A study on the reconstruction of Los Acantilados Beach

Final Report

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General notice to the reader:

In the academic programme for Hydraulic Engineering we have in the 4th year (i.e. in the first year of the Master Programme) the requirement that students should do in a group of four to six persons a so-called "groupwork". It is also called "Master Project". During this groupwork they should make a full design of something. The work should be integral, starting with terms of reference, and ending with the real design. This can be a structure, but also it can be a harbour lay-out, a policy plan design, etc. The total time available for the project is in the order of two months and will provide 10 European Credits. It has to be practical and applied.

It is certainly not an M.Sc. thesis assignment (the thesis work is individual, 6 months and more focussed on research or advanced design work on details). But it is also not an appren-
ticeship, internship or traineeship where the student has to work together with a group of experienced people. For this groupwork they have to solve the problem on their own (of course with guidance).

This report is the result of such a Master Project. This report has been assessed by staff of TU Delft. It has been provided with a passing mark (i.e. a mark between 6 and 10 on a scale of 10), and consequently considered sufficient for publication.

However, this work has not been fully corrected by TU Delft staff and therefore should be considered as a product made in the framework of education, and not as a consultancy report made by TU Delft.

The opinions presented in this report are neither the opinions of TU Delft, neither of the other sponsoring organisations.

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A study on the reconstruction of Los Acantilados Beach

Final Report
Project group Argentina 2004
Master Project of Faculty of Civil Engineering
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Preface

This report is written within the scope of the Master Project at the faculty of Civil Engineering of Delft University of Technology in The Netherlands. The study of a coastal erosion problem in Argentina was carried out by four students of different specializations within civil engineering.

The research was performed in Mar del Plata (Argentina) at the "Centre of Coastal Geology and Quaternary Research" of the Universidad Nacional de Mar del Plata (National University of Mar del Plata). Without the extensive support received from many different people during the research and stay in Mar del Plata, this study would have never been possible. Hereby, we would like to thank everybody who supported us during our stay and some of them in particular.

In the first place we thank Dr. Federico Ignacio Isla for his enthusiasm in tutoring us. His knowledge about coastal problems was of great use. The many field trips and meetings with people he arranged were very interesting and lead to a great contribution to our research. We are very grateful for his help. In Appendix XX a logbook is added with the different fieldtrips and meetings.

For eight weeks our presence shook up the section and therefore we want to thank our colleges of Geología de Costas for their patience in answering our questions and the noise we sometimes created. We thank Luis Cortizo for the nice conversations and "mate" he thought us to drink. Dr. Germán Bertola was a help in answering our geological questions. We thank Mariëla for her beautiful smile and Viviana for showing us how fast and vivid Argentine women can speak. We enjoyed working in the vicinity of them all.

Not in the least we also want to thank our tutors of the TU Delft, Prof. Dr. Ir. M.J.F. Stive and Ir. H.J. Verhagen, and our tutors of the Bouwdienst Rijkswaterstaat Ir. H.A. Lavooij and Ing. G.E. Beaufort for their tips and hints during our research.


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Without the help of the following companies and universities, this project would not be such a success. We therefore thank them for their support.

Public Works and Water Management, (Rijkswaterstaat)

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ARGOSS ADVISORY and RESEARCH GROUP on GEO OBSERVATION SYSTEMS and SERVICES

Universidad Nacional del Mar del Plata

Delft University of Technology
Abstract

The city of Mar del Plata is situated some 400 km South of Buenos Aires, the capital of Argentina. The city has two main incomes, namely industry and tourism. In summer, beaches of this Atlantic Ocean faced destination are packed with typical Argentine beach tents, which can be rented, and people from all over Argentina come to Mar del Plata. The 600.000 inhabitants are outnumbered 3 to 1 since almost 2 million people visit the town during the months December-February.

The crowded beaches in the centre of the town cause the popularity of the more quiet and more expensive beaches south of the town. The surroundings of the beaches around Punta Mogotes, make it a good place to spend the summer. The beaches around Punta Mogotes however, are not in possession of the local or provincial government. Playas del Faro, which mean beaches of the lighthouse, is the last remaining coastline in Argentina which is private. It’s common in Argentina to give concessions for a part of the beach, so this can be exploited by the concessionaire. This concept is applied for Playas del Faro.

In the south of these beaches, big erosion problems are present. The most southern concession is called Los Acantilados ('the cliffs'), named after the cliffs and the neighbourhood which is located a few hundred of meters land inward on top of the cliffs. Once economy flourished here, but with the total disappearance of the dune and beach system in front of the cliffs prospects are bad. With the provincial road and houses some hundred meters away, safety is not an issue. The biggest problem therefore is the lack of beach, which needs to be solved.

The erosion is caused by a few reasons. The most important one is the lack of sand input from the south. The wave climate causes an average long shore current over the year from the south to the north. The city of Miramar, located 15 km south of Mar del Plata has had erosion problems since the early years of the previous century and has been constructing counter measures ever since. Further north of Miramar more groyne systems, the one more effective then the other, can be found. The most northern groyne is a rather large groyne of over two hundred meters situated in front of the house of the president. From this point to the research area of Los Acantilados no beaches, except some small pocket beaches, but only high cliffs can be found. Another reason for the erosion is the presence of heavy storms. Local experts say that in a year with more storms then usual, erosion is even worse. This problem is related with the problem above, as well as with the presence of human interference in the dune system. With no input of sand into the system, the sediment, which is placed on the fore shore by a storm, is immediately picked up by the long shore current instead of being transported back on the beaches by the waves of a milder wave climate.

Three main solutions are possible for this problem: periodical nourishment, detached breakwaters and a groyne scheme. Nourishment itself is a nice solution with little negative effects. However it is expensive when compared with the construction of groins. The local quarry is situated less then 12 km from Los Acantilados. Constructing a groyne from shore is therefore six times less expensive then building a detached breakwater with the use of floating equipment. Besides the financial factor the groyne scheme has the advantage of being a more 'permanent' solution although having negative erosion effects downstream. After thorough consideration it was decided to design a groyne scheme.

First of all the location and the lengths of the groynes were designed. Seven groynes with different lengths and spacing were developed, blocking over 80 % of the long
shore sediment transport. The three most northern groynes were designed with decreasing lengths to spread the impact of erosion caused by the designed scheme. To minimize the costs the realization has to be done from shore, this has some effects on the design. Smaller stones have to be used on the structure then guidelines propose and the groyne is build directly from the crest instead from the crest of the core. This implies that more damage may occur. Since this will be easy and cheap to repair this is considered acceptable. Between the groynes a nourishment of 1,200,000 m$^3$ sand will be needed. The total costs of the project are 4,3 million for the groynes and 22,8 million for the nourishment, making a total of 27,1 million pesos.

Since costs are rather high a minimum cost alternative to stop the erosion of the cliffs is presented too. In front of the cliffs riprap has to be placed with a height of 2,95 m above mean sea level. The riprap will cost a maximum of 3800 pesos per meter depending on the depth in front of the cliffs.

The report consists of eight chapters. Chapter one gives an introduction, an overview of the research area and the boundary conditions. Chapter two is made especially for the people of Mar del Plata and consists of possible measures for problems with coastal erosion. From this, possible measures for this specific problem were derived. Chapter three continues with ways to finance the reconstruction of the beach and this followed by chapter four with a accurate description of the three main alternatives, namely periodical beach nourishment, detached breakwaters and a groyne scheme. In chapter five a choice is made between these alternatives and the groyne scheme is designed in detail in chapter six. In chapter seven a description is given how to build riprap as a way to stop cliff erosion, but not creating new beach. Finally, in chapter eight conclusions and recommendations are given.
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Figure 0.1  Area Mar de Plata – Miramar Map H-210
1 Introduction

1.1 Description of the location

1.1.1 Introduction

The town of Mar del Plata is situated at the Atlantic Coast of Argentina, 400 km south of Buenos Aires, the capital of Argentina. It is considered to be the most important destination for holidays of Argentine inhabitants who spend their holidays in their own country. With 600.000 inhabitants it’s a medium sized city in South America, but in the three months of the summer it is visited by over 2 million tourists, especially inhabitants of Buenos Aires. Tourism, therefore, clearly is the mayor motivator of the local economy. The many tall tourist apartment complexes and hotels near the coast confirm this idea. See figure below.

![Figure 1.1 Photograph of skyline Mar del Plata](image)

Mar del Plata is found to be a desirable place because of the combination it offers of the nice climate in summer, the comfortable hotels, the relative small distance to Buenos Aires, the beautiful beaches and the refreshing presence of the Atlantic Ocean. Unfortunately, the latter two cause an ever during conflict at the Mar del Plata coast. Erosion of the beach is a problem with which the population and hotel entrepreneurs of the city are rather known to. In the past many countermeasures have been taken to change the erosion from the coast. The large breakwaters that protect the Mar del Plata harbour have had an enormous effect on the sediment transport. See figure 0.1. Beach nourishments have been executed to maintain the large beaches in front of the city. Along the coastline many groins are to be found.
Just south of Mar del Plata is the area of “Los Acantilados”, which name means: “The Cliffs”. Here the economy once flourished on the luxurious beach life. The prosperous upper class came here to spend a more restful day at the beach then they would have on the beaches in front of the town. Unfortunately, the beaches of Los Acantilados have suffered from erosion so that beach life is no longer possible and the economy of the area has dropped. For this reason, the people of Los Acantilados have erected a plan to bring back the beach and the prosperity it brings.

A difficulty is the ownership of the beach and coastline. Historically the beach and a part of the cliffs belonged to a family, now united in an association (S.A.I. Playas del Faro), while the foreshore is governmental property. This gives a conflict about who should pay for the reconstruction of the beach, who is the owner and the one who may give the concessions when finished. The beach is exploited by concessionaires who rent tents to the public and pay a concession to the association. Therefore, the government is not very interested in investing in this part of the coast. The part of the cliffs owned by the association is relatively small so lack of (parking-) space may exist when tourism returns to the area.
1.1.1.1 Research Area

The research area can be seen in the map below and will be described here. More pictures of the area are available in appendix II.

Figure 1.3 Overview of the research area
To the North, the research area is limited by Punta Cantera, see (1) in the picture 1.3. On the end of this rocky point a groyne is situated. At the North of this groyne lies Playa Punta Mogotes, which ends at the large southern breakwater of the harbour of Mar de Plata (see overview map before this chapter), where a significant amount of sand accumulates.

Figure 1.4 Photograph of the coast of Los Acantilados

Further south another coastal morphological phenomenon can be seen, (2). Due to the rocky reef in front of Punta Mogotes a 3 km long shallow area extends into the ocean, causing the waves to break early and creating a tombolo or salient, which can be seen on the right in the figure 1.4. The beach between Punta Cantera and Punta Mogotes is said to be stable. Together with the tombolo this is an area where tourism flourishes.

Looking south of the tombolo, at (3), the beach starts to lose its historical profile. This original profile, of this part of the coast consists of a rocky sub layer. This sub layer consists of two materials, namely Tosca Stone and 'Loess Pampeano', of which the second one erodes very easily and is in the majority of the cliffs, see appendix III.

On top of this, historically there were sand dunes which extended into the sea for 200 m. compared to its current location. Directly south of Punta Mogotes this profile still can be witnessed, but two to three kilometers further south at Playa Los Acantilados, the profile still shows a beach but the dunes have disappeared.

Further south, (4), the sandy beach disappears totally. Big rocks lie at the foot of the cliffs as a sign of structural erosion and standing on the rock beach, small ebb gullies are clearly visible as a sign of how easy the cliffs erode. Coming to Punta Martinez de Hoz, just after La Barranca de Los Lobos, there is no more beach left and the waves hit directly onto the cliffs.
To have an idea of the magnitude of the erosion one can take look at some data from the past. An important place where the erosion takes place is Playa Los Acantilados. In appendix II and IV it can be seen that erosion is a long existing problem and at Los Acantilados almost 7 meter was lost in the last 30 years.

The whole part of this area has another problem, which causes erosion of the cliffs: seeping groundwater. The ‘Loess Pampeano’ is a porous material and thus many small waterfalls are visible, which erodes the cliffs. Nevertheless the erosion caused by the seeping groundwater can be neglected with respect to the erosion caused by wave attack, and therefore will not be studied further in this report. When the problem of the eroding beach by wave attack is solved this may be the next point of attention.

From the map in appendix IV it shows that it is not only a problem for this part of the coast, but that the whole area around Mar del Plata has problems. In fact the town of Villa Gesell, which is 100 km north of Mar del Plata, has problems of erosion too and consider nourishment of the beach. A survey in front of Villa Gesell with help of the projectgroup showed that sand is available in the fore shore. Nourishment therefore is possible. Specialists claim that sand is available in front of Los Acantilados beach.

1.1.1.2 Ecological features in the research area

As outlined before the area is dominated by sand and rocky headlands and therefore the environment is characterized by aquatic nature. Due to heavy wave attack there is a constant high turbidity and thus low light intrusion. Consequence is that there is not a high concentration of plants. The reef however thus forms a perfect habitat for all kinds of species of animals. With a community of 200 to 500 Fur Seals (Arctocephalus Australis) living and hunting in the port of Mar del Plata and on the Banco de Pescadores (Fishermen’s bank) clearly the area has a valuable environmental status. Also the fact that on the reef sport fishing and further out to sea commercial fishing is very popular indicates a healthy and diverse fish stock.
1.1.1.3 Cause of erosion

In the last centuries there has always been erosion of the dunes and beaches along the coasts south of Buenos Aires. The main erosion occurs during the storms. This was never a problem until people were starting to use the beaches and dunes. The harvesting of sand and fixation of the dunes by construction of buildings or planting vegetation has increased the rate of erosion. The storms cause a cross shore transport of sand from beaches and dunes to the foreshore. In the periods with a milder wave climate in between the storms often in the summer sand is transported back to the beaches and blown onto the dunes, so-called aeolian transport. With a lack of sand, due to the human intervention, this dynamic equilibrium can’t be restored.

For the erosion of the beaches of Los Acantilados there are several causes. A cause of the erosion of Los Acantilados beach is the harvesting of sand just south of the tombolo of Punta Mogotes. Large parts of Mar del Plata were built with the sand harvested at this accretion area. The harvesting of sand is prohibited since 1987 because of the erosion of the beaches. However the tombolo is said to be growing slightly with sand coming from the beaches of Los Acantilados and further south.

Another reason for the acceleration of the erosion is the construction of groynes south of the beach. There is a groyne field in Miramar 30 kilometres south of Mar del Plata and on numerous beaches between Miramar and Mar del Plata. A few years ago a private beach resort about 4 kilometres south of Los Acantilados beach also constructed a groyne. This resulted in that the research station of the Universidad Nacional de Mar del Plata, a few hundred metres north of the groyne, has lost their beach just in front of their property. The only beaches now remaining just north of that groyne are small pocket beaches, see picture 1.7. In fact the total sediment input from the south in the system is close to zero, as can be seen in appendix II.

There is also less sediment becoming available from the rivers along the Argentine coast. The last decades many dams for hydropower were built in the south of Argentina which trap sediment. One only has to take a look at the fact that 41 % of Argentina’s energy comes from hydropower to imagine the impact it has on the system. The hydropower companies therefore can be held responsible for the erosion and the economical damage.

According to some sources the amount of storms per year in the area has increased, possibly because of the global climate change. Also an increase in rainfall the last few decades indicates a different climate.

Yet another reason for the erosion might be a small sea level rise likely caused by the global climate change. Data, appendix V, from Buenos Aires and Quequen, 100 km south of Mar del Plata, show that sea

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level rise follows the main global development. UNESCO\textsuperscript{2} however has reported that both sea level rise and fall occur in different parts of the world.

\textsuperscript{2} Relative sea-level change: a critical evaluation, Unesco, 1990
1.1.2 Problem definition

The problem of the coastline between Punta Mogotes and La Barranca has mainly an economical nature, and is not really a problem of safety. In the past a nice wide beach was accessible which attracted much tourism to the area. Nowadays the beach has diminished and tourism has dropped. Consequently, local people notice several economical changes in their situation. First there is the devaluation of their properties such as houses, hotels and land. Second is the decrease in income the tourists used to provide.

Another issue is the elimination of capital when further erosion of the cliffs is allowed: the premises on the edge of the cliffs will collapse in the coming years (see Figure 1.8) and eventually the coastal route will disappear in the ocean too. Therefore the economical threat of the eroding beach and cliffs is not only an issue of the owners of the beach and the concessionaires who have buildings on the cliffs but also of the authorities of the coastal route.

Only incidentally hazardous situations may occur when stones and debris would fall down from the eroding cliffs and the estates standing on the cliffs. This is only likely to occur during a storm when the presence of people is not likely. Therefore safety of the public is not a problem issue.

In order to find a solution for the economical problem owners, concessionaires and local government will have to cooperate. The city may profit from new input in local economy, the association may receive more concession fee and the concessionaires may have more income when more guests can be received. For an increase in tourism also more parking space is required which must have place on property of the city. Probably the best way to let the association and the local government work together and both gain profit from the beach is to create a joint venture. Plans in this direction exist already, however the process is going slow.

The presence of a beach between Punta Mogotes and La Barranca would be an immense input in the economy of the village, especially because there is an existing need for more and quieter beaches in the vicinity of Mar del Plata. Tourism could return to the area and Los Acantilados could flourish again like in the old days.
1.1.3 Aim of the project

The problem definition states an economical problem of lacking tourism. This has to be solved, preferably by creating a new beach because of two reasons. One is that tourism is attracted by the presence of a beach and second is that the cliffs and the buildings on top and the provincial road are protected by a beach. Therefore our primary aim is to find a solution to create a beach.

The technical solution, the construction method, costs and financial benefits have to be considered thoroughly. Many choices in the decision making process have to be made with finances as motivator or concession issue. The aim of this project therefore is formulated as the following:

“Finding a solution to create a sustainable beach between Punta Mogotes and Punta Martinez de Hoz. This solution has to be both technical and economical reasonable and feasible.”

1.1.3.1 Technical goals

To ascertain that the right aim is followed the next technical goals are set. These can be seen as steps in the process.

TG1. Determine the possible causes of the erosion
TG2. Determine the profile of the beach and the near shore
TG3. Determine the wave and tidal climate
TG4. Determine the sediment gradation and the properties of other materials in the profile
TG5. Determine the wave induced sediment transport in the profile
TG6. Make an inventory of the local habits of construction
TG7. Examine the different alternatives to reconstruct the beach
TG8. Work out the best solution(s)

1.1.3.2 Social/economical goals

SG1. Determine the economic value of each meter accumulated beach
SG2. Make an inventory about the financial possibilities
SG3. Produce a report that is of value for people concerned

1.1.4 List of demands

A list of demand is generated by refining the aim and goals into quantified rules (as far as possible). The demands are subdivided in technical, functional, economical, environmental and juridical demands.

1.1.4.1 Technical demands

TD1. The width of the beach is preferably 50 meter, in order to be able to realize the typical Argentine tent beach.
TD2. Nourished sands should have about the same characteristics as the original sands, see appendix VIII.
TD3. In the bathing zone the ground should be comfortable for bathing guests. For this reason no rocky materials may be present.
TD4. Swimming must be a safe and comfortable occupation of bathing guests. For this reason no rip currents may be present.
TD5. The swimming water should have a clean appearance as a sign of the quality of the water. For this reason the presence of fine particles in suspension should be minimized.
TD6. Downstream effects on sediment transport should not be too large
TD7. The lifespan of hard measures has to be 50 years.

TD8. Hard solutions have to be designed to withstand design storm conditions, see appendix VII.

TD9. Sand extraction from the sea should be done outside the dynamic zone.

TD10. The slope of the dry beach may not be uncomfortable and therefore the angle of the beach to horizontal should be smaller than 1:50.

1.1.4.2 Functional demands

FD1. During tourist high season (from December till February) beaches and tourist facilities should not be hindered by construction activities. In the months November and March, the hinder should be minimized.

FD2. The entire length of the beach in operational stage should be accessible for public and vehicles. Hard structures may not form an obstruction of the path.

FD3. Phasing of the construction may be necessary and even on parts of the beach it may not be economically feasible to construct new beach. To avoid erosion of upstream beaches by any hard structures construction has to be done from the north southwards.

FD4. Any coastal defence measures may not form a danger to structures or persons.

1.1.4.3 Economical demands

EcD1. Funds for beach protection are limited in Argentina and therefore costs should be minimized or spread in time.

EcD2. Because of the economical nature of the problem, the coastal defence measures should be economically feasible and reasonable.

1.1.4.4 Environmental demands

EnD1. The flora and fauna in the coastal area may not experience severe damage due to any coastal defence measures.

EnD2. The reef may not experience a significant accumulation of sand or structural damage.

EnD3. Since the area is part of the natural habitat of the fur seal and many fish, measures may not influence their existence.

1.1.4.5 Juridical demands

JD1. At present the issue of ownership of the newly found beach is not clear. Before any measures can be taken, this has to be clear.

JD2. All plans have to be approved by Argentine law before the construction process starts.
1.2 Local conditions

1.2.1 Bathymetry

More information how the bathymetry is obtained can be read in Appendix IX. A bathymetric survey done from a boat would definitely give a more accurate bottom profile, but since one of the goals is to create new beach, and thus a new bathymetry of the surf zone, the current accuracy is considered to be good enough. Besides that a survey would cost a large amount of money and planning time, which are both not available. The fifteen different profiles or rays, which were schematised, can be used for later calculations by hand and UNIBEST. These profiles are visualized with help of MS Excell in figure 1.9.

![Figure 1.6 Depth profiles](image)

One can clearly see the reef through the profiles 12 to 15. More to the south, profiles 6 through 11 show a small strip of beach and a very steep fore shore. While profile 1 trough 5 show how the cliffs directly end in the ocean and with a mild slope continue out into the ocean. In appendix IX these three main groups are plotted and trend lines are derived for the beach and fore shore.

1.2.2 Critical depth

The determination of sediment transport depends on a large amount of parameters. One which is directly associated with the bathymetry of the area is the active transport area. This area where the long shore and cross shore transport is active. What happens outside this area is of very little influence on the transport quantities and directions. To assess the active transport a common procedure is to define a critical depth.

This is done with the formula Hallmeier, 1981$^3$

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$^3$ Assessing the impact of sand extraction on the shore stability: project for a methodological framework European marine sand and gravel – shaping the future, EMSAGG Conference 20-21 February 2003, Delft University, The Netherlands
$d_{ct} = 2,28H_{s(12h,t)} - \frac{68.5H_{s(12h,t)}^2}{gT_s^2}$

With:

- $d_{ct}$ = Critical depth
- $H_{s(12h,t)}$ = Significant wave height which occurs 12 hrs/yr on average
- $g$ = Gravitational acceleration
- $T_s(t)$ = Wave period

With a determined $H_{s(12h,t)}$ by the Alkyon wavdata this results in a critical depth of 7,9 m below mean sea level. This depth will be used with the UNIBEST Calculations, see appendix XII.

### 1.2.3 Sediment transport

#### 1.2.3.1 Process

Before starting to think about solutions it’s necessary to have an inside how the sediment transportation is in this specific area. The fact that there is significant erosion implies a big transport capacity of the area. Calculations with UNIBEST give the following $S_x$ curve.

![Long shore transport capacity](image)

**Figure 1.7 Long shore transport capacity**

This figure was derived, assuming that the whole area has a sand beach. In fact this only accounts from profile 6, where there is only a small san beach left and further and up to further North East. With hardly any sediment input in the system, the long shore current picks up sand where the beach starts and thus causing erosion. Local experts say that when there are more storms during a winter then normal, the erosion is even worse. Erosion during storms is normal and caused by cross shore transport. Sand is placed on the fore shore, transported further downstream by the long shore current and then, during the milder summer, the sediment is transported cross shore back onto the beach. Normally this wouldn’t be a problem, eroded beach/dunes upstream would supply sand to replace the downstream eroded part.

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4 Dr. Schnack, Former director of the institute of Coastal Research of Mar del Plata and Dr Isla decano of the facultad naturales y ciencias and director of Institute of Coastal Research of the university of Mar del Plata
This system is called a dynamic equilibrium. But since there is no sand available upstream, the storm-induced cross shore transport causes extra erosion.

1.2.3.2 Quantification

Various calculations were made on the amount of the potential sediment transport. The hand calculation was made with profile 8 and simplified wave climate to compare this with UNIBEST the same calculation were done with UNIBEST. Furthermore the calculation with UNIBEST was done for all profiles and an average sediment transport for all profiles was determined. An overview is given in Table 1-1. In the appendices the different backgrounds and calculations can be seen.

Table 1-1 Quantification of transport with different methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Profile</th>
<th>Wave climate</th>
<th>Quantity (m3/year)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand calculation CERC</td>
<td>8</td>
<td>Simplified</td>
<td>1.100.000</td>
<td>Appendix XIV</td>
</tr>
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<td>Simplified</td>
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<td>Appendix XIII</td>
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<td>Simplified</td>
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<td>Simplified</td>
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<td>Appendix XII</td>
</tr>
<tr>
<td>UNIBEST calculation Bijker</td>
<td>8</td>
<td>Simplified</td>
<td>250.000</td>
<td>Appendix XII</td>
</tr>
<tr>
<td>UNIBEST calculation CERC</td>
<td>All average</td>
<td>Elaborate</td>
<td>140.000</td>
<td>Appendix XII</td>
</tr>
<tr>
<td>UNIBEST calculation Bijker</td>
<td>All average</td>
<td>Elaborate</td>
<td>519.000</td>
<td>Appendix XII</td>
</tr>
<tr>
<td>Previous calculation</td>
<td>Avarage</td>
<td>Not known</td>
<td>150.000-200.000</td>
<td>Comment 1</td>
</tr>
<tr>
<td>Local estimation</td>
<td>Avarage</td>
<td>Not known</td>
<td>160.000</td>
<td>Comment 2</td>
</tr>
</tbody>
</table>

1: Port and Coastal Study Mar del Plata, April 1997
2: Ministro Obras Publicas (Public Works) of the province of Buenos Aires

As can be read in Appendix XII the calculations with UNIBEST, combined with Bijker approximate the sediment transport the best.

1.2.4 Sediment gradation

For reliable sand analysis recent samples are necessary. On 27th of September 2004 samples were taken from research area. The samples were analysed by the Centro de Geologia de Costas y del Quaternario of the Universidad Nacional del Mar del Plata. The results and an analysis of these results are given in appendix VIII. Here only the grain sizes, which will be used for calculations, are presented.

Table 1-2 Grain size

| D50 | 250 µm |
| D90 | 330 µm |
1.2.5 Boundary conditions of the research area

When trying to focus on an area of research the boundaries have to be chosen carefully. In a coastal erosion study two boundaries are already determined. To the landside this is where no (wind induced) sand transport is active. To the sea side the area is ended by a line outside the breaker zone where there is also no sediment transport.

The southern boundary can be set by the cliffs of Punta Martinez de Hoz. Here the coast makes a bend and is the only logical boundary in the surroundings because it’s where the original beach ended. Further south only cliffs are to be found. A breakwater was build south of this point in 1998. Since then small pocket beaches have started to diminish. It is believed that nowadays no or very little sediment enters the area. Two cases endorse this opinion. The first is found at the breakwater at Miramar. Sand is found until the head of this breakwater. Further seaward all sand has eroded and the bottom changes to rock, so very little sediment transport can be possible here. The second case is a research location of the university, where shrimps are bred for research. The researchers stated that the water inlet at the foot of the cliffs used to be on a sandy bottom and much trouble was found with sand accumulation in the pump. Nowadays hardly any sand was present. Figure 1.11 shows the current situation.

![Figure 1.8 Photograph rocky fore shore](image)

In the north of the research area of the beach of Los Acantilados two interesting points are to be distinguished. The first is the tombolo or salient of Punta Mogotes. This is the point that would be the logical boundary in the focus that it is the end of the beach. Not until seventeen years ago it was allowed to harvest sand from this tombolo and therefore it did not grow. But since it was prohibited the tombolo started growing again, indicating a negative sediment transport gradient here. Nowadays the salient is stable or growing slightly.

The second is the groyne at Punta Cantera. The beach between Punta Mogotes and Punta Cantera is stable whilst north of the
groyne the beach is encounters severe erosion. This might endorse the theory that there is no littoral transport directly over this groyne and therefore could be a technical interesting boundary because the sediment transport can be said to be zero.

Nevertheless it is decided to take Punta Mogotes as the boundary of our research area because this is the end of the area of economical interest. With these boundaries calculations will be made.

1.2.6 Wave climate
The wave climate in this part of the Atlantic Ocean is mainly from the direction south. An analysis of the data is presented in Appendix VII. The results that are used for calculations are shown below. The average of $H_s$ is 1.3 m.

Storm conditions are calculated with storm durance of 12 hours.

<table>
<thead>
<tr>
<th>Table 1-3 Storm conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_s$ Storm Surge once in 50 years</td>
</tr>
<tr>
<td>$H_s$ Storm Surge once in 100 years</td>
</tr>
</tbody>
</table>

For the input in the modeling software Table 1-4 is used where the $T_s$ is always rounded up and the wave directions from the coast side are deleted. The wave climate is then as below.

<table>
<thead>
<tr>
<th>Table 1-4 Wave direction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Winter (Jun.-Aug.)</td>
</tr>
<tr>
<td>Days</td>
</tr>
<tr>
<td>$H_s$ Average (m)</td>
</tr>
<tr>
<td>$T_s$ Average (s)</td>
</tr>
<tr>
<td>Spring (Sept.-Nov.)</td>
</tr>
<tr>
<td>Days</td>
</tr>
<tr>
<td>$H_s$ Average (m)</td>
</tr>
<tr>
<td>$T_s$ Average (s)</td>
</tr>
<tr>
<td>Summer (Dec.-Feb.)</td>
</tr>
<tr>
<td>Days</td>
</tr>
<tr>
<td>$H_s$ Average (m)</td>
</tr>
<tr>
<td>$T_s$ Average (s)</td>
</tr>
<tr>
<td>Autumn (Mar.-May)</td>
</tr>
<tr>
<td>Days</td>
</tr>
<tr>
<td>$H_s$ Average (m)</td>
</tr>
<tr>
<td>$T_s$ Average (s)</td>
</tr>
</tbody>
</table>

For the input in the simplified calculation by hand the wave climate is modelled as below.

<table>
<thead>
<tr>
<th>Table 1-5 Simplified wave climate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Year</td>
</tr>
<tr>
<td>Days</td>
</tr>
<tr>
<td>$H_s$ Average (m)</td>
</tr>
<tr>
<td>$T_s$ Average (s)</td>
</tr>
</tbody>
</table>
1.2.7 The tidal regime

The tidal variations in the area of interest are presented in the table below. The tide is semi-diurnal, but one with a remarkable daily irregularity. The reference level is with respect to average sea level given on the sea chart of the Argentine Marine (Servicio de Hydrografía de Naval de la Armada Arentina). For more details see appendix VI, one can see in this appendix the reference level of 0,91 m. This is a local level on shore and is in fact 0,91 m above average sea level. The important values derived from this appendix are given below.

Table 1-6 Tidal regime

<table>
<thead>
<tr>
<th>Highest high</th>
<th>Average high</th>
<th>Sea level to chart data</th>
<th>Average Low</th>
<th>Lowest low</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ 1,12 m.</td>
<td>+ 0,40 m.</td>
<td>0 m.</td>
<td>- 0,38 m</td>
<td>-0,75 m</td>
</tr>
</tbody>
</table>
2 Possible measures

Erosion of the coast is a phenomenon that occurs all over the world. Local circumstances determine what measures are the most promising solution. Before any decision is made, an overview of the possible solutions is given below. Next these measures are evaluated with respect to local circumstances. A distinction is made in three groups of measures indicating different levels of approach:

2.1 The zero-option

In this case, no action will be taken and the situation and eroding processes will stay the same. This option is not really a solution to a problem but moreover a policy-analysis instrument to evaluate the costs and benefits of different coastal protection strategies. In the choice making process this alternative is used as comparison model to other possible solutions.

2.2 Measures to eliminate the cause of the erosion

Earlier build structures (breakwaters and groins) or sand mining can be a cause of erosion. Sometimes hard structures do more harm than good. Removing structures or preventing the mining can have a structural positive effect on the erosion. Also placing an artificial bypass over a sediment blocking structure is an cause eliminating measure.

2.3 Measures to counteract the erosion, or to alleviate the effect of coastal erosion

This third type contains measures with a mitigating nature. These can be subdivided in three groups that are discussed below.

2.3.1 Soft solutions

The term soft solution is used for methods that use sands as construction material, artificial nourishment of the beach. Three subdivisions can be made:

1) Dune nourishment gives extra protection in case of extreme hydraulic conditions. This can be useful if the sand depot of the dunes is relatively small. Sand will be put on the front of the old dunes, making its volume larger. The nourishment will only erode during heavy storms with wave attack on the dunes itself. The everyday transport of sediment is not changed.

2) Beach nourishment is used to quickly create a new or larger beach. Sand is put on both wet and dry beach. The erosion can initially have a higher rate along the shore until a dynamic equilibrium profile has been formed. After that the original erosion rate will re-establish.

3) Foreshore nourishment is a method that is less material effective but may be cost effective. Sand is dropped on the foreshore of the beach. Because of the larger sand body in the profile the dry beach will grow. The wave energy moves the sand particles onto the beach.

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3 Port and coastal study Mar del Plata, Final Report, p. 39, Directorate-General for Public Works and Water Management (Rijkswaterstaat), April 1997
Figure 2.1  Types of beach nourishment
2.3.2 Hard solutions
To the group of hard solutions belong the structures, which consist of steel, concrete, wood, stone and other materials that not consist of little particles. To this section belong the groyne, detached breakwater and seawall.
Groynes are used to interrupt the littoral sediment transport and to accumulate sand at its up drift side. At the down drift side erosion will occur. A groyne is most effective when it stretches out through the breaker line. A groyne or a groyne field can be an effective solution, however if they are not used properly, the erosion problem can shift down drift.

Figure 2.2 Groyne and series of groynes
A detached breakwater reduces the wave energy in its lee side. Therefore the littoral transport gradient diminishes and sand accumulates behind the detached breakwater. Erosion will occur on the down drift side as a result of the increasing transport gradient.

**Figure 2.3  Detached breakwater**

An artificial bar is like a detached breakwater but is fully submerged. For this the effect will be less effective.

**Figure 2.4  Offshore bar**
A seawall or revetment is an on-land structure that will protect the hinterland directly from the wave attacks. The sediment transport increases due to reflection against the seawall. In the up and the downstream transition areas even more erosion will take place. Its use is only for local protection of land or premises. It has a damaging effect in a situation with structural erosion.

**Figure 2.5 Seawall**

### 2.3.3 Combination

In practice, a combination of soft and hard solutions is very common. A perched beach is a combination between nourishment on the beach and a low underwater dam. The slope of the coast on the landside of the dam is very gentle, while the slope on the seaside is steep. Less sand is needed in this case than with nourishment only. This may come handy when not enough sand available. Of course an underwater dam is quit expensive. The dam can consist of a stone gradation or large bags of sand. Due to ongoing erosion, the perched beach has to be filled regularly.

**Figure 2.6 Perched beach**
2.4 Evaluation possible measures

In this part the possible measures will be evaluated in combination with local circumstances. This narrows the alternatives down to a number that can be reasonable implemented.

2.4.1 Zero option

The zero option as said before is not really a solution. But in the case of Los Acantilados, it has been years this way. Because there is difficulty of the ownership of the new beach and the willingness to pay related to this. That is why the zero option has to be seriously evaluated.

As the erosion continues, at some point the road, which connects Mar del Plata to the south, will be in danger. See appendix I, chart H-250. The current average cliff erosion rate is 1-2 m. per year see Appendix IV, Historical erosion data. Therefore it is a matter time for the erosion to reach the 40 m limit.

This regulation is practiced by province, which implies that if the distance from a coastal road to the waterline is less than 40 m action by the province is to be taken. In several of cases to the north of Mar del Plata this is done with protection of the cliffs with riprap. In the case of Los Acantilados, a zero option could be unsatisfying to create beach, but helpful to stop the erosion and maintain a safe passage for the coastal traffic.

2.4.2 Measures to eliminate the cause of erosion

This type of measures have a mainly a theoretical background and are in practice very difficult to implement. As outlined in the previous section, the main cause of erosion is a difficult issue, but primarily initiated by the sand trapped by upstream groynes and breakwaters. The structures upstream were build to prevent erosion in their area. Break down those structures will in theory create a large availability of sediment downstream, but again cause huge problems upstream. Once one begins with building hard structures to prevent erosion, there is hardly a way back. A measure to eliminate the cause of erosion is therefore one, which will only cause more inconvenient problems.

2.4.3 Measures to counteract the erosion

Three types of measures have been explained in the previous section; soft, hard and a combination of soft and hard. In the following first the soft measures will be shortly evaluated and secondly the hard measures.

2.4.3.1 Soft measures

In the case of Los Acantilados the sediment is trapped upstream and there is no sediment input in the research area. To establish a new beach the sand nourishment, soft measure, in any case is needed. In Argentina only little equipment available and a foreign contractor who has experience with this kind of work has to be hired to nourish the beach. Usually, once in a few years new nourishment has to be applied on the beach if no protection of the beach is constructed. The costs will mainly depend on the frequency and the volume of sand of the nourishments. The type of nourishment will be closer investigated in the section alternatives.
2.4.3.2 Hard measures

Hard measures, outlined in the previous section were; groyne or a groyne field, detached breakwater, artificial bar and a seawall. A hard measure in this case will be a useful and necessary supplement on nourishment.

A seawall is a hard measure, which can function on it self, but in this case would be a very strange solution because there is no beach and no important premises are to be protected. Furthermore structural erosion an in combination with a seawall will always cause problems downstream of the seawall.

Artificial bar(s) could be a solution in combination with nourishment. Artificial bars have proven to have a low efficiency regarding the wave damping and would work better the when they are grouped; the bars could be build from sand or gravel. A detached breakwater in front of the beach will stop the waves from breaking on the beach and thus stopping the transport of sand from the beach. The detached breakwater can be designed merged or submerged. The detached breakwater may extend along the full length of the beach or as a series of smaller breakwaters. The breakwaters can be constructed using stones or other materials like old ships. The construction of detached breakwaters has to be done by floating equipment from specialized contractors who have experience with the construction of breakwaters. A detached breakwater, however, is a good option when a beach is mainly used for tourism because from the beach the breakwater is hardly noticed; especially when a submerged breakwater is used. These hard measures in combination with the nourishment could be an interesting alternative.

A single large breakwater seems a solution. However it needs to be of a very substantial length. To establish an accumulation area over the whole stretch of 8 kilometres the breakwater would be out of proportion. Because of this length the influence on the surrounding area will be very large. For this reason one works with groyne fields. Thus a big breakwater is no alternative.

Groyne fields have proven to work to prevent erosion worldwide. They are often applied on the Argentine coast to protect the beaches. South of Los Acantilados there is a groyne field in Miramar and in Mar del Plata there also is a groyne field present. The construction of the groins is done by trucks, which dump the rock directly from the beach into the sea. During construction trucks and cranes are used for placing the stones and no floating equipment is necessary. The construction of the groynes has to be accompanied by nourishment as well, because there is hardly any sand input from the south. Rock can be used from nearby quarries and a rock plateau near the surface is present on which the groynes could be constructed. For these reasons the construction of the groins in Los Acantilados is a reasonable potential alternative.

Combinations of hard and soft measures always seem very promising. One measure neutralizes the bad effects of another. As shown in the previous section a perched beach would be a combination of interest. However a perched beach is useful when there is very steep beach slope. In the case of Los Acantilados this is only the case for the first 150 meters. After these 150 meters, the slope becomes mild. The nourished beach would intersect with the milder anyhow. So the effect of a perched beach is little.

2.4.4 Conclusions on possible measures

Nourishment will be necessary to create a new beach. This could be periodical nourishment or nourishment combined with a hard construction, in the form of a detached breakwater or a groyne field. The next section will elaborate on these alternatives.
3 Financing of the reconstruction of the beach

The rehabilitation of the beach of Los Acantilados will cost a lot of money. The financing of a project like this involves a lot of parties. In this case the province and a private company are involved as owners of the beach and the municipality as a large beneficiary of the beach.

3.1 Benefits of the Beach

About 5.2 km of the research area is owned by a company called ‘Sociedad Anonima Inmobiliaria Playas del Faro’ of which the stakeholders are members of one family. The company gives out concessions to concessionaires who exploit beach plots. The area from the tombolo to the end of the property is divided in 23 parts so on average, each plot is about 230 meters wide. The most northern parts of the area near the salient cost about US$ 30,000 per year. These are the most exclusive beaches in the area of Mar del Plata. Further south the costs are about US$ 10,000 and in the south the plots cost about US$ 4,000. These plots are cheaper because no large area for construction and parking is available and the beach is nearly or totally gone. Six of these southern plots however don’t have a concessionaire so now there is no profit of these parts.

The beach south of the property of S.A.I. Playas del Faro is property of the province this is about 2.8 kilometers. In this area the beach is completely eroded onto the cliffs and no beach is available. The province of Buenos Aires owns also the rest of the coast in its territory. Most of the public beaches also have concessionaires who built and exploit catering services and tents on the beaches, however the municipalities give out the concessions and so receive the money.

Figure 3.1 Concessions of Playas del Faro

From first estimation it is found that the length of the eroding part of the beach is about 5 kilometers long. And that in the future, erosion will develop in northern direction which will result in problems for more concessions of “Playas de Faro”. Constructing a new beach in this area will immediately create 10 more concessions at the beach owned by the province. Playas del Faro will get 6 new beach plots and 5 adjacent beach plots will not suffer from erosion in the future.

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6 Information comes from a brochure ‘Playas del Faro - Mar del Plata – Argentina’ and a interview with the company’s manager mister Anibal A. Villola
It is difficult to determine the value of a beach and what the profits are for the owners and the local authorities. However some estimation is needed to be able to consider the different alternatives. The new beach will get 16 new plots that can be rented to concessionaires for US$ 10,000. And 5 more concessions will be relieved from problems in the near future so their profit is estimated on US$ 5,000 per annum. So the direct profit of the beaches could be US$ 185,000 per annum for the total beach. In this calculation it is presumed that a clean beach is constructed without any hard constructions. The value of the concessions however also depends on how the beach is constructed. A beach with groins will give a considerably less profit because it is less attractive. If only parts of the beach are constructed the profits will be considerably less too.

Construction of a new beach also will have secondary effects on the local economy. More tourists imply that more hotels and more restaurants are needed in the neighborhood of “Los Acantilados”. Also the crowded beaches near the city centre of Mar del Plata will be relieved and an increasing beach capacity will attract more people to the municipality of Mar del Plata instead of other places like Pinamar, Miramar and Villa Gesell. The area next to the beach, on the cliffs, in the south will be more valuable because no parking space is available on the territory of the private owners and there is hardly any space for construction near the beaches except territory from the province and some local owners. The beach will also protect the cliffs from further erosion and the road on it, which is also property of the province.

The secondary profits and value of the beach can only be reliably estimated by an economic investigation which is beyond the scope of this report and even than it is difficult to estimate. The decision on an estimation of the value of the beach for the municipality and province is also a political decision and has to be left to the local politics.

### 3.2 Financing the project

For the rehabilitation of the beach a joint venture between the municipality, the province and Playas del Faro S.A. is proposed. To what financial extent the different parties will participate, has to be negotiated. At this moment the manager of Playas del Faro S.A. seems willing to join such joint venture. The province has some money for the coast in its territory. However this budget is small and also has to be spent on different issues than beaches.

The municipality, one of the larger beneficiaries doesn’t have any budget for the rehabilitation of the beaches. The municipality of Mar del Plata earns a lot of money out of tourism and renting of the concessions of the beach, but doesn’t spent any money on maintaining or rehabilitating beaches. The municipality has a committee on coastal issues, which asks the province for money. The committee of the municipality will not ask the province for a contribution in the rehabilitation of the beaches of Los Acantilados but will focus more on the beaches north of its territory. The municipality is not willing to join a joint-venture in the near future.

Without money from the local authorities it will be hard to rehabilitate the beaches in the near future. It is hardly economical feasible and so not attractive for any private investor, the profit for Playas del Faro S.A. will be about US$ 85,000. In the near future an initiation of this project seems not likely. However beach surface is becoming scarce and prices of beach tents this year alone in some places have risen from US$ 700 to US$ 1000 per season. This could in the future also affect the prices

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7 Information comes from a meeting with the chairman of the municipal committee on coastal issues and councillor of the Municipality of Mar del Plata, mister Gustavo Pulti
of the concessions. Some politicians in Mar del Plata are now willing to reserve some money for maintaining the beaches although there is still resistance against a joint-venture with a private company. However when political and economical conditions improve this project could still be undertaken.
4 Alternatives and their effects

In this section for each of the alternatives different subjects as dimensions, realization, costs and environmental impacts will be discussed.

4.1 Periodical Sand Nourishment

With periodical sand nourishment sand will be nourished once in a few years without stopping the erosion. Periodical sand nourishment will realize a beach which will be ideal for bathing guests. The dimensions of the beach will be determined by the specifications set by the bathing guests. In the future the beach dimensions can be altered because every few years larger or smaller amounts of sand can be nourished.

4.1.1 Dimensions

For a first estimation of the amount of sand that will have to be nourished, one can use simplified slope angles for the different beaches as shown in appendix IX. For the northern part of the research area there already is a beach with a minimum of 50 meters available. Therefore beach nourishment would be only necessary for profiles 1 through 11. The stable beaches to the north of the research area show a mild, and thus pleasant for bathing guests, beach slope\(^8\) of 1:100 to 1:50. For calculations these slopes were used.

The amount of sand to be nourished depends on two factors. The first is the initial amount needed to create the desired beach. The second depends on the erosion. A new beach will not stop erosion of the beach surface and thus the anticipated quantity of sand that will be lost in the time in between beach nourishment has to be taken into account too. Besides that, other losses will occur, for instance losses due to difference in grain size. For first calculations losses will be estimated on 50 % of the initial needed nourishment\(^9\). This initial nourishment is calculated in appendix XV and from there the total becomes 4.300.000 m\(^3\). A repetition of the nourishment is needed every five years. The losses of 1.400.000 m\(^3\) in five year seem to be very large. However the potential sediment transport as shown in section local conditions are significant and the rule by thumb of 50 % losses is used.

4.1.2 Realisation

Sand nourishment in Los Acantilados can be implemented in three different ways; a direct beach nourishment, a foreshore nourishment or a combination of those two. In beach nourishment the sand is brought to land with pipes and further distributed by earthmoving equipment. Foreshore nourishment is done by nourishing sand in the breaker zone and waiting for the waves to redistribute the sand and put it on the beach. Foreshore nourishment requires much more sand than beach nourishment. The advantage of foreshore nourishment is that no earthmoving equipment is needed and the surf zone doesn't have to be crossed by the dredging equipment.

In Los Acantilados the main objective is to create a large beach and therefore beach nourishment is the better option for Los Acantilados. There is a small surf zone which makes foreshore nourishment harder and beach nourishment easier to realize. Yet another and more important reason to apply beach nourishment is the possibility of immediate use of the beach. Since there is not a lot of money available in Argentina a fast benefit from the beaches is needed. These benefits are more important then the fact that a fore shore nourishment could be cheaper compared to direct beach nourishment. For this reasons first calculations were done with beach nourishments.

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\(^8\) H-250, Rada Mar del Plata, Publicado por el Servicio de Hidrografía Naval - Armada Argentina – Buenos Aires 2003 Ultima corrección.

\(^9\) Handboek Zandsuppleties, Rijkswaterstaat, 1988
A quick word is said about the availability of sand nearby. A study\textsuperscript{10} shows that there is indeed sand available to dredge and nourish the beach with. However when nourishment will be done, it is advised to make a new and precise scan of the bottom of the sea in front of Los Acantilados.

4.1.3 Costs

Although there are many coastal problems in Argentina not many nourishment project were realised, and therefore hardly any prizes are known. However a proposal\textsuperscript{11} for a beach nourishment project on Playa Grande in the centre of Mar del Plata gives a very good indication of the costs. The nourishment of 250,000 m\textsuperscript{3} will cost 6 U$S/m\textsuperscript{3} and the proposal is done by Sudamericana de Dragados with is a part of Jan de Nul Group from Belgium. This is one of the worlds leading dredging company’s, which makes the proposal reliable. Prizes are given in Table 4-1.

\begin{table}[h]
\centering
\caption{Proposed dredging costs Jan de Nul Group}
\begin{tabular}{|l|c|c|}
\hline
\textbf{Costs} & \textbf{US Dollars} & \textbf{Arg Pesos} \\
\hline
Mobilisation & US$ 500.000 & $ 1.650.000 \\
Dredging and nourishment 250.000 m3 a 6 US$ S/m3 & US$ 1.500.000 & $ 4.950.000 \\
Total Costs & US$ 2.000.000 & $ 6.600.000 \\
\hline
\end{tabular}
\end{table}

According to the Ministros Obras Publicas (Public Works) prizes from Dredging International, another big Belgian company, were comparable. An indication on the mobilization costs from yet another dredging company, Van Oord from the Netherlands, give comparable results: 500.000 to 1.000.000 euro. The higher prize can be explained by the fact that the ship has to sail a larger distance than the local ship from Sudamericana de Dragados.

A first estimation for the costs for the first five years is done here:

\begin{table}[h]
\centering
\caption{Estimation dredging costs}
\begin{tabular}{|l|c|c|}
\hline
\textbf{Costs} & \textbf{Euro} & \textbf{Arg Pesos} \\
\hline
Mobilisation & 500.000 & € 1.800.000 \\
Dredging and nourishment 4.300.000 m3 a 5,5 €/m3 & 23.650.000 & € 85.140.000 \\
Total Costs & 24.150.000 & € 86.940.000 \\
\hline
\end{tabular}
\end{table}

It’s important to realize that these costs are only costs for a beach that will last five years. After these five years a new nourishment will be needed. The amount of this nourishment will be significant less, namely in the order of the calculated loses in the first five years: 1.400.000 m\textsuperscript{3}. One can still imagine that the costs will be huge.

Off course there are a few ways to spend less money on this alternative. First of all, one can nourish a smaller amount of sand. For 30 m of beach a quick calculation shows that approximately 2.400.000 m\textsuperscript{3} without losses and 3.600.000 m\textsuperscript{3} with losses will be needed. At 5,5 €/m\textsuperscript{3} this still will be 19,80 million euro or 71,3 million pesos. Secondly the 5,5 €/m\textsuperscript{3} can be questioned. The proposed nourishment, from Jan de Nul Group on Playa Grande, is for a difficult reachable beach with a significant less amount of sand. With 4,5 €/m\textsuperscript{3}, a risky low estimation, the 30 m beach will cost 16,20 million euro or 58,3 million pesos. The last way to save money is to shorten the length of the nourishment area. South from the ‘Balneario Los Acantilados’, which is the southern limit of the private area, no economical development has ever taken place. This area is represented by profiles 1 – 5 with a length of 2,5 km. This would mean a reduction on the initial nourishment of 1.100.000 m\textsuperscript{3}. The total amount with the losses now becomes 2.700.000 m\textsuperscript{3} of sand. For 30 m beach this roughly means

\textsuperscript{10} Disponibilidad de arena para el refulado de las playas de Miramar y Chapadmalal, Argentina. F. I. Isla 2003
\textsuperscript{11} Relleno hidraulico Playa Granda – Mar del Plata for the Ministros Obras Publicas (Public Works) of the province of Buenos Aires
2.400.000 m$^3$ and with a prize of 4,5 €/m$^3$ and mobilization costs total costs end up to 10,8 million euro or 38,9 million pesos. One has to bear in mind that with these costs reductions still beach will have to be nourished after five years and that with the smaller beach, less benefits are to be gained.

4.1.4 Environmental impacts

The first environmental impact is the impact of the fore shore. The fore shore, which for a great part consists of the ‘Loess Pampeano’, will be covered by sand. This will kill local organisms. An exact impact can not be quantified, but it will be relatively small, since not to much live is already present.

Secondly there is the reef. Large beach nourishment may enhance the danger of sand accumulation on the reef. Although some accumulation will occur it is expected that the tombolo behind this reef will grow and that most of other eroded sand from southern beaches will pass this area and will be transported to the north. There are two reasons for this expectation.

At first the reef is 500 m offshore separated by a deeper part from the beach, see chart H-250 appendix I. Under normal conditions the long shore transport zone is 250 m wide. So the sediment transport to the reef is negligible.

The second reason is that pictures from the past, for example picture II.11 in appendix II, do not show a sort of sand bar in front of the tombolo when there was a wide beach present.

The last environmental effect can be expected for the beaches to the north and is not entirely negative. The large amount of sand that will erode will bring more sand in suspension and therefore cause less erosion on the northern beaches. A higher a rate of accumulation in front of the harbour mouth however can be expected.
4.2 Detached Breakwater

4.2.1 Location

Normally a detached breakwater is located just outside the breaker zone, in this case just over 50 m off shore, with no nourishment, and over 200 m off shore, with nourishment. A closer look at the depth profile and wave climate makes it possible to make a more precise estimation. With increasing depth the quantity of needed material increases and thus also the costs of the breakwater increase. Therefore the distance from the shore must be kept as small as possible. However, the breakwater becomes more effective, to a certain extend, when placed further out sea. Besides that, dangerous rip currents can occur round the breakwaters. When placed further out to sea, it’s safer for bathing guests.

Figure 4.1, derived with UNIBEST see appendix XII, shows which waves contribute the most to the long shore current and thus sediment transport. It is stressed here that this figure was obtained with a more detailed wave climate then that was used for the sediment transport calculations by hand. Waves with a $H_s = 1.6$ m from South, are the main cause transportation and thus the location of the detached breakwater should be chosen to counteract these waves.

![Long shore transport capacity for separated wave dir. Bijker (1971)](image)

**Figure 4.1 Long shore transport capacity**

Off course erosion also takes place during storms, when there is a higher significant wave height and thus a wider breaker zone. Detached breakwaters in this case will not stop long shore current seawards of the breakwater. It will stop or reduce (in case of a submerged breakwater) cross shore transport, which is very common during storms. This effect is one of the advantages of a detached breakwater and thus the location of the breakwater does not has to be adjusted for $H_{ss}$.

Waves with a $H_s$ of 1.6 m break at depth of 2.0 to 2.6 m. ($\gamma = 0.8 – 0.6$). It now depends on the bathymetry where this point is located off shore. When applied to profiles 1 – 5 this point is 200-280 m off shore, for profiles 6 – 12 this 50 m off shore and profile 13-15 already have their own natural submerged detached breakwater(the reef). These however are the current profiles. See appendix IX to see where the profiles are located. Profiles 1-5 and profiles 13-15 will keep the same bed slope. Profiles 6 – 12 partly do not have beach right now but will have a beach after either natural sand accumulation or beach nourishment. This will be discussed later. It does, however, imply that with a milder bed slope the breaker point, will be located at approximately 200 to 250 m. So now we can conclude that to make an effective
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detached breakwater it should be located some 300 m offshore were it is 5.5 to 6 meters deep, depending on the location. This seems rather deep on a bed slope of indeed 2:100, but the breakwater will be placed on the current bed an not on the nourished bed. This will be discussed later.

Furthermore the orientation of the breakwater needs to be clear. This orientation has a great influence on how much material is used, but also how effective the breakwater will be. With help of the “short wave theory”, see appendix XIII, the angle of attack of the waves at the breaker line was calculated. It showed 10° with the beach profile orientated to 154°. Roughly one can say that the waves at 300 m off shore approach under an angle of 5°to 20°. In Figures 4.2 and 4.3 the two options for the orientation can be seen. The first shows a breakwater that is constructed along the entire coastline and the second picture show multiple breakwaters constructed along the coast with a better orientation towards the waves. A combination is of course possible too, multiple breakwaters but not adjusted to the wave direction.

Both constructions have, naturally, advantages and disadvantages. Both share the advantage that not the entire length or all the breakwaters have to be constructed. If one only wants to protect half of the beach, for example profiles 6 – 11, the southern parts just do not need to be constructed. With the long breakwater more success is guaranteed, less to no waves will pass the breakwater. This then depends on the choice of a merged or submerged breakwater, which will be discussed later. With multiple breakwaters there always will diffract waves round the breakwaters and besides that, although far from shore, dangerous rip currents can occur. The advantage of the multiple breakwaters off course is a reduction on material. This seems to accounts even more for the orientated breakwaters, since they need less length to shelter the same area. However with their orientation they will not be constructed on the same depth all over the length of the breakwater. It now depends on the slope of the bottom whether this last effect is significant or not. For profiles 1-5, this slope is rather mild, but for profiles 6 – 11 the slope is steep and thus a significant increase in the amount of material can be expected.

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12 This does not imply that for profiles 6 – 11 one can start construction at profile 6. To get a milder wave climate at profile 6, the breakwater has to be located a bit more South along the coast, because of the Southern direction of the waves.
Since these technical disadvantages and advantages not clearly separate one alternative from the other, the costs will make the difference, discussed later.

### 4.2.2 Materials

Usually a detached breakwater is constructed by using stones or concrete blocks. Many guidelines of such breakwaters are available and there is a lot of experience available all over the world. Because a quarry, see section 6.3.3 with good quality stones is nearby the costs are relatively low. Besides that, local contractors will be used to work with stones. For these reasons using stones is a good option for the detached breakwater in front of Los Acantilados.

However a much cheaper solution could be using shipwrecks. A detached breakwater with shipwrecks preferably must be designed submerged because the attractiveness of the beach will be less if the wrecks are frequently visible. However before shipwrecks could be used several things have to be cleared.

The alternative of using shipwrecks is worth further investigation in this area because of several reasons. The port is very close to the beach so towing the ships to its final destination will not be expensive and sailing out can and will only be done when the weather is good. If the port was further away one had to rely on predictions for good weather. In the port of Mar del Plata there are many ships left by owners who went bankrupt. Using those ships would not only solve the erosion problem but also clean the harbor.

Before the construction can start the ships have to be cleaned and stripped from all unnecessary attributes and only the haul will be left. After that the ship will be towed into place and be sunken down in a controlled way. Labor is not very expensive in Argentina and so cleaning and stripping the ships, which is mainly labor intensive, can be done cheap. The last advantage of this area is the presence of the rocky platform near the beach so no special filters have to be constructed to prevent the wreck to sink away in the sand.

However when designing a submerged detached breakwater with the use of shipwrecks, it will be very difficult to predict the effects of the breakwater on the sediment transport and erosion along the beach. Before starting the design a good and thorough examination has to be done. One can imagine that the wave transmission, with submerged ships is still high.

Yet another way to construct a detached breakwater is the use of geotubes. These are big ‘bags’ of geotextile filled with sand. A ship maneuvers itself in the right position on the geotube is dropped from the ship and the offshore breakwater is ready. Geotubes have a relatively short history of existence and there...
is still a lot of research that needs to be done.

For this project the cheapest and most practical solution is to use quarry stone to build the detached breakwater. Therefore stones are used to further design this alternative. However the recommendation is made, that with the especially the use of shipwrecks are worth further research. This solution is not often used in the world and with the problems in the harbor and the lack of refunds at hand; the beach of Los Acantilados could serve as a pilot project.

4.2.3 Dimensions

The dimension of a detached breakwater is influenced by a few parameters. Most important are the design wave height and the needed size of the protection. Under normal conditions the design wave height is 1,6 m. The $D_{50}$, nevertheless, must be calculated with conditions in storms. The calculations are to be seen in Appendix XVII, Armour size. A $D_{50}$ of 1,47 m is concluded. With Ahrens (1987) the following cross section was obtained, see appendix XVI, Dimensions detached breakwater.

![Figure 4.6 Cross section detached breakwater](image)

4.2.4 Nourishment

Because there is no or hardly any sand transport from the South, no real beach will accumulate and nourishment is needed. For the nourishment the amounts from the alternative periodical nourishment can be used. With a construction to reduce the erosion to almost zero, the 50 % rule of thumb for a first estimation of the losses is not used.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Amount of sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full length 50 m beach</td>
<td>2,900.000 m³</td>
</tr>
<tr>
<td>Short length 50 m beach</td>
<td>2,800.000 m³</td>
</tr>
<tr>
<td>Short length 30 m beach</td>
<td>2,400.000 m³</td>
</tr>
</tbody>
</table>

4.2.5 Realisation

There are different ways to construct a detached offshore breakwater. One can build the structure from floating material like a ship, pontoons or split barges. The other possibility is to construct the breakwater by building an entrance road rectangular to the coastline and use this to reach the place of the future breakwater with trucks. In fact this is like building a big groyne and then extending it in direction parallel to the coast. This seems like a rather strange solution: but if this option is cheaper then using floating material it becomes a realistic option. A decision has to be taken whether the perpendicular access road has to be removed after completion of the offshore breakwater. An evaluation on the hinder and benefits of the access groyne for the beach and the financial aspects of removing it leads to a conclusion.
In this case there is a mayor problem with the lack of availability of floating equipment. When calculations were made in the year 2004 by the ministry of public affairs for the province of Buenos Aires\textsuperscript{13}, it turned out that the minimal possible costs of a construction build by floating material would cost six times the cost of construction from shore. This disadvantage makes construction from shore the better alternative.

4.2.6 Costs

The costs of the breakwater depend mainly on the amount of stones that have to be placed. The average price, according to the provincial engineers for a breakwater is 300.000 to 400.000 pesos per 100 m, build from the shore. A more precise is the price to place stones at the breakwater: 40-45 pesos per ton. Building from floating material is at least 6 times more expensive. With a weight of 2650 kg/m\textsuperscript{3}, a cross section of 190 m\textsuperscript{2} and an assumed pore ratio of 0,25, a detached breakwater will cost:

\[190\times 2650 \times 10 - 3 \times 0,75 \times 45 = 17.000 \text{ Pesos/m}^1\]

Clearly the rather large depth, on which the parallel part of the breakwater is build, causes an increase in the costs. The costs for building the breakwater off shore are 102.000 pesos/m\textsuperscript{1}. To construct a ‘help’-breakwater to 300 m off shore will cost 1.200.000 pesos/breakwater. Various building procedures now determine a minimum price.

The research area is 8,2 km long. To prevent erosion just south of Punta Mogotes, were in the current situation beach is available, the start of the breakwater system here is required. To minimize the costs and solve the biggest economical problems, the system can be build to profile 6. The total length now becomes 4000 m. This can be done in the following ways as showed in schematic figures 4.7

![Figure 4.7 Layout of detached breakwaters](image)

With the following total costs in argentine pesos, in which distances were estimated:

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Length off shore</th>
<th>Costs</th>
<th>Number of ‘help’-groynes</th>
<th>Costs</th>
<th>Total Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>One off shore</td>
<td>4000</td>
<td>408,000,000</td>
<td>0</td>
<td>0</td>
<td>408,000,000</td>
</tr>
<tr>
<td>Multiple off shore</td>
<td>3000</td>
<td>306,000,000</td>
<td>0</td>
<td>0</td>
<td>306,000,000</td>
</tr>
<tr>
<td>Multiple from shore</td>
<td>3000</td>
<td>51,000,000</td>
<td>5</td>
<td>6,000</td>
<td>57,000,000</td>
</tr>
<tr>
<td>One off shore</td>
<td>4000</td>
<td>68,000,000</td>
<td>2</td>
<td>2,400</td>
<td>70,400,000</td>
</tr>
</tbody>
</table>

Multiple T-bone shaped breakwaters are the cheapest solution. However to get a detached breakwater, it would be necessary to remove material from the ‘body’ of the breakwater. On the one hand this saves material, one can build the groynes one by one, but on the other hand it costs extra labour. This solution does however offer a

\textsuperscript{13} Conversation with Roberto S. Sciarrone and Ruben E. Melendez from the Ministros Obras Publicas (Public Works) of the province of Buenos Aires
great deal of flexibility: one can build the groynes one by one or decide whether the body of the T-bone is kept, to save money or to spend it when it’s available.

Unfortunately the costs have to be increased with the costs of beach nourishment. With a low estimation of the dredging costs at 4,5 €/m$^3$ or 16,5 pesos/m$^3$ the costs for the nourishment become:

**Table 4-5 Costs of different nourishments**

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Amount of sand</th>
<th>Mobilisation costs</th>
<th>Dredging costs</th>
<th>Total costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full length 50 m beach</td>
<td>2.900.000 m$^3$</td>
<td>1.800.000</td>
<td>47.900.000</td>
<td>49.700.000</td>
</tr>
<tr>
<td>Short length 50 m beach</td>
<td>1.900.000 m$^3$</td>
<td>1.800.000</td>
<td>30.800.000</td>
<td>32.600.000</td>
</tr>
<tr>
<td>Short length 30 m beach</td>
<td>1.700.000 m$^3$</td>
<td>1.800.000</td>
<td>27.500.000</td>
<td>29.300.000</td>
</tr>
</tbody>
</table>

This results in the minimal costs for this alternative become 57.000.000, of the multiple breakwaters build from shore, plus 29.300.000, for a short length beach of 30 m wide, is 86.300.000 pesos.

### 4.2.7 Environmental impacts

Constructing a groyne system along the coast will always have big impacts on the environment. The sediment transport will nearly completely be stopped and so there will be no or hardly any sand input into the system at the North of the tombolo at Punta Mogotes. This situation however already exists nowadays resulting in minor erosion at the north of the tombolo. This situation will worsen. Besides this influence on the coastal system, the flora and fauna will be affected too. Big structures will be build and a significant amount of sand will be nourished. This will have an effect on organisms on the bottom. On the other hand the breakwaters parallel to the coast will attract fish and maybe even seals.
4.3  Groyne field

4.3.1 General

Groynes are used to interrupt the littoral drift. A groyne field (multiple groynes parallel to each other) is often used to stabilize the sand of a beach. Stabilization of the nourished beach can be useful because beach nourishment alone may be an expensive solution when the transport rate of sediment is high. The length of the groynes and the distance between them depend on local conditions. At Los Acantilados the needed sand nourishment forms a gentile slope on the foreshore. Therefore the waves may collapse at a large distance from coast. This implies long groynes, although also can be decided for a solution that does not stretch out totally through the breaker zone. The littoral drift is not stopped totally but this may be cost efficient even though the beach erosion speed may be higher. This has also less negative consequences for the downstream area.

4.3.2 Groyne types

Different types of groynes exist which are suitable for different situations. An overview of three feasible options is given below.

4.3.2.1 Rubble mound groynes

The locally most used option is a rubble mound groyne made with stones mined from the Mar del Plata quarry. A rubble mound groyne is build up with a core of filter material and an armour layer. The filter material has to be a finer stone to prevent sand to be washed out of the foundation of the groyne, this kind of stone is also cheaper than armour rock. The armour material exists of large heavy rocks that are stable during serious wave attack. The height of the groyne is determined by the amount of waves that may overtop the groyne. Overtopping of a groyne is not too harmful because sediment transport mainly takes place near the bottom. The width of the crest of the groyne is often determined by the construction method. When the groyne is build from the land (by unloading trucks at the end of the groyne) the size of a truck and crane is the determining parameter. When construction is done from the sea (a floating crane) only the stability of the stone is the dominant factor. The third important parameter is the slope of the groyne. This has a correlation with the stone size. A larger stone allows a steeper slope and vice versa.

4.3.2.2 Timber groynes

A timber groyne can be a cost efficient solution for the situation of Los Acantilados. The advantage of wooden groynes is that they are more flexible in use. When damage to the groyne occurs or erosion of the beach is detected, the groyne can be re-adjusted. A disadvantage is that maintenance has to be done every year for else damaged groynes may very fast decay and lose their function. The sturdy wave climate demands a well constructed groyne. Also a good creosote and coal tar treatment of the timber is very important. A semi permeable groyne is easily made by just hammering round poles into the seabed with spacing between them of for instance 1 diameter. Semi permeable groynes can be used to the north to start the littoral drift of sand slowly. Disadvantage of this solution is that wood is a more scarce material than rock in this part of Argentina so cost for construction and maintenance are expected to be high. Also, maintenance is essential to ensure the function of the groyne. This may not work well in a country in a financial crisis and people who are not used to see maintenance as an important issue. On top of that it is questionable whether it is possible to hammer the poles in the subsoil off shore. There probably is rock present, which makes expensive drilling necessary. For these reasons is decided not to recommend a solution with timber groynes.
4.3.2.3 Concrete groynes  
Concrete groynes are used in the area but not with great result. Most of the concrete groynes are destructed by wave action and are left to die. The reason that the groynes are destructed is both because bad engineering and the large wave action in the area. From both perspectives it is not thought wisely to recommend concrete groynes for this situation.

4.3.2.4 Conclusion groyne types  
The rubble mound groyne will be elaborated further because this type of groyne is found to be the best fitting solution for three reasons:
• Availability of rock nearby the location
• Knowledge of construction available at local contractors
• Little maintenance is needed.

4.3.3 Functional design  
For the reduction of sediment transport in the area mainly the length of the groynes, relatively to the length of the breaker zone, and the width between the groynes is of importance. This width surely should not be too large, because then the effect is only felt near the groyne. Constructing the groynes too close to each other would make the beach not very attractive and the project very expensive, see picture below.

Figure 4.9 Spacing of groynes  
Also, constructing groynes with a small spacing may cause problems with the steepness of the beach. A fieldtrip to the beach of Miramar (20 km south of Mar del Plata) showed a beach with relatively short groynes with a spacing of only 100 m. The beach was retained well by the groynes but the steep beach caused that the public did not like to go into the water, resulting in lower occupation of this particular beach.

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Groynes can be constructed both perpendicular to the coast or with a small angle along with the littoral drift. In this situation the littoral drift is not constant in the same direction and thus must be constructed perpendicular to the coast to have the most effect.\(^{15}\)

On the near foreshore of the Los Acantilados beach a slope of 1:100 is constructed. This means that in normal conditions the breaker zone stretches 240 meters out into the sea. In storm conditions this is even further into the sea.

Calculations with UNIBEST show that especially the zone with a direction of SW-NE encounters much erosion. This can be explained by the main wave direction, which is from the south. Therefore, in the area with an angle closest to 45 degrees to the south the radiation stress causes the largest littoral transport. This requires a denser groyne field to stop the littoral transport. In areas with a smaller or larger angle the littoral drift decreases so less sturdy measures can be taken.

In the zone diagonal to the main wave direction littoral drift must be stopped totally so groynes have to be constructed with a length of 240 meter \((L_0)\). The spacing is chosen to be twice the length of the groyne, 480 meter, which is rather close to each other but obeys to the rule of thumb to design a spacing of 2 to 5 times the length of a groyne. A section of 5 groynes is constructed this way.

On both sides of this section the angle to the main wave direction is changing in a way that less littoral drift is occurring. Therefore a less rigid structure is required and the spacing between the groynes can be enlarged. This is designed to change gradually. The first spacing is \(2,5 \times L_0\) (= 600 m), the second is 3 times (=720 m) and the third spacing is 4 times \(L_0\) (= 960 m).

To the north erosion of the salient is feared because the sediment transport is stopped upstream and starts again at the salient. Therefore it is desired to build up the littoral drift of sediment slowly again. To accomplish this, a percentage of sediment in upstream sections is allowed to pass the groynes. This can be done by making the groynes semi permeable or shorter. For rubble mound groynes decreasing the length is more feasible. The groynes to the north have a decreasing length in two steps to half \(L_0\). In total 11 groynes have to be constructed, an overview of the proposed preliminary design is given in Figure 4.8, (not in scale).

4.3.4 Construction of the rubble mound groyne

The paved entrance to the beach at Punta Mogotes allows construction from land. The rock can be transported and put on the groyne by truck. Building the groyne from water is said to be up to six times more expensive so this option is considered not reasonable.

4.3.5 Structural design

As said the groyne is constructed with a core of quarry run and an armour layer of larger rocks. As a preliminary design a talus is taken of 1:3. With this talus the size of the armour is calculated in Appendix XVII and amounts 1,5 m. On the head of the groyne an even larger rock is needed of 1,9 m. Two layers of armour rock are used. To be able to drive a lorry over the groyne a width of 3 m of the crest is needed. The height of the core of the groyne is designed to be equal to high water level of the tide, which is 1,12 m above chart datum. On top of this core two layers of armour rock are placed with a D50 of 1,9m At the head the depth is 5,3 m. In the picture

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4.3.6 Nourishment

Since at this moment no beach is available nourishment is needed. For first calculations for the nourishment the amounts from the alternative periodical nourishment can be used. With a construction to reduce the erosion to almost zero, the 50 % rule of thumb for a first estimation of the losses is not used.

Table 4-6 Volume of nourishment

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Amount of sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full length 50 m beach</td>
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</tr>
<tr>
<td>Short length 50 m beach</td>
<td>1.900.000 m³</td>
</tr>
<tr>
<td>Short length 30 m beach</td>
<td>1.700.000 m³</td>
</tr>
</tbody>
</table>

4.3.7 Costs

The total length of all the groynes is 2400 meter, at a prize of 400.000 pesos per 100 meter, the total amount of the construction of the groynes will be approximately 9.6 million pesos.

The costs have to be increased with the costs of beach nourishment. With a low estimation of the dredging costs at 4,5 €/m³ or 16,5 pesos/m³ the costs for the nourishment become:

Table 4-7 Costs of nourishment

<table>
<thead>
<tr>
<th>Alternative</th>
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<tbody>
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<td>1.800.000</td>
<td>47.900.000</td>
<td>49.700.000</td>
</tr>
<tr>
<td>Short length 50 m beach</td>
<td>1.900.000 m³</td>
<td>1.800.000</td>
<td>30.800.000</td>
<td>32.600.000</td>
</tr>
<tr>
<td>Short length 30 m beach</td>
<td>1.700.000 m³</td>
<td>1.800.000</td>
<td>27.500.000</td>
<td>29.300.000</td>
</tr>
</tbody>
</table>

The minimum costs now becomes 9.600.000 + 29.300.000 = 38.900.000 pesos
4.3.8 Environmental impacts

The environmental impacts are about the same as for the detached breakwater. So also in this case the sediment transport will be stopped and probably cause erosion north of the groins. Also the overview of the beach will change in fact the beach is being divided in pieces by the construction of the groins.
5 Evaluation of the alternatives

To make a good comparison between the possible alternatives a multi criteria analysis (MCA) is shown below. The main categories are functionality, structure, construction, environmental and financial; all subdivided in specific aspects. Below the MCA a consideration is given and a conclusion with the alternative that will be elaborated.

5.1 Multi Criteria Analysis

<table>
<thead>
<tr>
<th>Functionality</th>
<th>Periodical beach nourishment</th>
<th>Off shore breakwater with sand fill</th>
<th>Groyne field with sand fill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attractiveness of the beach</td>
<td>Very attractive, the appearance of the beach remains natural</td>
<td>Moderate attractive, the view to the horizon of the sea is blocked by the breakwater</td>
<td>Moderate attractive, the beach is interrupted by rubble mound structures</td>
</tr>
<tr>
<td>Bathing safety</td>
<td>Very safe, no unnatural currents occur and no structures are found</td>
<td>Safe, rip currents and hard structure is far out of the bathing zone</td>
<td>Moderately safe, rip currents may occur near the groynes close to the beach, hard material is present</td>
</tr>
<tr>
<td>Beach comfort</td>
<td>Very good, nice sand and comfortable slope of the beach</td>
<td>Moderate, small particles may settle so muddy beaches may occur</td>
<td>Good, nice sand but steep slopes near groynes</td>
</tr>
<tr>
<td>Water comfort</td>
<td>Mediocre, waves break calm because of gentile slope of beach</td>
<td>Good, the breakwater leads to comfortable smaller wave heights</td>
<td>Mediocre, waves break calm because of gentile slope of beach except near the groyne</td>
</tr>
<tr>
<td>Accessibility of the beach</td>
<td>Very good, no restrictions</td>
<td>Very good, no restrictions</td>
<td>Poor to moderate, groynes stretch out onto the beach</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Structure</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Durability / sustainability</td>
<td>Not durable, every 5 years a sand fill is needed</td>
<td>Durable, the breakwater(s) have a lifetime of 50 years and erosion of the beach is low</td>
<td>Very durable, the groynes have a lifetime of 50 years and beach erosion is very low</td>
</tr>
<tr>
<td>Reliability</td>
<td>Reliable, if maintained correctly; vulnerable in storms</td>
<td>Very reliable</td>
<td>Very reliable</td>
</tr>
<tr>
<td>Accessibility of the beach</td>
<td>Very good</td>
<td>Very good</td>
<td>Poor to moderate, structure on the beach</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Construction</th>
<th>Good</th>
<th>Poor</th>
<th>Mediocre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction hinder</td>
<td>Very good, when nourishing from sea no hindrance is made to other beaches</td>
<td>Bad, construction has to be done by access road over other beaches during summer so beaches have to be closed</td>
<td>Bad, construction has to be done by access road over other beaches during summer so beaches have to be closed</td>
</tr>
<tr>
<td>Possibility of phasing of construction</td>
<td>Good, when refill of the beach is needed larger beach may be created</td>
<td>Moderate, the breakwater(s) are very large so large sections have to be done at once</td>
<td>Good, while previous build groynes retain the sand, a new section can be made</td>
</tr>
</tbody>
</table>

| Environmental | Good, only little change will occur | Moderate, small particles may settle causing muddy bottom though near the breakwater new flora and fauna may come into existence | Good, only little change will occur |
| Ecology of the fore shore | Moderate, in this solution sanding up of the salient and reef is likely | Good, this solution has the least effect on downstream area | Moderate, small erosion of the salient is likely |
| Ecology of downstream area | | | |

| Financial | initial investment | 38.900.000 | 86.300.000 | 38.900.000 |
| future investment | big | none | none |
| maintenance | re-nourishment every 5 year | Modest | modest |
| benefits | Higher | Average | Lower |

5.2 Conclusion

Evaluating the three alternatives one can clearly conclude that a beach nourishment is far out the best solution if money is not considered. It implies no hindrance to other beaches during construction. Also the attractiveness and comfort of the beach and water is very good. Weak point of this alternative is that the beach needs to be maintained every few years. This has a mayor impact on the cost in the future because the restoring activities are almost as expensive as the initial costs.

A comparison between the alternatives “Groyne field” and “Off shore breakwater” is approximately equal. The structures are very reliable and durable and phasing is good possible. Disadvantage for both is that during construction hindrance of the other beaches is present during summer.

To come to a decision the paramount motive is money. Financial means are scarce so economics often are the decisive motivator. Two alternatives have the same initial investment, however periodical nourishment requires large investments in the future. Also the construction of a conventional offshore breakwater will be very expensive. For this reason the groyne field is chosen and will be elaborated further.
6 Elaboration of the groyne field

6.1 Location and length of the groynes

For the determining of the lengths of the groynes, first the location with respect to the coast is discussed. In the previous section Alternative groyne field, the location was determined with the theory that the groynes should be relatively closed spaced where the erosion is the heaviest. This are rays 4 to 10. As outlined before the section slightly south of the tombolo, rays 11 to 14 are accreting at this moment. Building large groynes here is therefore not necessary. What is necessary in this area when building groynes further south, is to let the long shore current pick up over a large area as possible to spread the impact of erosion.

6.1.1 Determining the length of the groynes

The length of a groyne depends on which part of the long shore transport one wants to block and on the quantities of the sediment input in the system. In the case of Los Acantilados therefore is little sediment input compared with the potential long shore sediment transport capacity. Therefore, when one wants to reconstructs a beach with sand nourishment in between the groyne sections a large blocking percentage is necessary to maintain the artificial beach.

With UNIBEST and the Los Acantilados model blocking percentages are derived for the 15 rays in the model. These blocking percentages are a function of the offshore distance with the coastline as a reference. One has to bear in mind that these are blocking percentages for a groyne when it is built on its one. Building a groyne field, the groynes will amplify each others efficiency, because of the reduced wave climates between the groynes. The amplification factor is assumed to be a percentage of 10%. A figure of the sediment blocking functions is shown below.

![Sediment blocking function rays](image)

**Figure 6.1 Sediment blocking function**

With the aid of this figure the lengths of the groynes lengths can be determined.
For an overview of how the groynes are located with respect to the rays, see Figure 6.2 below.

In red are different rays or profiles and in black the proposed groynes. The rays are numbered from South West to North East 1 to 15. The groynes are lettered North East to South West GA to GK. In the table below the rays and corresponding groynes are outlined.

### Table 6-1 Groynes and corresponding rays

<table>
<thead>
<tr>
<th>Groyne</th>
<th>Corresponding ray(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GA</td>
<td>Between 11-12</td>
</tr>
<tr>
<td>GB</td>
<td>Exactly on 10</td>
</tr>
<tr>
<td>GC</td>
<td>Exactly on 9</td>
</tr>
<tr>
<td>GD</td>
<td>Exactly on 8</td>
</tr>
<tr>
<td>GE</td>
<td>Between 7-8</td>
</tr>
<tr>
<td>GF</td>
<td>Exactly on 7</td>
</tr>
<tr>
<td>GG</td>
<td>Between 6-7</td>
</tr>
<tr>
<td>GH</td>
<td>Between 5-6</td>
</tr>
<tr>
<td>GI</td>
<td>Exactly on 4</td>
</tr>
<tr>
<td>GJ</td>
<td>Exactly on 3</td>
</tr>
<tr>
<td>GK</td>
<td>Between 1-2</td>
</tr>
</tbody>
</table>

If a groyne is not exactly proposed on a ray but in between two rays, the differences in blocking percentages are linear interpolated.

![Figure 6.2 Layout groynes and rays](image)
For determining the length of the groynes first blocking percentages of the groynes must be determined. A section is formed by two groynes and in a section nourished sand must be trapped as well as possible. Therefore one could build the groynes with a length that they totally block the long shore current and thus the sediment transport. However this is an unrealistic approach because when a storm occurs the breaker zone can stretch out as far as 500 m. As previously outlined the approach here is to stop the sediment transport in combination with the average wave climate. This means that to stop the largest part of the sediment transport a percentage of 80% to 85% is advised. The other 15% to 20% will be lost during storm events from one section to the other and finally downstream the groyne field. This is for the downstream erosion of the groyne field in the rays 10 to 13 a good mitigation. With the years there will be less sand lost out of the section because of the volume of sand in the section will become less.

The next table shows the proposed blocking percentages in combination with the length of the groyne build alone and build in a field.

### Table 6-2 Proposed blocking percentage

<table>
<thead>
<tr>
<th>Groyne</th>
<th>Blocking percentage</th>
<th>Length of groynes</th>
<th>Blocking percentage in field</th>
</tr>
</thead>
<tbody>
<tr>
<td>GA</td>
<td>20 – 25%</td>
<td>45 m</td>
<td>18 – 23%</td>
</tr>
<tr>
<td>GB</td>
<td>45 – 50%</td>
<td>85 m</td>
<td>41 – 45%</td>
</tr>
<tr>
<td>GC</td>
<td>70 – 75%</td>
<td>110 m</td>
<td>63 – 68%</td>
</tr>
<tr>
<td>GD</td>
<td>80 – 85%</td>
<td>160 m</td>
<td>72 – 77%</td>
</tr>
<tr>
<td>GE</td>
<td>80 – 85%</td>
<td>160 m</td>
<td>72 – 77%</td>
</tr>
<tr>
<td>GF</td>
<td>80 – 85%</td>
<td>160 m</td>
<td>72 – 77%</td>
</tr>
<tr>
<td>GG</td>
<td>80 – 85%</td>
<td>250 m</td>
<td>72 – 77%</td>
</tr>
<tr>
<td>GH</td>
<td>80 – 85%</td>
<td>370 m</td>
<td>72 – 77%</td>
</tr>
<tr>
<td>GI</td>
<td>80 – 85%</td>
<td>370 m</td>
<td>72 – 77%</td>
</tr>
<tr>
<td>GJ</td>
<td>80 – 85%</td>
<td>370 m</td>
<td>72 – 77%</td>
</tr>
<tr>
<td>GK</td>
<td>80 – 85%</td>
<td>370 m</td>
<td>72 – 77%</td>
</tr>
</tbody>
</table>

### 6.1.2 Discussion on the length of the groynes

The lengths of groynes GI, GJ, GK and GH, are very large. This would not be groynes anymore but small breakwaters. As outlined earlier the locations of these groynes are not in an economic interesting area because there are no balearnario´s (beach clubs) being concessioned. Not only for this reason but also for the fact that the groynes need to be of an extensive length of about 300 m – 335 m, which would mean a very large cross section because of the large depth at that distance offshore, it is better not to build these tree groynes. For the groynes GD, GE, GF, GG the lengths are around 105 m. These are reasonable lengths to build. Important is that for the most southern groyne in the field the reduction factor on the length can not be applied.
The groynes GA, GB and GC are designed with this length because a low blocking coefficient is needed to let sediment bypass and the starting of the long shore current downstream the groyne field. Groyne GA, GB and GC should respectively have a length of 40, 75 and 95 m. Groyne GA is constructed on beach where no erosion problems are, which seems strange, but groyne GA should be build to spread the impact of erosion which will start because of the upstream groynes. However the beach which currently functions well and is wide enough, should not be burdened with groynes not only from an aesthetic point of view, which is very important for the bathing guest, but also constructive the length is very short. Groyne GA is not included in the design for these reasons.

### 6.1.2.1 Length of the groynes on the beach

The length calculated until now are lengths from the new or nourished waterline. Building a groyne will be done before the sand is nourished, this implies that one first has to build the groyne 50 m into the sea because of the construction method used. This method is the conventional one with land-based equipment, as trucks and backhoes.

This water line is about 50 meters from the current waterline. The final length of a groyne on the beach should be longer than the highest high waterline. This extra length depends on the beach slope, which is 4:100. For more detailed beach slopes see Appendix XVII and section 6.33 The design is shown in the picture below.

![Overview groyne section on the beach](image)

**Figure 6.2 Overview groyne section on the beach**

This extra length is a maximum length of 78 m, and depending on the profile to be nourished. If in the current section is already beach for instance in ray 10 the groyne can be build from the current beach.
6.1.3 Spacing of the groynes

For determining the spacing of the groyne the rule of thumb is used which states that the distance between groynes in a groyne field should 2 – 5 times the length of the groyne. After the more detailed analysis on the length, the spacing needs to be adjusted. The spacing of the 4 middle groynes changes from 420 m to 320 meter, because of a decrease of the length. With the groynes closer together 4 groynes of 105 meter will not be long enough. Therefore an extra groyne is needed and will be in the final design. This groyne is numbered GD2, see Figure 6.4 on the right, which is not in scale for the length of the groynes.

Figure 6.3 Proposed groyne scheme
6.1.4 Final design groynes

The final design proposal for the location and the length of the groynes is building 7 groynes in total, 5 large ones (GG, GF, GE, GD and GD2) and two smaller ones (GC and GB). Groyne GG is larger because it is not sheltered by a more Southern Eastern groyne.

See Table 6-3 below for more specifications. The groynes are to be build perpendicular the coast. The coastal angles given are derived with the chart H-250 see appendix I, these angles are approximation and should therefore be checked. For groyne GD the coordinates are given, with these coordinates the other coordinates of the groynes can be derived. With current water line at the time of the start of construction the coordinates should be determined exactly.

Table 6-3 Groyne specifications

<table>
<thead>
<tr>
<th>Groyne</th>
<th>Total length (m)</th>
<th>Length from the nourished Water line</th>
<th>Spacing with upstream groyne</th>
<th>Coastal Angle</th>
<th>Coordinates begin construction point</th>
</tr>
</thead>
<tbody>
<tr>
<td>GB</td>
<td>115 m</td>
<td>60 m</td>
<td>525 m</td>
<td>154°</td>
<td>TDB</td>
</tr>
<tr>
<td>GC</td>
<td>153 m</td>
<td>90 m</td>
<td>420 m</td>
<td>154°</td>
<td>TDB</td>
</tr>
<tr>
<td>GD2</td>
<td>175 m</td>
<td>105 m</td>
<td>320 m</td>
<td>150°</td>
<td>TDB</td>
</tr>
<tr>
<td>GD</td>
<td>175 m</td>
<td>105 m</td>
<td>320 m</td>
<td>150°</td>
<td>57° 34' 90 W 38° 6' 85 E</td>
</tr>
<tr>
<td>GE</td>
<td>175 m</td>
<td>105 m</td>
<td>320 m</td>
<td>141°</td>
<td>TDB</td>
</tr>
<tr>
<td>GF</td>
<td>185 m</td>
<td>105 m</td>
<td>480 m</td>
<td>141°</td>
<td>TDB</td>
</tr>
<tr>
<td>GG</td>
<td>240 m</td>
<td>160 m</td>
<td>-</td>
<td>135°</td>
<td>TDB</td>
</tr>
</tbody>
</table>

TDB = To be determined when start building
6.2 Dimensions of the groynes

In this section the dimensions of the groynes are elaborated and detailed. The structure of this section is a bit different than usual because during the detailed calculations, results were obtained that were not satisfying and realizable. Therefore recalculations had to be made with slightly adapted conditions for the design storm and related damage parameters.

The dimensions of the groins, like the height and the width are mostly set by the way of realization. Because no floating equipment will be used because this is expensive, the groynes will be constructed from the beach by use of earthmoving equipment. For the following calculations groyne GF with a length of 175 m and a local depth of 5,2 m in the current average profiles 6-11, see section lengths and location. The calculated value for $H_{ss} = 5,1$ m. The depth at the head of the breakwater, after nourishment, is uncertain, but has a maximum of 5,2, the design wave will still break here and is used.

6.2.1 Height

Because only land based earthmoving equipment will be used for the construction of the groins, the height of the core has to be designed sufficiently high, so cranes and trucks will be able to drive on the groyne during construction. Therefore a sufficient tidal window has to be present, meaning that the crest of the core has to be at least 0,4 meters above the mean water level, this is the average high sea level. Above the core an armour layer will be placed. Overtopping after construction in case of the groins is no issue either because most of the transport takes place near the seabed.

6.2.2 Width

The width of the groins is set by the width of the trucks driving on the groyne or either by the design guidelines. Because of that the crest of the core has to be 3 meters wide so a truck can drive over the crest. The Shore Protection Manual (1984) says the crest also has to be over 3 times the $D_{50}$ of the armour layer wide. So because the $D_{50}$ of the armour layer is 1,70 m, explained below, a minimal width of 5,00 m is designed.

6.2.3 Slope

To prevent waves from collapsing on the groins, which has to be prevented at all times, only very steep slopes of over 1:1,5 or a slope milder than 1:2 is required. Because steep slopes are unstable, a slope of 1:2 is chosen so the Irribaren parameter with the highest possible waves is 1,8 , meaning waves will be plunging on the groins.

6.2.4 Layers

In appendix XVII the stone diameter was calculated, namely $D_{50} = 1,70$. The mass, with a density of 2650 kg/m$^3$ now is 13 ton. The $D_{50} = 0,8D_{50}$ , so $D_{50} = 2,1$m. The grading of the quarry stone needs to be narrow to minimize the damage and is expressed in $D_{85}/D_{15} = 1,5$. The armour layer now should be of the following grading:

<table>
<thead>
<tr>
<th>$D_x$</th>
<th>Size (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_{15}$</td>
<td>1,7</td>
</tr>
<tr>
<td>$D_{50}$</td>
<td>2,1</td>
</tr>
<tr>
<td>$D_{85}$</td>
<td>2,5</td>
</tr>
</tbody>
</table>
The groyne has to be geometric stable structure. This has to be obtained in various ways. For one, the armour layer needs to be at least $2D_{n50}$, which is 4.1 m thick. The following accounts for the thickness of the layer according to Shore Protection Manual (1984) and CUR/CIRIA (1991):

$$t = mK_vD_{n50}$$

With:

- $t$ = Layer thickness (m)
- $m$ = Number of layers of armour units (-)
- $K_v$ = Layer thickness coefficient (-)
- $D_{n50}$ = Nominal diameter of the cube (m)

With 2 layers and $K_v = 1$ for quarry rock, the layer should be about 4.1 m thick.

Secondly the previous mentioned core needs to guarantee the permeability as well as the stability. This can be calculated with rules for a geometric open filter, but also with rule by thumb that the under layer must consist of units of 1/10 of the block weight\(^{16}\), when stones from a quarry are used with a concrete or quarry-rock layer above it. This implies a stone of approximately 1300 kg or $D_{n50} = 0.79$ m and $D_{50} = 1.0$ m. Rules for geometric filters state the following:

$$\frac{D_{f15}}{D_{b15}} > 4 - 5$$  \hspace{1cm} \text{Permeability}$$

$$\frac{D_{60}}{D_{10}} < 10$$  \hspace{1cm} \text{Layer Stability}$$

With $D_{f15} = 1.70$ m, then $D_{b15} > 0.35-0.42$ m. The permeability however is not as important as when designing an embankment. The core can consist of stones with a wider grading, namely 2.5. With these two gradings, both layers will be stable. If the rule of thumb is used and thus permeability is guaranteed, then the first under layer should be made of the following:

**Table 6-5 Stone size under layers**

<table>
<thead>
<tr>
<th>$D_x$</th>
<th>Size (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_{15}$</td>
<td>0.6</td>
</tr>
<tr>
<td>$D_{50}$</td>
<td>1.0</td>
</tr>
<tr>
<td>$D_{85}$</td>
<td>1.5</td>
</tr>
</tbody>
</table>

There are no specific rules for the breakwater head, but since this is exposed to the heaviest wave action, advices for 1 to 4 times heavier stones can be found. The Shore Protection Manual (1984) recommends using stones twice as heavy at the breakwater head than at the trunk of the breakwater. So stones with a weight of 26 tons are needed, with an under layer of 2600 kg. The stones of the core at the breakwater head should be 1,20 m, according to SPM (1984), but since permeability and stability won’t be a problem if the same stones are used for the entire core, stones with $D_{50}$ of 1,1 m and 1800 kg will be used. This is less expensive and makes construction easier. The thickness of this layer is 2 times the grain diameter. From this point the next under layers consist of stones with the weight of the above layer divided by 20.

| Layer 2 | 1800/20 | 90 kg |
| Layer 3 | 90/20 | 4.5 kg |

All the layers are as follows, when build on rock:

<table>
<thead>
<tr>
<th>Table 6-6 Stone sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Where</strong></td>
</tr>
<tr>
<td>Armour trunk</td>
</tr>
<tr>
<td>Armour head</td>
</tr>
<tr>
<td>Layer 1</td>
</tr>
<tr>
<td>Layer 2</td>
</tr>
<tr>
<td>Layer 3</td>
</tr>
</tbody>
</table>

6.2.5 Base on sand

For groins build on sand the design needs a different approach. First the connection with the bottom will be discussed, since this is important for the core of the groyne.

At some locations where groins are planned, the base consists of sand. This is a problem because the sand round and under the groyne can scour and thus causing instability or even partly collapsing of the groyne. There are three ways to solve this problem. First of all the sand can be dredged until the bedrock. From here the groyne can be build in the same way as the groynes mentioned above. But dredging is expensive, although a ship might be nearby for the beach nourishment. Moreover with dredging more material is needed to construct the groyne. Thorough research will be needed to the depth of the bedrock and the costs of dredging a ditch, before deciding for this option.

Secondly a filter can be used on these sites to ensure the stability. This can be done in two ways, by a granular filter or a geotextile. Placement of a geotextile in the surf zone is however a very expensive and difficult operation compared to the granular filter. A granular filter needs many layers. To reduce the number of layers, layers with a very wide grading need to be used. The filter rules as mentioned above are used, together with the following rule:

\[
\frac{D_{f15}}{D_{885}} < 5
\]

-> Geometric open

---

The following layers will be needed:

### Table 6-7 Layer gradation on sand

<table>
<thead>
<tr>
<th>Layer</th>
<th>Layer 3 (mm)</th>
<th>Layer 4 (mm)</th>
<th>Layer 5 (mm)</th>
<th>Sand (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D85</td>
<td>250</td>
<td>21</td>
<td>1.8</td>
<td>0.330</td>
</tr>
<tr>
<td>D50</td>
<td>150</td>
<td>14</td>
<td>1.5</td>
<td>0.250</td>
</tr>
<tr>
<td>D30</td>
<td>50</td>
<td>7</td>
<td>1.2</td>
<td>0.170</td>
</tr>
<tr>
<td>Grading</td>
<td>5</td>
<td>3</td>
<td>1.5</td>
<td>1.9</td>
</tr>
</tbody>
</table>

In the above table stones are used with a small grading (less than 5). One could replace the layer 4 and 5 by one layer of small quarry run:

### Table 6-8 Alternative layer gradation on sand

<table>
<thead>
<tr>
<th>Layer</th>
<th>Layer (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D85</td>
<td>19</td>
</tr>
<tr>
<td>D50</td>
<td>10</td>
</tr>
<tr>
<td>D30</td>
<td>1</td>
</tr>
</tbody>
</table>

This is of course a very wide grading but still obeying to the rules of a geometric filter and easily deliverable by a quarry so probably cheaper. The thickness of the different layers is calculated as above.

Now all the layers are as follows, when build on sand:

### Table 6-9 Layers on sand

<table>
<thead>
<tr>
<th>Where</th>
<th>Density</th>
<th>D50</th>
<th>Weight</th>
<th>Thickness</th>
<th>Grading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Armour trunk</td>
<td>2650 kg/m³</td>
<td>2.1 m</td>
<td>13000 kg</td>
<td>3.4 m</td>
<td>1.5</td>
</tr>
<tr>
<td>Armour head</td>
<td>2650 kg/m³</td>
<td>2.7 m</td>
<td>26000 kg</td>
<td>4.3 m</td>
<td>1.5</td>
</tr>
<tr>
<td>Layer 1</td>
<td>2650 kg/m³</td>
<td>1.1 m</td>
<td>1800 kg</td>
<td>1.8 m</td>
<td>2.5</td>
</tr>
<tr>
<td>Layer 2</td>
<td>2650 kg/m³</td>
<td>0.40 m</td>
<td>90 kg</td>
<td>0.64 m</td>
<td>2.5</td>
</tr>
<tr>
<td>Layer 3</td>
<td>2650 kg/m³</td>
<td>0.15 m</td>
<td>4.5 kg</td>
<td>0.24 m</td>
<td>5</td>
</tr>
<tr>
<td>Layer 4</td>
<td>2650 kg/m³</td>
<td>0.01 m</td>
<td>quarry run</td>
<td>rest</td>
<td>very wide</td>
</tr>
</tbody>
</table>

#### 6.2.6 Toe

The width of the toe berm is the is given by the maximum\(^1\) \(B_t = 2H, B_t = 0.4h\) and \(B_t = 3D_{50}\); these values are respectively 10.2 m, 2.1 m and 6.3 m (8.1 m at the head). The height should be at least twice the \(D_{50}\) of the armour layer, which is 4.2 m (5.4 m at the head). The sand based groynes are a more complicated. The calculated filter layers are especially desired at the toe of the groyne. The Shore Protection Manual (1984) gives a few guidelines. For small gravel particle to sand the filter has to be at least 10 to 20 cm thick (Pilarczyk). However when quarry stones are used under uncertain conditions a thickness of 30 cm is advised.

#### 6.2.7 Considerations

When you want to place a \(D_{85}\) near the toe for instance as a toe stone, it means that one has to move a stone with a diameter of 3.1 m with a weight of 53 ton over 10 m with a crane or backhoe. This is not possible and expensive floating equipment will be needed. In fact all the armour layer stones are rather big. The \(D_{50}\) of the trunk of the groyne ways more then 10 ton, which itself is hard to move. The realization with only land based material is hardly possible and makes the construction even more expensive. With the lack of funds in Mar del Plata, it’s not realistic to design such a structure. Therefore certain choices are made with regard to the list of demands to be able to design a more realistic solution:

\(^1\) Shore Protection Manual (1984)
• The reoccurrence interval of the design storm is changed from 50 year to 25 years, with a storm duration of 8 hours. This means a reduction on the design wave and so \( H_{ss} = 4.1 \) m. This implies a larger chance on damage of the structure, but since the primary goal of the groyne is to stop sediment transport damage can be allowed and easily repaired.

• In appendix XVII the stone diameter is calculated with the formula of Van Der Meer. In this formula a damage coefficient was used of 2, meaning hardly any damage. This coefficient was set to 5, for the same reason as mentioned above.

6.2.8 Recalculations

With the two changes mentioned above the new \( D_{50} = 1.2 \) m. Analogue to the above new dimensions can be recalculated. The height of the groyne is now designed different. To save material and reduce the width of the groyne at the bottom, the crest is constructed at average high sea level, Chart Data + 0.4 m. This means extra difficulties with the realization which will be discussed in section 6.3. The \( D_{50} \) still determines the width. Three times \( D_{50} = 3.60 \) m. The slope is kept at 1:2, which gives an Irribaren parameter with the highest possible waves of 2.1, meaning waves will be plunging on the groins.

6.2.9 Recalculated layers

All the layers should now be as follows, when build on rock:

<table>
<thead>
<tr>
<th>Table 6-10 Proposed layer sizes on rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Where</td>
</tr>
<tr>
<td>Armour trunk</td>
</tr>
<tr>
<td>Armour head</td>
</tr>
<tr>
<td>Layer 1</td>
</tr>
<tr>
<td>Layer 2</td>
</tr>
<tr>
<td>Layer 3</td>
</tr>
</tbody>
</table>

The following layers for the geometric filter will be needed:

<table>
<thead>
<tr>
<th>Table 6-11 Proposed filter sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td>( D_{85} ) (mm)</td>
</tr>
<tr>
<td>--------------------</td>
</tr>
<tr>
<td>230</td>
</tr>
<tr>
<td>140</td>
</tr>
<tr>
<td>150</td>
</tr>
<tr>
<td>Grading</td>
</tr>
</tbody>
</table>

Now all the layers are as follows, when build on sand:

<table>
<thead>
<tr>
<th>Table 6-12 Proposed layer sizes on sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Where</td>
</tr>
<tr>
<td>Armour trunk</td>
</tr>
<tr>
<td>Armour head</td>
</tr>
<tr>
<td>Layer 1</td>
</tr>
<tr>
<td>Layer 2</td>
</tr>
<tr>
<td>Layer 3</td>
</tr>
<tr>
<td>Layer 4</td>
</tr>
</tbody>
</table>
6.2.10 Recalculated toe

The width of the toe berm is the is given by the maximum \( B_t = 2H \), \( B_t = 0.4h \) and \( B_t = 3D_{50} \), these values are respectively 8.2 m, 2.1 m and 3.6 m (4.5 m at the head). The height should be at least twice the \( D_{50} \) of the armour layer, which is 2.4 m (3.0 m at the head).

### Toe Stone Weight (minimum stone weight)

\[
W_{\text{min}} = \frac{\gamma_a H^3}{N_s^3 (SG - 1)^3}
\]

where \( N_s \) = stability number is the maximum of

\[
N_s = 1.3 \left( \frac{1 - K}{K^{1/3}} \right) \frac{h_t}{H} + 1.8 \exp \left[ -1.5 \left( \frac{1 - K^2}{K^{1/3}} \right) \frac{h_t}{H} \right]
\]

or \( N_s = 1.8 \)

where \( K = \) a parameter associated with the maximum horizontal velocity at the edge of the toe apron

\[
K = \frac{2k h_t}{\sinh 2k h_t} \sin^2 k B_t
\]

(Tanimoto, K., Yagyu, T., and Goda, Y., 1982)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Signification</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K_{\text{min}} )</td>
<td>Stone weight</td>
<td>4800</td>
<td>kg</td>
</tr>
<tr>
<td>( \gamma_a )</td>
<td>Specific stone density</td>
<td>2650</td>
<td>kg/m³</td>
</tr>
<tr>
<td>( H )</td>
<td>Design wave</td>
<td>4.1</td>
<td>m</td>
</tr>
<tr>
<td>( S )</td>
<td>Scour consideration</td>
<td>1</td>
<td>m</td>
</tr>
<tr>
<td>( G )</td>
<td>( \gamma_a/\gamma_w )</td>
<td>2650</td>
<td>kg/m³</td>
</tr>
<tr>
<td>( N )</td>
<td>Stability number</td>
<td>2.03</td>
<td>-</td>
</tr>
<tr>
<td>( K )</td>
<td>Max. velocity parameter</td>
<td>0.59</td>
<td>-</td>
</tr>
<tr>
<td>( h_t )</td>
<td>Depth at toe</td>
<td>5.2</td>
<td>m</td>
</tr>
</tbody>
</table>

The stone weight of 4800 ton corresponds with the armour stone of the trunk, which is 4.6 ton. So for the toe of the groins the same stones can be used. Decided is to use the stones of the head armour layer as double toe stones stability is still expected. Constructing strictly following the guidelines would make the design be unrealizable. The cross sections of the breakwaters can be seen in appendix XIX. Besides that the toe of the groyne will disappear in the nourished sand, causing extra stability.

---

6.2.11 Short groins
Groins GB and GC (see Appendix I, fig. I,7) will be shorter and thus the local depth will be smaller, certainly when the new beach has been nourished. The local depth at the top of these groins now determines the design wave. Since scour will occur, one can not really predict what the depth will be. That a smaller significant design wave can be used for the groyne extending 60 m into the sea is clear and so it is designed that whole groyne will have the same armour layer as the trunks of the bigger groynes.

6.3 Realization
The realization of the design is very important during the design process, because the realization set the height of the groins. The realization can be split in two phases, the construction of the groins and the beach nourishment. The groyne construction is done before the beach nourishment because erosion of the beach is feared during construction of the groynes if realization was done vice versa. The realization of both is described below.

6.3.1 Construction of the groins
The construction of the groins is preferably done with land based equipment. This is much cheaper than constructing with the use of ships and also easier because it is difficult to operate ships in the surf zone. However the use of land based material also limits the maximum stone size.

To reduce needed material volume and groyne width the armour stones are placed in the same construction phase as the core. This is done because the stones of the toe are very heavy so a normal backhoe cannot place them if they have to be placed further than 15 meter from the crest of the groyne. The width reduces largely with a smaller height. A disadvantage is that the supply of stones is easier over a core stone than over armour stone.

Lorries carry the stones from quarry to the beach. The beach is accessible by the small road of the beach club of Punta Mogotes (Horizonte del Sol). From here the trucks have to drive over a temporarily road on the beach to the construction location. A temporary access ramp leads them onto the groyne. The lorry drives to the constructed end of the groyne where the rock is unloaded by a crane. The armour rock on the crest is placed orderly to allow the trucks to drive over it. If difficulties with driving over the groyne occur a smoother driveway can be made by spreading out a finer gradation of rock on the groyne.

The whole cross section of the groyne is constructed at once, which allows a groyne with a low crest and therefore less material can be used. A disadvantage of this method is that different sizes of rock have to be supplied to the constructed end. A good planning and communication between crane driver and shore is necessary about what size of rock has to be supplied. The crane at the groyne end is necessary because the large armour rocks have to be placed orderly. The construction height of the groyne is equal to the average high sea level. Therefore construction is not possible during spring tide and storm surge. The crane at the end of the groyne has to place the armour rocks at the toe of the groyne. Therefore it has to have a span of 12,5 m carrying a mass of the armour stone of 9 tons. This requires a large crane. The crane can work on till the end of the groyne is reached.
6.3.2 Foundation preparations
At the bottom two kinds of materials are found. In the southern sections mostly rock (Loess Pampeano) is present. To the north sand layers lay on this rock so here has to be constructed on sand so two different designs of groins have to be constructed. For the groins that are going to be build at locations with bedrock no special arrangements for the foundation have to be made. The groins will be constructed directly on the bedrock. When building on sand first a filter layer has to be constructed, because the filter layer is rather thick first a layer of 1,2 meters of sand has to be removed by digging. After that, the filter layers can be placed, see appendix XIX for cross section. From this point construction is the same as for the groins directly placed on rocks.

6.3.3 Quarry
The quarry where the stone needs to be derived from is relatively close to the beach of Los Acantilados, near to the town of Batan, a 12 km drive by truck, see Figure 6.5.
The quarry normally delivers stones and sand to local contractors in the range of 0 - 256 mm. This stones are derived from blocks as large as a mini van. Clearly these stone are too small for the breakwater. The sizes of the stones that are needed can be ordered specifically. The prizes, as mentioned previously with transport to the beach, will be between 40 and 45 pesos.

6.3.4 Realization of the nourishment

Different types of nourishments are used for beach fill projects. The best applicable methods for Los Acantilados are nearshore nourishment and direct beach nourishment. As outlined previous, with direct beach nourishment the losses are kept to a minimum. In this method, the sand fill is placed at one time throughout the stretch of shore to be protected. If the equipment is available by the contractor, there can be simultaneously worked on more sections between groynes. Usually, fill is pumped as a slurry onto the beach via hydraulic pipeline, then reworked into the desired configuration using earthmoving equipment. Additional pipeline is added in sections to extend the placement zone along the beach. The largest grain sizes in the slurry will settle out closest to the slurry discharge point. Likewise, the finer grain sizes will settle out at greater distances.

6.3.4.1 Preferable sediment size

Sand is abundantly available on the foreshore (1 to 2 km offshore), but still a survey has to be executed in order to localize the coarse sands and sand with shells. Coarse sand with shells and shell fragments will erode slower because of their larger mass. Also, a coarse material has a larger internal angle of friction and therefore a steeper slope of the foreshore can be realized. If a hopper dredger or barge is used to transport fill to the site, many of the borrow material fines are washed out with overflow, Thus providing a larger grain size distribution of fill material than that based on in situ samples from the borrow site.

6.3.4.2 Equipment

If a trailing suction hopper dredger is available (loaded draft 9 m for large hopper dredger, smaller hopper 6 m), long borrow areas may be preferable for long production runs. If the dredging is done by a trailing suction hopper dredger, offloading with rainbowing which is possible on large new hoppers, may not be possible because of the limited water depth, in this case the rainbow installation can be used to pump the sand to the beach. Smaller hoppers are in most cases not equipped with a rainbow installation and have to pump the sand by pipelines to the beach sections.

A cutter head pipeline dredger may be more economical where borrow areas are more uniform in dimension (i.e., square) and the deposit is relatively thick (1.5 m or greater) so that the dredger and pipeline do not need to be moved far.

If a pipeline dredger is utilized in a congested navigation area, the pipeline may have to be submerged except at the dredge or at the location of any booster pumps or pump house barges. The contractor should maintain a tight discharge pipeline at all times. The joints of the pipeline should be so constructed as to preclude spillage and leakage. Upon development of a leak, the pipeline should be promptly repaired and the dredge may have to be shut down until a complete repair has been made.

---

20 Information from Coastal Engineering Manual Version of 2004 (last update may 2004) Part-V-Chapter 4
6.3.4.3 Equipment
In Appendix XVII a total amount of 1.200.000 m$^3$ of sand is calculated. With the approach of Dean (1977) the bed slope becomes 2:100. The beach slope is set at 4:100 in order to save construction length of the groynes.
6.4 Costs

The total costs of the project are a summation of the costs of the groin scheme and the costs of the nourishment. In this section both cost are calculated separately and finally added to result in 27.1 million pesos (7,5 million euros).

6.4.1 Costs of the nourishment

The costs for the nourishment are easy to be calculated. In section 4.1 periodical nourishment, various explanations were given for the costs of the nourishment. The mobilization costs were set at 500.000 €. Jan de Nul gave a prize of the 6 U$/m$^3$ for local nourishment. At the time of the writing of this report the exchange rate of the euro is fluctuating. It’s therefore advised strongly to recalculate the costs once the project will be applied. For now the costs of mobilization are set at 1.800.000 pesos and a nourishment cost at 17,5 pesos/m$^3$.

The costs for nourishment will be:

<table>
<thead>
<tr>
<th>What</th>
<th>Costs in Euros</th>
<th>Costs in pesos</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobilization</td>
<td>500.000</td>
<td>1.800.000</td>
</tr>
<tr>
<td>Nourishment</td>
<td>5.800.000</td>
<td>21.000.000</td>
</tr>
<tr>
<td>Total</td>
<td>6.300.000</td>
<td>22.800.000</td>
</tr>
</tbody>
</table>

6.4.2 Costs of the groins

The costs of the groins depend on the amount of stones that need to be used. To determine this, the area per height of the groyne has to be calculated. The cross sections as given in appendix XIX are not equal for the entire length of the groyne. This can be seen in the picture below, were groyne GF, the second groyne from the South, with a length from the average sea level of 105 m, was drawn in the current and expected new equilibrium profile. With increasing depth the cross section of the groyne becomes larger.

![Equilibrium beach profile](image)

Figure 6.6 Equilibrium beach profile

Now two parameters have to be determined. The first is the total volume of the groyne and secondly the relationship between the total volume and the amount of stones. Calculations below are done with the above mentioned groyne GF. Other groynes are calculated in the same way and results are given below.
6.4.3 Volume of the groyne

First the assumption is made that the three most southern groynes are constructed on rock. It is emphasized here, this needs thorough research before construction. The cross section at the head of the groyne, constructed on rock is $2 \times 49.84 \, \text{m}^2 = 100 \, \text{m}^2$:

![Figure 6.7 Volume of the groyne](image)

From figure 6.6 a few important cross sections are derived so an approximation of the total volume can be calculated:

**Table 6-15 Measures groynes**

<table>
<thead>
<tr>
<th>Distance from A.S.L (m)</th>
<th>Local depth (m)</th>
<th>Area cross section ($\text{m}^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-80</td>
<td>CD +0.4</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>CD +0.0</td>
<td>6</td>
</tr>
<tr>
<td>50</td>
<td>CD – 4.0</td>
<td>50</td>
</tr>
<tr>
<td>105</td>
<td>CD – 5.2</td>
<td>100</td>
</tr>
</tbody>
</table>

Volume = $80 \times 3 + 50 \times 28 + 75 \times 55 = 5765 \, \text{m}^3$

In the same way the following volumes were derived:

**Table 6-16 Rock volume of the groynes**

<table>
<thead>
<tr>
<th>Groyne</th>
<th>Volume ($\text{m}^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GB</td>
<td>2639</td>
</tr>
<tr>
<td>GC</td>
<td>4139</td>
</tr>
<tr>
<td>GD2</td>
<td>5562.5</td>
</tr>
<tr>
<td>GD</td>
<td>5562.5</td>
</tr>
<tr>
<td>GE</td>
<td>5735</td>
</tr>
<tr>
<td>GF</td>
<td>5765</td>
</tr>
<tr>
<td>GG</td>
<td>9890</td>
</tr>
<tr>
<td>TOTAL</td>
<td>39293</td>
</tr>
</tbody>
</table>
6.4.4 Specific weight and costs.

The total amount of stones depends on the specific weight of the groins. The specific weight of the stone is 2650 kg/m$^3$. Each layer of the groyne has its own specific weight, but the volume is calculated for the whole groyne. A pore diameter of 0.25 is chosen for the groynes and then the specific groyne weight is 2000 kg/m$^3$. The total used tons are given below. The prize to get a ton of quarry material to the coastline is 40 to 45 pesos. Since the top layer has to be placed carefully, see section 6.3 realization, a more conservative 55 pesos/ton is used:

<table>
<thead>
<tr>
<th>Groyne</th>
<th>Weight (tons)</th>
<th>Costs (pesos)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GB</td>
<td>5278</td>
<td>290.290</td>
</tr>
<tr>
<td>GC</td>
<td>8278</td>
<td>455.290</td>
</tr>
<tr>
<td>GD2</td>
<td>11125</td>
<td>611.875</td>
</tr>
<tr>
<td>GD</td>
<td>11125</td>
<td>611.875</td>
</tr>
<tr>
<td>GE</td>
<td>11470</td>
<td>630.850</td>
</tr>
<tr>
<td>GF</td>
<td>11530</td>
<td>634.150</td>
</tr>
<tr>
<td>GG</td>
<td>19780</td>
<td>1.087.900</td>
</tr>
<tr>
<td>TOTAL</td>
<td>78586</td>
<td>4.322.230</td>
</tr>
</tbody>
</table>

With a total length of 1218 m the prize per 100 m is 355.000 pesos. This too corresponds with prizes named by the engineers of the Ministry of Public Works of the Province of Buenos Aires, namely 300.000 to 400.000 pesos per 100 m.

The total costs of the project are 27.1 million pesos.
6.5 Phasing

6.5.1 General
Financial means are the big motivator for a decision to include phasing into the plan. Constructing the groyne field in several parts means that investment can be spread out over a larger time span. Therefore several options are given for three different budgets. The authors emphasize that the different alternatives do not attain the same quality level, but are given as a handout of the possibilities for politicians and decision makers.

6.5.2 Budget 1: Large budget
If a large budget is available the best final result is reached. The whole groyne field is build at once, in total 7 groynes (GB to GG, see picture 6.8). To prevent unwanted erosion during the construction period advised is to build the groynes from the north. After construction of the groyne the nourishment can be done in the sections south of the groynes GB to GG. The amount of initial nourishment is 1,2 million m$^3$. The total length from the water line of the groynes initially is 675 m (5x105m + 90m + 60m) and 1218 m overall. The groynes cost 4,3 million Peso (1,43 million Dollar). Nourishment costs 21 million Peso (7 million Dollar) and 1,8 million Peso mobilization (0,6 million Dollar). The total amount of initial costs is 27,1 million Peso (9 million Dollar). After a time period of approximately 20 to 40 year a refill is needed. This nourishment will be of a considerable smaller amount of sand than the initial nourishment.

6.5.3 Budget 2: Medium budget
This alternative of renewal of the beach is built in two stages. Possible time spacing between first and second construction period would be 5 to 10 years. The first stage of the construction of the groyne field is to start from the north with 4 groynes (GB, GC, GD, GD2) followed by sand fill. The groynes have a length as described in the previous chapter 6.1 “Location and length of the groynes” (see also picture 6.8). These lengths have to be obeyed because the groynes are relatively cheap in comparison to nourishment. Saving money now on groyne cost would mean a larger investment in nourishment in the future. In this case applies: “Pennywise is pound foolish”. Starting from the north is a safe manner of constructing because the present beach is protected from erosion by the new groynes. The currently present beaches that suffer only little erosion are protected and held tight first. The needed volume of nourishment is calculated from the present and new bottom line. At the location of the nourishment some beach is present (lowering the needed sand), but the steep slope of the foreshore increases the needed volume resulting in a volume half of the needed volume when the whole beach was nourished. The realized beaches will be ensured for the near future 20 to 40 years. After the first phase the next section of 3
groynes is build, for instance 5 years later. Probably a small compensation refill must
be applied to the first section at the same time.

The first four groynes cost 2 million Peso (0,66 million Dollar) with a total length of
618 m. The amount of initial nourishment is 600,000 m³. The Nourishment including
mobilization costs 12,3 million Peso (10,5 + 1,8 million), (4,1 million Dollar). The total
amount of initial costs is 14,3 million Peso (4,8 million Dollar). The volume of
secondary nourishment is 600,000 m³ and costs 12,3 million Peso. The length of the
groynes of the second stage is 600 m and costs 2,4 million Peso. The total costs of the
second phase is 14,7 million Peso (4,9 million Dollar). After a time period of
approximately 20 to 40 years after the second stage a refill is needed. This
nourishment will be of a considerable smaller amount of sand than the initial
nourishment.

6.5.4 Budget 3: Small budget
If only a small budget is available an alternative has to be
found that is effective with low investment. Construction of
one groyne with a small beach fill is recommended. The
location of the groyne should lie at the point at the coast
where the transition between erosion and accretion is. This is
in between GB and GC. With a length of the groyne of 125 m,
80 percent of the littoral sediment transport is stopped. This is
the most economic length because the needed length increases
very fast with increasing blocking coefficient. Also the dept at
75 m offshore is not too big so little material is needed. The
cross section of the GB groyne can be applied for the
construction of these groynes. Small nourishment is needed
because beach is present. Nourishment can be done over a
length of 400 meter south of the groyne with a volume of
100,000 m³ resulting in a 50 m wide beach. A smaller dredging
vessel can be used resulting in lower mobilization cost but a
somewhat higher bulk cost. These costs are estimated on 7 u$
or 21 Peso per m³.

The beach will move in time to the groyne and make a curve
towards the end of the groyne. The beach upstream (to the
south) will slowly disappear. If possible a second groyne can
be build 5 to 10 years later. The second groyne should be build
500 meter south of the first and should have a similar length.
This time also nourishment should be applied with a length of
400 meter south of the build groyne. In the first section and
probably also just to the north of the first groyne a refill is
needed. A third construction phase, again 5 to 10 years later,
can be applied in the same way as the second.

The amount of initial nourishment is 100,000 m³ with a cost of
2,1 million Peso (0,7 million Dollar) The length of the first
groyne is 125 m, costing 350,000 Peso. The total cost of the
first phase is 2,45 million Peso (0,82 million Dollar). The
following stages have approximately the same length of the
groyne. The amount of nourishment increases because less
sand is present in the more southerly profiles and partly refill
is needed. The costs therefore are also somewhat higher than
the first stage.

Figure 6.9 Phasing for small budget
7 Riprap

The option of stopping the erosion, but not creating new beach is not a solution for the aim of this project. However with the lack of resources in Mar del Plata it’s considered necessary to give a solution to stop the cliff erosion. Riprap has proven itself as an effective measure in the municipality of Mar del Plata. Local authorities, contractors and engineers have experience with and confidence in the solution. Besides that, local conditions are suitable for riprap: a quarry is nearby, as said there is experience and the subsoil in front of the cliffs is often a good foundation, since it’s rocky.

7.1 General

Ripraps are often used in situations where granular or sandy materials are present and have to be protected against wave attack. In those cases wave overtopping is the dominant design parameter. In cases with cliffs of hard rock no riprap is needed. In the case of Los Acantilados the rock is very soft and vulnerable to the impact of wave attack. Nowadays erosion of one meter per year of the cliff edge exists. Because of the rare occurrence of this type of cliff erosion no design manuals could be found. The material used for riprap should be fieldstone or rough quarry stone. Stone should be hard, angular, and of such quality that it will not disintegrate on exposure to water or weathering. Because it is not as aesthetically pleasing as rock, broken concrete is a less favorable riprap alternative. If concrete is used, it should be clean and otherwise meet design criteria. Asphalt should not be used as riprap.

7.2 Location

Two different types of placement can be used: stones placed directly against the cliffs or a heap of stones in front of the cliffs with spacing to the cliffs. Both types are shown in the Figure 7.1 and 7.2 below. The first type needs a structure of only armour stones because when the cliffs would erode the stones start moving and an eventual core could be exposed. Building the structure with sizes so that no erosion would take place would mean a height of eight meters to stop overtopping. This is not the case when stones are heaped because is does not need the cliff for its stability. Also, overtopping of this type not necessarily means erosion of the cliffs because waves do not break against the cliffs. In the vicinity of Mar del Plata the second type is used.

![Figure 7.1 Riprap type 1](image1)

Nowadays an erosion speed of the cliffs up to one meter in a year is found. Totally blocking erosion of the cliffs is not realistic moreover because the seeping groundwater causes erosion of the cliffs too. That’s why is chosen for the second type.
7.3 Dimension

For calculating the height of the riprap in front of eroding cliffs, as said before, no design manuals could be found. Therefore a design philosophy is elaborated which is: “when the water level is equal to the riprap crest height, the design wave collapses on the riprap so there is no wave impact onto the cliffs”. Therefore the height is set to the maximum water level during design storm conditions (once in 50 years). With this height all the waves during design storm conditions will break on the riprap and only little transmission will occur. However during most of the time only little water will flow over the riprap and no impact is expected.

The design storm conditions are a once in 50 year storm with a Hss = 5,1 m, highest high sea level and maximum wind and wave set-up.

Table 7-1 Design conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>H.H.S.L.</td>
<td>Chart data + 1,12 m</td>
</tr>
<tr>
<td>Wave set-up (storm conditions)</td>
<td>1,4 m.</td>
</tr>
<tr>
<td>Wind set-up (storm conditions)</td>
<td>0,43 m.</td>
</tr>
</tbody>
</table>

The H.H.S.L. can be found in chapter 1, the wave set-up in appendix XII en the wind set-up in appendix X. So the height of the riprap is 2,95 m. above mean sea level.

7.3.1 Stone size

The design wave is the wave that can occur just in front of the riprap. The water depth during design conditions here is 1,12 m + 1,4 m + 0,43 m + possible water depth of the bed below average sea level (A.S.L). In this case the possible water depth in front of the riprap is set on a maximum of one meter below average sea level so 3,95 meters water depth. The depth profiles see appendix IX, and observations suggest there no greater depths then 1 m will occur, making the total depth 3,95 m. A conservative calculation with a breaker index of 0,8 is made, which gives a design wave of 3,2 m. The stone size is calculated with van der Meer with an S of Appendix XVII and the stone size needed against the attack of waves with 3,2 m is a D_{n50} of 1,1 m. and a slope of 1:2,5. This slope is only needed at the seaward side, at the landward side the steepest slope of 1:1,5 can be applied.

7.3.2 Width

The width of the rip rap should be 3D_{n50} wide, which is 3 m.

7.3.3 Core

To stabilize the armour layer a sub layer with a wide grading is needed21 of W/10 is 265 kg, D_{n50} = 0,46 and the D_{50} = 0,58 m. This stone should have a wide grading to ensure the stability of the armour layer. When a grading of 3 is chosen, the two layers are as shown in table 7-2.

Thickness
The thicknesses of the two layers have a minimum of 2D_{n50}. Results can be seen in Table 7-2.

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Table 7-2  Armour layer riprap

<table>
<thead>
<tr>
<th></th>
<th>Armourlayer (m)</th>
<th>Core (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_{15}$</td>
<td>1,00</td>
<td>0,32</td>
</tr>
<tr>
<td>$D_{50}$</td>
<td>1,25</td>
<td>0,58</td>
</tr>
<tr>
<td>$D_{85}$</td>
<td>1,50</td>
<td>0,90</td>
</tr>
<tr>
<td>Grading</td>
<td>1,5</td>
<td>2,8</td>
</tr>
<tr>
<td>Minimum thickness</td>
<td>2</td>
<td>0,9</td>
</tr>
</tbody>
</table>

This results in a cross section as shown in appendix XIX.

7.4 Realization

The material should, if possible placed directly on rocky subsoil. If not, the wave energy at the bottom of the structure will erode the sand under de stones and slowly they will sink into the sand and causing serious instability and malfunction of the riprap. The riprap can be constructed by making an access road to its crest and dumping rock on its construction end. Applying smaller stones to the crest, between the large armour layer stones, causes a smoother surface, on which can be driven by truck.

7.5 Costs

The costs are calculated by determining the needed volume of rock and multiplying this with the price of placing a ton of stone on the beach, namely 45 pesos. The quarry stones have a specific density of 2650 kg/m$^3$, with a pore ratio of 0,25 the specific density of rip rap is 2 ton/m$^3$. The rip rap structure has a cross section of 43 m$^2$, per stretching meter this is 86 ton and thus 3870 pesos/m$^1$. This is a maximum, when the bed in front of the cliffs is above m.s.l. the costs will reduce rapidly.
8 Conclusions and recommendations

The main objective of the project was to obtain an analysis of the erosion and to find an economical and technical feasible solution to create a sustainable beach between Punta Mogotes and Punta Martinez de Hoz. The following conclusions were drawn:

8.1 Conclusions

The main causes of the erosion in the past and the present are:

- No sand input from the south. The sand input from the south is diminished because of the following reasons:
  - Harvesting of sand and fixation of the dunes in the south by plants and buildings.
  - The construction of groins just south of the beach which trap the little sand coming from the south.
  - Damming of Argentine rivers in the south by power plants so no sediment input from the rivers.
- The harvesting of sand from the beach. Although the harvesting is not allowed anymore and stopped completely, in the past large amounts of sand were taken from Punta Mogotes.
- The orientation of the Coast in respect of the wave climate. This part of the coast has an orientation of about 45° on the main wave direction. For this gives the maximum of wave induced sediment transport.
- The lack of dunes. Because no dunes are present anymore no sediment buffer is available and there is no possibility of recuperation of the beaches after storms.

For the rehabilitation of the beach, beach nourishment in combination with the construction of a groyne scheme of 7 groins is proposed for the northern part of the beach. Beach nourishment alone is not feasible because of the fact that the rate of erosion is to high. For the fixation of the nourished beach groins are used because they are relatively cheap and give good results in beach protection. For the southern part of the beach nothing is proposed because of the large construction costs of the groins and expected low benefits.

The total costs of the project will be 27,1 million argentine pesos or US$ 8, 4 million. Because the beach is owned by a private company economical feasibility is very important. However for the present economical situation the rehabilitation is not economical feasible and will not be financed by ‘Playas del Faro S.A.’. The project can only be financed if the municipality and the province will finance a part of the construction costs, because they are stakeholders, because of the beach will protect the road and help the local economy. An ideal form would be a joint venture between the province, municipality and Playas del Faro S.A.

If the rehabilitation of the project is not undertaken in the near future the cliffs will erode further and damage on the road could occur. To only protect the cliffs with a riprap the costs will be 3,800 argentine pesos per meter at maximum.
8.2 Recommendations

Because of the high costs compared to the low benefits some cost reducing recommendations are proposed:

If the groyne system is constructed in different phases the costs will rise little however the profits earned from the earlier phases could be used to finance the latter phases. And in the end the total investment will be regained faster.

The beach nourishment could be done with coarser sediment than proposed. Using a coarser material for the beach nourishment will mean that a steeper equilibrium profile will set in so lesser sand is needed. However which sediment to use also depends on the availability of sediment in front of the coast and so an investigation of the sediment in front of the coast is needed.

The construction of groins was proposed because this is much cheaper than the construction of detached breakwaters. However when detached breakwaters are constructed of old shipwrecks, which are cleaned and stripped, the construction costs could be much less. The results however are unpredictable and a pilot project could be undertaken.

At this moment there is hardly any cooperation between 'Playas del Faro S.A.' and the municipality of Mar del Plata and neither between other municipalities along the coast. Most of the beaches along the Atlantic coast of the Buenos Aires province suffer from erosion and cooperation could lower the costs for instance the mobilization costs of a dredging vessel.

A detailed bathymetric survey has to be done before the project is undertaken. In the report the bathymetry was calculated from a map and some older measurements. However a more detailed bathymetry would give probably different results and could also change the total amount of sand needed.