main route through Point Pedro town cannot accommodate all the traffic anymore. This pressure point will have to be monitored closely, and in case traffic will get congested, an expansion of this bypass road will be an option.

4. Point Pedro's main square can become a bottleneck.
The main road runs along two sides of the main square of the village, where most shops, restaurants and the Point Pedro fishery market are located. As the building density in this area is relatively high and traffic need to be able to park at this location, again, congestion might become a problem. As with pressure point 3, no direct problems are expected, but again, this area needs to be closely monitored, and the current traffic situation might have to be adjusted to meet the needs of the future.

5. Stores and shops along the road block further expansion.
As previously mentioned, the main road crossing Point Pedro will have to be widened. However, this can only be done up to a certain point, since dwellings and shops are present at either side of the road. This limits the possible width of the main road, and it will not be possible to widen the road by more than two lanes without drastically changing the entire infrastructure in the centre of town.

PROJECT POINT PEDRO
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