Hambantota Fishery Harbour

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Siemen Everts  4025350
Eric Julianus  4012240
Mark Marijnissen  4036808
Bas Voorend  4006801
Project group

Project group Hambantota exist of four master students from Delft University of Technology with different master specialisations:

- Siemen Everts  Rivers, Ports and Waterways (Ports)
- Eric Julianus  Coastal Engineering
- Mark Marijnissen  Construction Management and Engineering
- Bas Voorend  Rivers, Ports and Waterways (Dredging)

Figure 1 left to right Eric Julianus, Siemen Everts, Mark Marijnissen and Bas Voorend during side visit in Hambantota
Preface

As part of the Master program at Delft University of Technology students can do a project abroad. We chose for a project in Sri Lanka, to investigate sedimentation in a small scale fishery harbour.

We would like to thank ir. H.J. Verhagen for bringing it us into contact with mr. ir. C. Fernando and for providing us with the project case. Ir. C. Fernando has helped us a lot with the gathering of information and arranging a wonderful workplace. We are also thankful for the valuable feedback of ir. H.J. Verhagen, ir. C. Fernando and ir. M.G.C. Bosch-Rekveldt.

During our stay in Sri Lanka we could attend a very valuable stakeholder meeting in Hambantota thanks to Royal HaskoningDHV and Engineering Consultants Limited. A special thanks for ir. Van der Spek and ir. Klein for feedback and allowing us to the stakeholder meeting with the fishermen of Hambantota.
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Terms and abbreviations

ADB : Asian Development Bank
ARGOSS : Provider of wind and wave data
CERC : Columbia Environmental Research Centre
CFHC : Ceylon Fishery Harbour Corporations
CHEC : China Harbour Engineering Company
DUT : Delft University of Technology
DFAR : Department of Fisheries & Aquatic Resources
EICC : East Indian Coastal Current
ECL : Engineering Consultants Ltd.
FI : First inter monsoon (March-April)
LHI : Lanka Hydraulic Institute
LAT : Lowest Astronomical Tide
MCA : Multi-criteria analysis
MHWN : Mean High Water Neap
MHWS : Mean High Water Spring
MLWN : Mean Low Water Neap
MLWS : Mean Low Water Spring
MIKE21 : Tool for coastal modelling
MLWN : Mean Low Water Neap
MLWS : Mean Low Water Spring
MSL : Mean Sea Level
N-E : North-East monsoon (December-February)
PDT : Project Director Team
SI : Second inter monsoon (October-November)
S-W : South-West monsoon (May-September)
SwanOne : Swan wave model that uses only 1D mode
Assumption

The months October, November and April show a large similarity with the South-West monsoon and the month March shows a large similarity with the North-East monsoon. For simplicity only 2 periods will be used, namely the South-West monsoon (April – November) and the North-East monsoon (December – March).
Summary

At the southern coast of Sri Lanka a small fishery harbour is located in Hambantota. Soon after construction of the harbour in 2006 the harbour started silting up at various places. From that point onwards the harbour’s basin has been dredged multiple times, but the problem turned out to be structural. In addition breaking waves are encountered near the entrance, which makes it difficult and dangerous for the fishermen to leave and enter the harbour. This problem has led to serious injuries and a fatal accident.

To aid the fishermen of Hambantota a student research project is executed to identify the causes of the harbour sedimentation and provide the government of Sri Lanka with possible solution directions to deal with this problem. The research questions are formulated as follows:

*Which processes are responsible for the sedimentation and harsh navigability conditions at the Hambantota Fisheries Harbour and why aren’t those processes dealt with in the existing design?*

*Which adjustments of the current design will prevent future sedimentation inside the harbour and improve navigability conditions for the fishermen and to what extend should the different stakeholders be involved to achieve this?*

General understanding of the large scale processes which occur at the southern coast of Sri Lanka is important before the specific problems at Hambantota can be analysed. Therefore this research project starts with an extensive system analysis. With global knowledge of the climate, tide and the wave conditions the specific problems in Hambantota were analysed. Beside a technical analysis of the port a stakeholder analysis was conducted to find out where mistakes were made and identify lessons learned to prevent problems in the future.

With improvements and learned lessons in mind possible solutions were generated and evaluated based on among others: durability, sedimentation and construction and maintenance costs. Weight factors were assigned by the Project Director Team and a multi-criteria analysis was used to find the most promising alternative.

The dominant process responsible for the transport of sediment into the harbour is diffraction. With this mechanism wave energy is turned around the breakwater head and directed into the harbour. This causes a sediment flow into the harbour and the sediment settles in the harbour basin. The sediment enters the coastal cell from the western boundary where mainly fine sediment is imported around the rocky headlands. Bad navigability conditions are caused by the presence of a shoal in front of the entrance which induces wave breaking at this location.

Overall the failure of the Hambantota Fishery Harbour project can be explained from bad communications between the various stakeholders. Improving the communication between the stakeholders will be essential for the adaption of the harbour to be successful. Therefore the Project Director Team should collaborate with Royal HaskoningDHV and ECL, involve the Hambantota Fisherman Association, Hambantota Fisheries Traders Association, the Harbour Manager and the Hambantota Fisheries Harbour Management Committee and consult most of the governmental stakeholders.
The ‘Block’ alternative is developed which blocks the incoming sediment transport by perpendicular extensions on both breakwaters. The alongshore transported sediment is accumulated in the buffer zones created with the extensions and periodic dredging is required to maintain the function of buffer zone. A shoal can't form since the sediment supply is interrupted, so breaking waves are no longer present. The extensions at the breakwaters not only provide a buffer zone, they also provide a sheltered area in front of the harbour entrance to enable fishermen to enter the Hambantota Fishery Harbour safely.
1. Introduction

Hambantota is a city located along the southern coast of Sri Lanka. In the late nineties the Central Government of Sri Lanka deemed it necessary to build a fishery harbour in Hambantota in order to contribute to the local and national economic development. Until that time the Hambantota fishermen simply put their boats on the beach and would drag them into sea when they went fishing. Within a year after construction of the harbour problems with sedimentation started to arise. From that point onwards the harbour’s basin has been dredged various times, but the problem turned out to be structural and has led to serious injuries and a fatal accidents among the fishermen (ECL, 2014; Fernando, 2014).

Recently the Central Government has decided that an adjustment of the fishery harbour is necessary to solve the current problems. The purpose of this report is to find out what the cause of these problems is and to find a possible solution to overcome these difficulties. The research questions are:

Which processes are responsible for the sedimentation and harsh navigability conditions at the Hambantota Fisheries Harbour and why aren’t those processes dealt with in the existing design?

Which adjustments of the current design will prevent future sedimentation inside the harbour and improve navigability conditions for the fishermen and to what extend should the different stakeholders be involved to achieve this?

The first question will be answered in Chapter 6 and the second question in Chapter 10. In order to provide an answer to these questions, first an analysis has to be made of the current problems. General understanding of the large scale processes which occur at the southern coast of Sri Lanka is important before the specific problems at Hambantota can be analysed. Therefore this research project will start with an extensive system analysis (Chapter 4), which will first cover global processes like tide, climate and ocean currents. Subsequently the nearshore conditions of Hambantota and the alongshore sediment transport capacity will be calculated. The system analysis will be concluded by analysing the coastline changes and providing an explanation why these changes have occurred.

Next, the fishery harbour of Hambantota will be studied in Chapter 5. The first part of this chapter will be about the location and usage of the harbour. Next the major harbour components will be critically looked at to find possible improvements which will be used in a later phase of the study.

The second part of Chapter 5 will consist of a stakeholder analysis. First the situation during the initiation and construction of the fishery harbour will be analysed to find out what has gone wrong and identify lessons learned to prevent problems in the future. Second, the present situation will be studied. The aim of this second part is to come up with a recommendation on how the different stakeholders should be involved to solve the current problems of the Hambantota fishery harbour.

Chapter 6 consists of a conclusion of the previous chapters and will end the analysis of the existing problems.

With the knowledge provided by the analyses on the system and the harbour, a set of ten alternatives will be created which could solve the current problems. Through a basic feasibility study the set of ten alternatives will be narrowed down to three alternatives (Chapter 7).
These three alternatives will be the input for a multi-criteria analysis (Chapter 8), which is used to decide which solution is most favourable.

Next a discussion on the findings of the report will be provided in Chapter 9. The report will be finalized with Chapter 10, in which the conclusions and recommendations will be presented.
2. Problem Analysis

This chapter will provide the problem definition, define the scope and set out the goal of the research project.

2.1 Problem definition

The Hambantota Fishery Harbour suffers from large sedimentation problems. Soon after construction in 2006 the harbour started silting up at various places. From that point onwards the harbour’s basin has been dredged various times, but the problem turned out to be structural. The shallow areas near the entrance of the harbour cause large breaking waves, which make it difficult and dangerous for the fishermen to leave and enter the harbour. This problem has led to serious injuries and a fatal accident. Because of the sedimentation some areas in the harbour can’t be used anymore because they are too shallow (ECL, 2014; Fernando, 2014).

2.2 Scope

Geomorphologic scope

In order to get a good understanding on why the sedimentation problems exist, the analysis should include different scales. The mega and macro scale are used to understand the system in and around Sri Lanka. The focus for these scales is mainly on ocean currents, wave system, wind system and seasonality. The meso scale is used to understand the sediment transport capacity near the Hambantota Fishery Harbour, which provides insight in the transport of sediment in the area. The micro scale can be used to determine actual sediment transport within the harbour, but due to the limited amount of sources and time, this latter scale won’t be used in the analysis. It will however be used for schematization of the processes around the breakwaters and inside the harbour.

![Figure 2 Project scope and different scales](image_url)
Stakeholders involved
The stakeholders who were involved in the design and construction of the Hambantota Fishery Harbour and/or involved in the new project of designing the adaption of the harbour are:

- Asian Development Bank;
- Central Government of Sri Lanka;
- Ceylon Fishery Harbour Corporation;
- CHEC;
- Department of Fisheries & Aquatic Resources;
- District Assistant Directors’ Office;
- Engineering Consultants Ltd.;
- Fisheries Inspectorate Division;
- Halcrow International;
- Hambantota Fisherman Association;
- Hambantota Fisheries Traders Association;
- Hambantota Fisheries Harbour Management Committee;
- Harbour Manager;
- Lanka Hydraulic Institute;
- Ministry of Fisheries and Aquatic Resources Development;
- Niras;
- Project Director Team;
- Royal HaskoningDHV.

2.3 Goal

The goal of this research project is twofold. The first goal of this research project is to investigate the processes that cause the siltation and source of the sediment. The second goal of this research project is to present a solution for the siltation and navigation problems by proposing an adaption of the current construction.
3. **Research methodology**

In this chapter the research strategy is described for every step taken in this report in chronological order. Furthermore the methods and sources which are used to obtain all the information are discussed.

3.1 **System analysis**

**Geography, climate, ocean currents and tide**

To get a better insight in the coastal system of the Hambantota bay an analysis is made of the geography, the climate, the ocean currents and the tide. The geography and ocean currents are analysed with the book Coastal Dynamics (Bosboom & Stive, 2013) and several papers. Information about the climate is obtained via the Sri Lankan Department of Meteorology (Meteorological Department Sri Lanka, n.d.). The tidal information of the Hambantota bay is measured and obtained via the British Admiralty Nautical Charts (United Kingdom Hydrographic Office, 2014).

**Waves & Wind**

Wave information is available from multiple sources, so a first step would be the selection of the ‘best’ source. This is not that easy since it is unclear which source is the most reliable. A selection based on the actual data can’t be made, so the method is considered how the information is obtained.

Both wind and wave data will be used to check the periodic behaviour in the region. Figures will also be presented to get a general understanding of the characteristic values per monsoon.

**Nearshore conditions & SwanOne**

Starting with offshore wind and wave data SwanOne is used to transform these offshore wave conditions to onshore wave conditions. In addition to the wind and wave data local bathymetry of the Hambantota Bay is used as input for SwanOne.

**Sediment transport capacity**

The Kamphuis formula is used to calculate the magnitude of the sediment transport capacity. This formula requires input of nearshore wave characteristics and sediment properties. Nearshore wave conditions will be calculated using SwanOne. Sediment properties are assumed to be uniform along the entire bay, since detailed information of the sediment properties along the bay is not available. The angle of the incoming waves with the shore normal of the coast provides the magnitude and direction of the sediment transport capacity. The transport capacity is calculated for five locations in the bay to collect insight in coastal system.

**Coastline changes**

Through Google Earth satellite images are obtained of the Hambantota bay for the period 2003 to 2014. The time series will be separated into two periods due to the construction of the harbour. The first time series consist of images before and the second time series after construction of the Hambantota Fishery Harbour. Every image is marked by its date in the year and its position in a monsoon. Information about coastline changes will be derived by comparing consecutive available images. Comparing images from time series before and after the construction of the harbour will give information about changes in the system caused by the harbour.
3.2 Harbour analysis

Before any kind of improvements can be suggested the current design should be checked. The analysis starts on a macro and meso scale with the location of the harbour. On micro scale the layout and processes inside the harbour are relevant.

The problems occurring in the harbour are more related to wave breaking in front of the entrance and sedimentation of the harbour basin than to problems with the breakwater height and cross-sections. Nevertheless a general analysis of the breakwater characteristics is made in this chapter.

Possible improvements will be summarised at the end to be used in later phases of this study.

3.3 Stakeholder analysis

The techniques which will be used in the stakeholder analysis are described in the article “What to do when stakeholders matter: Stakeholder Identification and Analysis Techniques” by John Bryson (2004).

The stakeholder analysis will start off with the identification of stakeholders. The stakeholders will be divided into role-groups to make clear what their role in the project is. Also the objective of each stakeholder will be identified. The purpose of this is to see whether stakeholders have conflicting interests, which could lead to problems, or if they have the same objective, what would be beneficial for overall stakeholder satisfaction.

Second, the interdependencies between the various stakeholders will be explained. These are interdependencies inside the role-groups as well as between stakeholders from different role-groups. Knowing the interdependencies can help in understanding why stakeholders behave the way they do.

With this information a stakeholder network will be made, which shows graphically how the various stakeholders are connected with each other.

Next step is to assess the stakeholders’ powers: what powers to the stakeholders have and how powerful are they compared to each other. This will also help in clarifying why stakeholders will act in a certain way.

From this point in the analysis of Part I and Part II will differ. In Part I a storyline will be provided of how the Hambantota Fishery Harbour was designed and constructed. Subsequently conclusions and lessons learned will be drawn. Part II will contain a Participation Planning Matrix, which will show which stakeholders should participate in each phase of the project and what level of participation is advised. Upon this participation planning the conclusions and recommendations will be build.

3.4 Creating possible solutions

Ten alternatives are presented and the idea behind it is explained. The alternatives are based on all the findings in chapter 4 and 5. Two types of alternatives can be distinguished namely soft and hard solutions. The soft alternatives focus on dredging not on building structures. The hard solution on the other hand makes small adjust to the breakwaters or completely change the current design.
To minimize the number of alternatives the northern and southern breakwater are examined independently of one another. Except for a few alternatives where there is a complete redesign of the alignment of the breakwaters.

To give a recommendation the best alternative has to be selected based on all the requirements. First the ten alternatives will be reduced to three alternatives with a quick comparison of the constructability, effectiveness, building costs, maintenance costs. It is possible that some of the alternatives will be combined afterward to get to the three most promising alternatives.

### 3.5 Multi-criteria analysis

A multi-criteria analysis will be used to decide which solution should be implemented to solve the existing problems. Because of the limited time and data available to this research project the MCA method that will be used is the permutation method. This method is based on ranking the different alternatives on an ordinal scale and therefore will be less time-consuming than other MCA methods for which exact values have to be calculated. The permutation method is further explained in Appendix K: MCA Permutation method.

The Project Director Team (PDT) will be consulted to make sure the multi-criteria analysis includes every aspect important in the decision-making process about the Hambantota fishery harbour and the appropriate weights are assigned to these aspects. To establish the weight factors the PDT will divide 100 points among the criteria according to their importance.
4. System analysis

In this chapter an extensive system analysis is made of the south coast of Sri Lanka and the Hambantota bay. First the coastal cell is defined and the large scale processes are described such as tide, climate and ocean currents. Subsequently the nearshore conditions in the Hambantota bay and the alongshore sediment transport capacity are calculated. In the end of the chapter coastline changes are identified and provides an explanation why these changes have occurred.
4.1 Geography

Location and coastal cell
Sri Lanka is an island located in the Indian Ocean to the southwest of India. Sri Lanka is situated on the Northern Hemisphere between 5°54’ N and 9°51’ N and between 79°41’ O and 81°51’ O (Google Earth, 2014). This study is about the fishery harbour in Hambantota, which is situated at the south coast between Tangalle and Kirinda. To get a good insight in all the hydraulic processes around the Hambantota fishery harbour a coastal cell is considered. The coastal cell starts at the rocky headland south of the Hambantota fishery harbour and ends at the Pitawatan Point.

Figure 3 Geographic location Sri Lanka, Hambantota, the Hambantota bay and the coastal cell (Google Earth)
Commercial harbour
To the east of the Hambantota fisher a commercial harbour is constructed. The breakwaters of the commercial harbour extend up to 12 m depth. The commercial harbour is not inside the coastal cell but it has to be taken into account to make a realistic schematisation of the sediment transport in the coastal cell.

Figure 4 Commercial harbour (Google Earth, 2014)
**Tectonic plate setting**
Sri Lanka is located on the Indo-Australian Plate and is situated in the middle of the plate so it has an Amero-trailing edge coast (Bosboom & Stive, 2013). Since plate boundaries are far away the Sri Lankan coastline is regarded as tectonically stable.

The continental shelf of Sri Lanka is between 2.5 and 25 km wide. The depth of the continental shelf is 30 to 90 m. At the end of the continental the depth increases rapidly to approximately 2000 m (see Figure 6). The continental slope has at the edge an inclination of 45°, which is one of the steepest in the world (see Figure 5) (Tomczak & Stuart Godfrey, 2003; Wijeratne & Charitha Pattiaratchi, 2006).

**Continental shelf Hambantota**
The continental shelf of Hambantota is approximately 20 km wide (Google Earth, 2014). The shelf of Hambantota has a rough bottom along the outer shelf edge as well as inshore. The intermediate zone is smooth (Tomczak & Stuart Godfrey, 2003).

![Figure 5 Continental margin Sri Lanka (Wijeratne and Charitha Pattiaratchi, 2006)](image)

![Figure 6 Depth chart region Sri Lanka (Wijeratne and Charitha Pattiaratchi, 2006)](image)
Swell

The island of Sri Lanka experiences swell from both the west and east, depending on the coastline under consideration. Since Hambantota is in the middle of the south coast it is in a transition area of the west coast and east coast swell. In Figure 8 this is clearly seen.

Taking a look at the data from ARGOSS the main annual direction of the swell approaching the coast at Hambantota is from the south, Figure 7. This also shows that Hambantota is in a transition area of the west and east coast swell.

Figure 7 Direction and height annual swell Hambantota (ARGOSS)

Figure 8 Worldwide distribution of wave environments (Davies, 1980)
4.2 Climate

Seasonality
The climate in Sri Lanka is dominated by the large continent of Asia and the Indian Ocean. The process of heating and cooling down of these land- and water masses cause variation in the climate. Land masses are more sensitive to temperature changes than sea masses. The temperature of the sea is more constant than the temperature at land. On warm land- and water masses the air will rise to higher places in the atmosphere (low pressure area). During this rising process, it will attract cooler air from lower places in the atmosphere (high pressure area) (Bosboom & Stive, 2013).

When the large land mass of Asia heats from May till September, its temperature rises faster than the water temperature of the Indian Ocean. This results in a low pressure area above the sea. The wind will blow from high pressure to the low pressure area. So warm and humid air from the Indian Ocean will flow to the Asian continent. This is the South-West monsoon (see Figure 9).

Vice versa happens when the Indian Ocean is contains more heat than the Asian continent. The air rises on the Indian Ocean and this will attract cool and relative dry air from the Asian land mass. This is the North-East monsoon. These processes determine the weather conditions, wind speed and wind direction in Sri Lanka (see Figure 9) (Bosboom & Stive, 2013).

The year can be divided into two monsoons and two transitions periods (Waidyasekera, 2012):

1. South-West monsoon May-September
2. Second inter monsoon season October-November
3. North-East monsoon December-February
4. First inter monsoon season March-April
Figure 9 Global wind patterns in January and July indicating the main wind systems (Bosboom and Stive, 2013)
Rainfall

1. **South-West monsoon (May-September)**
Rains and windy weather is characteristic for this time of the year. There is extensive rainfall all over the country especially for the South-Western areas (Waidyasekera, 2012).

2. **Second inter monsoon season (October-November)**
The typical weather conditions for this period are strong winds and wide spread rain which are experienced all over the country. The rainfall is nearly evenly distributed over Sri Lanka (Waidyasekera, 2012).

3. **North-East monsoon (December-February)**
During this monsoon there is dry and cold wind blowing from the Indian land-mass which results in a cool and dry weather for the whole country. The north and eastern areas experiences the most rainfall and the Western period is the driest during this monsoon (Waidyasekera, 2012).

4. **First inter monsoon season (March-April)**
This is the warmest period of the year and uncomfortable conditions like thunderstorms and rain during the afternoon and evening are common for this season. The southwest experiences more extensive rainfall than the rest of the country (Waidyasekera, 2012).

![Figure 10 Rainfall during S-W, SI, N-E and FI (Meteorological Department Sri Lanka, n.d.)](image-url)
Air temperature

The temperature in Sri Lanka strongly depends on the location. The low lands have a very homogeneous annual temperature, between 26.5 °C and 28.5 °C. With increasing height it gets colder, the mean annual temperature can fall to 15.9 °C. The warmest months in Sri Lanka are April and August, the coldest month is generally January (Waidyasekera, 2012).

Figure 11 Average annual temperatures Sri Lanka (Meteorological Department Sri Lanka)
4.3 Ocean currents

Sri Lanka has a unique oceanographic location. The island is located in the Indian Ocean with on the eastern side the Bay of Bengal and on the western side the Arabian Sea. Furthermore, the seasonality makes it a complex system. During the South-West monsoon there is a current from the Arabian Sea to the Bay of Bengal called the West Indian Coastal Current (see Figure 12). The WICC has velocities between 0.5 – 0.8 ms\(^{-1}\) when fully established. There is one other important phenomenon during the southwest monsoon called the Sri Lanka Dome. This is a recirculation feature at the east coast of Sri Lanka which generates a current to the south along the east coast of Sri Lanka.

When the North-East monsoon is present the current is reversing from east to west which results in the Eastern Indian Coastal Current along the coast of Sri Lanka (see Figure 13). The velocity of the EICC rarely exceeds 0.2 m s\(^{-1}\) (de Vos, Pattiaratchi, & Wijeratne, 2014; Tomczak & Stuart Godfrey, 2003).

![Figure 12 Circulation pattern South-West monsoon](image1)

![Figure 13 Circulation pattern North-East monsoon](image2)
4.4 Tide

Form ratio

The character of the tide can be defined by the form factor. The form factor is determined by the amplitude of the two main diurnal components \( K1 \) and \( O1 \) divided by the amplitude of the two main semi-diurnal components \( M2 \) and \( S2 \) (Bosboom & Stive, 2013).

\[
F = \frac{K1 + O1}{M2 + S2} \tag{eq. 4.1}
\]

Because there are no known tidal components for Hambantota assume Hambantota has nearly the same tidal components as Kirinda (de Vos et al., 2014) which gives a form factor of 0.325.

<table>
<thead>
<tr>
<th>Category</th>
<th>Value of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semidiurnal</td>
<td>0 – 0.25</td>
</tr>
<tr>
<td>Mixed, mainly semidiurnal</td>
<td>0.25 – 1.5</td>
</tr>
<tr>
<td>Mixed, mainly diurnal</td>
<td>1.5 – 3</td>
</tr>
<tr>
<td>Diurnal</td>
<td>&gt; 3</td>
</tr>
</tbody>
</table>

Table 1 Tidal character expressed by the form Factor \( F \) (Bosboom and Stive 2013)

In Hambantota there is a mixed, mainly semi-diurnal tide. The form factor is very close to the values for the semi-diurnal tide, so the tide in Hambantota is nearly completely semi-diurnal what is also showed in Figure 15.
Tidal range
To calculate the tidal range in Hambantota the data in Kirinda is not accurate enough. Figure 17 shows measurements to the east and the west of Hambantota. The location to the east, where Kirinda is located, gives a much lower tidal range than to the west. So it is unreliable to use the components from Kirinda to calculate the tidal range, this will underestimate the tidal range in Hambantota. To determine the tidal range in Hambantota the admiralty tide tables are used which give the height of the tide with respect to Colombo (United Kingdom Hydrographic Office, 2014). The tidal range at Hambantota is 0.5 m.

<table>
<thead>
<tr>
<th>Tide</th>
<th>Height [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ML, Z₀</td>
<td>0.4</td>
</tr>
<tr>
<td>MHWS</td>
<td>0.6</td>
</tr>
<tr>
<td>MHWN</td>
<td>0.4</td>
</tr>
<tr>
<td>MLWN</td>
<td>0.3</td>
</tr>
<tr>
<td>MLWS</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Table 2 Tide Hambantota (United Kingdom Hydrographic Office, 2014)

Global the tidal regimes can be divided in three categories, which are also showed in Figure 14.
- Micro-tidal regime: mean spring tidal range < 2 m;
- Meso-tidal regime: mean spring tidal range 2-4 m;
- Macro-tidal regime: mean spring tidal range > 4 m. (Bosboom & Stive, 2013)

In Hambantota there is a spring tidal range of less than 2 m so a micro-tidal regime.
Figure 15 Tidal environments of the world (Davies, 1980)

Figure 16 World distribution of mean spring tidal range (Davies, 1980)
4.5 Currents

Tidal current
To determine if the tidal current velocity is significant for the sediment transport a rough calculation is made. The tide current velocity is defined as follows:

\[ V_{\text{tidal}} = C \sqrt{d_{\text{ref}} \frac{dh_0}{dy}} \]  
\[ C = 18 \log \frac{d}{k_s} \]

\( V_{\text{tidal}} \) = tidal velocity \([\text{m s}^{-1}]\),
\( C \) = chezy coefficient \([\text{m}]\),
\( d \) = depth
\( d_{\text{ref}} \) = reference depth \([\text{m s}^{-2}]\),
\( dh_0 \) = difference in water level \([\text{m}]\),
\( dy \) = alongshore distance \([\text{m}]\),
\( k_s \) = bottom roughness \([-]\)

To calculate the tidal current velocity the tidal surface slope alongshore is required. The surface slope is determined between Hambantota and Gale when the tide is at equilibrium point in Hambantota. The difference in water level is 0.019 m (Figure 14) over 112 km at a depth of 7.5 m with a bottom roughness of 0.06. This results in a tidal current velocity of 0.044 m s\(^{-1}\) (Bosboom & Stive, 2013; Google Earth, 2014).
4.6 Waves

For information about waves two sources are available: one is local (LHI), and one is online and applicable around the globe (ARGOSS). To decide which data source is to be used for this study they will be compared on method of gathering the data, not on actual data.

Comparing sources

The method used to gather data is explained per source, based on reliability a source is chosen which is used for this study.

LHI

The Lanka Hydraulic Institute (LHI) made a report about the wave climate in Sri Lanka based on available wave measurements, which they extrapolated for the entire coastline of Sri Lanka using MIKE21. The actual locations of the wave measurements are shown in Figure 17 green dots, while Hambantota is depicted as a red star. The west and south coast of Sri Lanka is well represented within the measurements and Hambantota is covered at both sides by measurements in Tangalle and Kirinda. The data is applicable to the 10 m depth contour line and available for both the sea and swell components of the sea surface (United Kingdom Hydrographic Office, 2014).

ARGOSS

Two offshore data sources can be selected in ARGOSS.

The first data source is satellite observations which cover over a large area like in Figure 18. Satellite data are obtained by radar measurements from satellites, which measures the reflection of a beam send to earth. With high waves the pulse will be distorted and the signal broadens, while a flat surface gives a narrow, non-distorted signal. The available satellite observations are irregular in space and time due to no fixed sample schedule.

The second data source is the model data which are simulated data that approach the real data. This method represents an area near the model point and not the whole selected area in Figure 18. This method will sample every three hours which makes it regular in time and space and create a time series. Besides this there are more wave data samples and satellite data are used to validate and calibrate model data.
Conclusion
Since the wave data from LHI is extrapolated from measured data at different locations the data for Hambantota is also affected by measurements at the west and east coast. These coastlines have a different wave climate compared to the south coast which might result in corrupted data.

ARGOSS provides wave model and satellite data. The wave model data are validated and calibrated with satellite observations. The large sample set, the validation and calibration make the wave model a more reliable data source.

Further research on waves will be done with time series from ARGOSS.
**General data**

The time series for 2013 from ARGOSS is shown in Figure 19 and the seasonality as discussed in previous chapters above is clearly visible.

![Figure 19 Time series 2013 Significant Wave Height (ARGOSS)](image)

Offshore data from ARGOSS was obtained to use in the calculation of the sediment transport capacity in the following chapters. Separated per monsoon the figures are presented in Table 3 to Table 6.

Appendix A: Wave characteristics, Appendix B: Wave transformation of shelf break and alongshore current and Appendix E: Wave transformation opposite waves show how these figures were obtained.

### SW monsoon

<table>
<thead>
<tr>
<th></th>
<th>$H_s$ [m]</th>
<th>$T_p$ [s]</th>
<th>$\phi$ ['']</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swell</td>
<td>1.7</td>
<td>13.9</td>
<td>189</td>
</tr>
<tr>
<td>Sea</td>
<td>1.1</td>
<td>5.2</td>
<td>234</td>
</tr>
<tr>
<td>Total</td>
<td>2.1</td>
<td>13.4</td>
<td>203</td>
</tr>
</tbody>
</table>

**Table 3 Wave characteristics during South-West monsoon**

### 2nd inter monsoon

<table>
<thead>
<tr>
<th></th>
<th>$H_s$ [m]</th>
<th>$T_p$ [s]</th>
<th>$\phi$ ['']</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swell</td>
<td>1.4</td>
<td>12.8</td>
<td>182</td>
</tr>
<tr>
<td>Sea</td>
<td>0.5</td>
<td>4.0</td>
<td>205</td>
</tr>
<tr>
<td>Total</td>
<td>1.5</td>
<td>12.6</td>
<td>187</td>
</tr>
</tbody>
</table>

**Table 4 Wave characteristics during Second Inter monsoon**

### NE monsoon

<table>
<thead>
<tr>
<th></th>
<th>$H_s$ [m]</th>
<th>$T_p$ [s]</th>
<th>$\phi$ ['']</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swell</td>
<td>1.1</td>
<td>13.0</td>
<td>161</td>
</tr>
<tr>
<td>Sea</td>
<td>0.5</td>
<td>4.3</td>
<td>62</td>
</tr>
<tr>
<td>Total</td>
<td>1.2</td>
<td>12.4</td>
<td>134</td>
</tr>
</tbody>
</table>

**Table 5 Wave characteristics during North-East monsoon**

### 1st inter monsoon

<table>
<thead>
<tr>
<th></th>
<th>$H_s$ [m]</th>
<th>$T_p$ [s]</th>
<th>$\phi$ ['']</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swell</td>
<td>1.3</td>
<td>13.3</td>
<td>182</td>
</tr>
<tr>
<td>Sea</td>
<td>0.3</td>
<td>3.7</td>
<td>155</td>
</tr>
<tr>
<td>Total</td>
<td>1.3</td>
<td>13.4</td>
<td>181</td>
</tr>
</tbody>
</table>

**Table 6 Wave characteristics during First Inter monsoon**
4.7 Wind system

1. South-West monsoon (May-September)
During the South-West monsoon warm and humid air blows from the Indian Ocean to the Asian continent (Beccario, 2014). This causes predominantly strong winds from the South-West. The average wind speed in this season is $7.7 \text{ ms}^{-1}$ (BMT ARGOSS, 2014).

Figure 21 Wind direction S-W monsoon (ARGOSS)

Figure 20 Wind currents S-W monsoon (Beccario, 2014)

2. Second inter monsoon season (October-November)
A transition period occurs after September. In October the wind direction is still from the South-West but the wind speeds decreases. From November the wind direction starts to change to the North-East (Beccario, 2014). The average wind speed in this season is $4.7 \text{ ms}^{-1}$ (BMT ARGOSS, 2014).

Figure 23 Wind currents SI monsoon (ARGOSS)

Figure 22 Wind currents SI monsoon (Beccario, 2014)
3. North-East monsoon (December-February)
During the North-East monsoon cold and dry air blows from the Asian continent to the Indian Ocean. This causes predominantly strong winds from the North-East. The average wind speed in this season is 5.2 ms\(^{-1}\) (BMT ARGOSS, 2014).

![Figure 24 Wind currents N-E monsoon (Beccario, 2014)](image)

4. First inter monsoon season (March-April)
Another transition period appears after the North-East monsoon. In March the direction is still from the North-East but the wind speed is less. In April the wind starts to turn and blow from the South-West again. The average wind speed in this season is 3.9 ms\(^{-1}\) (BMT ARGOSS, 2014).

![Figure 26 Wind currents First inter monsoon (Beccario, 2014)](image)
4.8 Nearshore conditions

Input SwanOne
As can be seen in the previous chapters the inter monsoons can be considered as transition periods rather than a separate period. The wave conditions during the months October, November and April show a large similarity with the South-West monsoon wave conditions. The wind conditions, which are considered as less relevant for the analysis, show less similarity. The wave conditions during month March shows a large similarity with the North-East monsoon wave conditions. For simplicity only two periods will be used, namely the South-West monsoon (April – November) and the North-East monsoon (December – March).

The offshore values from ARGOSS are not applicable for the processes that take place near the Hambantota coast. To generate nearshore conditions the program SwanOne is used. Based on local bathymetry, wave data, wind data and currents SwanOne calculates the wave transformation from the offshore boundary to a location closer onshore.

Local bathymetry has a big influence on the wave transformation due to mechanisms like shoaling and refraction. As input for SwanOne one cross-shore profile is used and is representing the full coast. This implies parallel depth contours and a uniform bed. Due to this simplification refraction is not taken into account and detailed bathymetry differences are neglected. The approach in this report is not meant to give very detailed answers so these simplifications are acceptable.

The offshore wave conditions are represented by three parameters: Significant wave height, peak period and dominant wave direction. With these parameters SwanOne will form a Jonswap spectrum representing the wave energy entering the system at the offshore boundary.

Currents can have a big influence on the wave transformations, but the both the oceanic and tidal currents are very small on the continental shelf and therefore have no noticeable effect on the transformations.

Local winds are taken into account, since they represent the monsoon character of the Sri Lankan climate. With a given wind speed and main direction SwanOne is able to account for local winds in the transformation.

As described above the transformation will be executed for two periods per year, for which the used values are presented in Appendix C: Nearshore conditions.
**Shelf break**

To determine the cross-shore profile the starting point is chosen at the -1000 m depth line, since the ARGOSS data is collected offshore with a maximal distance from over a 100 km. As a consequence the shelf-break is included, with steep slopes compared to the surrounding profile. Since the data is partly collected from the area between the shelf-break and the coastline it should be considered to remove the shelf break from the cross-shore profile. To see whether these steep slopes in relative deep water have a big influence the figures in Appendix B: Wave transformation of shelf break and alongshore current are generated from SwaneOne using different cross-shore profiles for the S-W monsoon.

Both figures show a big similarity since the offshore wave characteristics are the same. The influence of the shelf break is clearly visible for both the wave height and the wave direction. Just after the shelf break a decrease in wave height can be observed, this might be explained by partial reflection of the incoming waves. The slight turn of the waves when they pass the shelf break can be explained by increased refraction.

A conservative choice would be the system with the highest waves nearshore, which means excluding the shelf break, but for this study the shelf break will be taken into account since it is a characteristic of the Sri Lankan coast and the difference for the onshore wave characteristics is relatively small. Furthermore most data is collected from the area beyond the shelf break, so including the shelf break would be a logical choice.
**Currents**

Ocean currents are running along the coast of Sri Lanka and as described in previous chapters they are seasonally as well. The flow can have impact on the wave transformation and the sediment transport along the shore. The impact on the transformation is assessed by taking the ocean currents into account, and comparing the output to the original output. As can be seen in Table 7 the biggest currents occur during the South-West monsoon. The current profile along the cross-section is unknown and hard to estimate, so a very unfavourable, unrealistic but simple uniform profile is assumed (green line). This assumption will result in a conservative comparison, since the current profile will be smaller in magnitude close to the shoreline, and be more like a quadratic function (blue line). In Figure 28 an overview is given of both current profiles together with the cross-shore profile (Tomczak & Stuart Godfrey, 2003).

<table>
<thead>
<tr>
<th></th>
<th>Magnitude [ms⁻¹]</th>
<th>Direction [°]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>South-West monsoon</strong></td>
<td>0,8</td>
<td>90</td>
</tr>
<tr>
<td><strong>North-East monsoon</strong></td>
<td>0,2</td>
<td>270</td>
</tr>
</tbody>
</table>

Table 7 Currents along the Sri Lankan coast (Tomczak & Stuart Godfrey, 2003)

Comparing the figures in Appendix B we see most differences offshore while the nearshore wave conditions are similar. A more realistic profile like a quadratic function with the same maximal value would have a much smaller effect, so for this study the effects of ocean currents will be neglected.
4.9 Sediment transport capacity

Sediment transport depends on the hydrodynamics and on the sediment properties. The sediment transport in alongshore direction is considered to take place within the width of the breaker zone. The latter starts from the 5 m depth line and its width depend on the variety in wave heights. In this area the wave height at the breaker point and the angle of incidence with the coast are important parameters. Other important parameters are the properties like grain size and density of the material (Bosboom & Stive, 2013).

For calculation of the sediment transport BULK-formula’s will be considered, since detailed information lacks and a general idea of the transports along the coast is a first priority. Two transport formulae are considered, namely the CERC and the Kamphuis formula. The following paragraph will elaborate on the formulae.
CERC formula
The considered form of the CERC formula is the most practical form and is called the CERC double angle degree formula (Bosboom & Stive, 2013).

\[
S = \frac{K}{16(s-1)(1-p)} \sqrt{\frac{g}{\gamma}} \sin (2\phi_b) H_b^{2.5}
\] (eq. 4.4)

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>Deposited volume of sediment transported [m$^3$ s$^{-1}$]</td>
</tr>
<tr>
<td>s</td>
<td>Relative density of sediment [-]</td>
</tr>
<tr>
<td>p</td>
<td>Porosity [-]</td>
</tr>
<tr>
<td>K</td>
<td>Coefficient [-]</td>
</tr>
<tr>
<td>g</td>
<td>Gravitational acceleration [m s$^{-2}$]</td>
</tr>
<tr>
<td>γ</td>
<td>Breaker index [-]</td>
</tr>
<tr>
<td>φ</td>
<td>Wave angle of incidence [°]</td>
</tr>
<tr>
<td>H</td>
<td>Wave height [m]</td>
</tr>
<tr>
<td>b</td>
<td>Conditions at the outer edge of the breaker zone [-]</td>
</tr>
</tbody>
</table>

Table 8 Content CERC formula (Bosboom and Stive 2013)

In general it can be concluded that, if all the other parameters are taken constant, the transport of sediment ($S$) depends on the variation of the wave angle of incidence ($\phi_b$) and the wave height at breaker point ($H_b$). The transport follows the sinusoidal shape and provides a so called $S$-$\phi$ curve. Transport is increasing from 0° to approximately 45° and decreasing from 45° to 90°. The angle of the incoming waves with the normal of the shore determines the magnitude but also the direction of the transport. Another big contributor to the magnitude is the wave height at the breaker point due to the power 2.5.

Remarks one the CERC formula (Bosboom & Stive, 2013):

- The transport is independent of sediment properties, beach slope and wave period. Sediment properties have large influence on the initiation of motion and settling velocity. Beach slopes determine the wave height and type of breaking which have influence on the sediment transport;
- The CERC formula is derived and only valid for beaches with a uniform sand range of 175 to 1000 μm.
Kamphuis

The Kamphuis formula includes three extra parameters. The peak period \((T_p)\), beach slope \((\alpha_b)\) and the grain diameter \((D)\). The peak period \((T_p)\) provides information about the wave length. The beach slope gives information about the beach properties. First of all the slope gives an indication about the internal friction angle and the sediment size. Second, the slope can be used to determine whether the beach is dissipative or reflective. The slope can also be used to categorize the type of waves and wave breaking on the beach. From the grain diameter can be deduced sediment properties like fall velocity and the initiation of motion. Including these parameters make this formula more location specific (Bosboom & Stive, 2013).

\[
S = \frac{I_m}{\rho (s-1)(1-p)} \quad \text{(eq. 4.5)}
\]

\[
I_m = 2.27 H_{s,b}^2 T_p^{1.5} \tan(\alpha_b)^{0.75} D^{-0.25} \sin(2\phi_b)^{0.6} \quad \text{(eq. 4.6)}
\]

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>(S)</td>
<td>Deposited volume of sediment transported ([m^3 \cdot s^{-1}])</td>
</tr>
<tr>
<td>(I_m)</td>
<td>Immersed weight of sediment transported ([N \cdot s^{-1}])</td>
</tr>
<tr>
<td>(\rho)</td>
<td>Density of the water ([kg \cdot m^{-3}])</td>
</tr>
<tr>
<td>(s)</td>
<td>Relative density of sediment ([-)]</td>
</tr>
<tr>
<td>(p)</td>
<td>Porosity ([-)]</td>
</tr>
<tr>
<td>(H_s)</td>
<td>Significant wave height ([m])</td>
</tr>
<tr>
<td>(T_p)</td>
<td>Peak period ([s])</td>
</tr>
<tr>
<td>(\alpha_b)</td>
<td>Beach slope angle ([^\circ])</td>
</tr>
<tr>
<td>(D)</td>
<td>Diameter sediment ([m])</td>
</tr>
<tr>
<td>(\phi)</td>
<td>Wave angle of incidence ([^\circ])</td>
</tr>
<tr>
<td>(b)</td>
<td>Conditions outer edge breaker zone</td>
</tr>
</tbody>
</table>

Table 9 Content Kamphuis formula (Bosboom and Stive 2013)

Remarks on the Kamphuis formula (Bosboom & Stive, 2013):

- The wave height at breaker point has a smaller influence \((H_{s,b}^2)\);
- The dependency on the wave angle of incidence at the breaker point is relative weak \((\sin(2\phi)^{0.6})\);
- The grain size diameter has a small influence \((D^{-0.25})\).
Comparison CERC and Kamphuis

In this paragraph will be elaborated on the characteristics of the CERC and Kamphuis formulae. On the basis of the available parameters and circumstances around Hambantota coast will be decided which formula will be used.

The CERC formula is only applicable on a coast with a uniform sand range of 175 to 1000 μm. From sand samples is obtained that the grain size is 540 μm and therefore the CERC formula is applicable.

The Kamphuis formula includes parameters like the peak period (T_p), beach slope (α_b) and the grain diameter (D). These parameters give an indication about the wave conditions and sediment characteristics. All three parameters can be obtained and makes the Kamphuis formula applicable.

A quantitative comparison between both formulae can’t be made, because no measured data is available to validate our calculations. With the parameters from our location a relative comparison can be made, which can be seen in Figure 29.

![Figure 29 Sediment Transport Capacity for both CERC and Kamphuis (own illustration)](image)

Since both formulae are applicable and the sediment transports range is around the same values, a decision has to be made on which formula is more relevant for the Hambantota bay. The additional parameters used in the Kamphuis formula make the outcome more location specific and therefore better applicable for our study.
Sediment characteristics

Sediment characteristics as presented in Table 10 are generated from six samples collected near the Hambantota Fishery Harbour (Engineering Consultants Limited, 2014b). Through density tests using a pyknometer and multiple sieving the sediment characteristics are determined.

Most sediment samples are collected within the harbour basin, as can be seen in Figure 30. Samples four and five will be used as representative for the entire Hambantota Bay, since more specific information is lacking.

<table>
<thead>
<tr>
<th>Sample location</th>
<th>Density [kg m(^{-3})]</th>
<th>(D_{10}) [mm]</th>
<th>(D_{50}) [mm]</th>
<th>(D_{90}) [mm]</th>
<th>Cobbles [%]</th>
<th>Gravel [%]</th>
<th>Sand [%]</th>
<th>Silt &amp; Clay [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2660</td>
<td>0.6</td>
<td>2.7</td>
<td>3.8</td>
<td>0</td>
<td>14.01</td>
<td>85.41</td>
<td>0.58</td>
</tr>
<tr>
<td>2</td>
<td>2690</td>
<td>0.12</td>
<td>0.3</td>
<td>1.3</td>
<td>0</td>
<td>3.14</td>
<td>95.68</td>
<td>1.18</td>
</tr>
<tr>
<td>3</td>
<td>2680</td>
<td>0.28</td>
<td>1.7</td>
<td>3</td>
<td>0</td>
<td>38.53</td>
<td>61.17</td>
<td>0.3</td>
</tr>
<tr>
<td>4</td>
<td>2680</td>
<td>0.24</td>
<td>0.54</td>
<td>1</td>
<td>0</td>
<td>0.37</td>
<td>98.75</td>
<td>0.88</td>
</tr>
<tr>
<td>5</td>
<td>2740</td>
<td>0.31</td>
<td>0.54</td>
<td>1</td>
<td>0</td>
<td>0.17</td>
<td>98.96</td>
<td>0.87</td>
</tr>
<tr>
<td>6</td>
<td>2760</td>
<td>0.35</td>
<td>0.7</td>
<td>1.1</td>
<td>0</td>
<td>3.8</td>
<td>95.43</td>
<td>0.77</td>
</tr>
</tbody>
</table>

Table 10 Sediment characteristics per sample location (Engineering Consultants Limited, 2014b)

Figure 30 Sample locations (Limited, 2014; Google Earth)
4.10  Beach states

The beach state, reflective or dissipative, can be estimated via the dimensionless fall velocity eq. 4.6. This gives only an indication because the actual beach state depends on more factors and local circumstances. From eq. 4.7 and Table 11 can be concluded that the coast during N-E monsoon reflective is and during the S-W monsoon a bit more dissipative but still dominantly reflective.

Figure 31 Beach states (Bosboom and Stive, 2013)
Dimensionless fall velocity:

$$\Omega = \frac{H_b}{w_s T} \quad \text{(eq. 4.7)}$$

<table>
<thead>
<tr>
<th></th>
<th>North East monsoon</th>
<th>South West monsoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave height at breaking point ([H_b])</td>
<td>1.17 m</td>
<td>1.59 m</td>
</tr>
<tr>
<td>Wave period [T]</td>
<td>12.4 s</td>
<td>13.9 s</td>
</tr>
<tr>
<td>Salinity (de Vos et al., 2014; Tomczak &amp; Stuart Godfrey, 2003) [PPT]</td>
<td>35.5 ppm</td>
<td>&lt;33 ppm</td>
</tr>
<tr>
<td>Wave period [T]</td>
<td>~28 °C</td>
<td>~28 °C</td>
</tr>
<tr>
<td>Salinity [(\rho)] (Hyperphysics, n.d.)</td>
<td>1023 kg m(^{-3})</td>
<td>1021 kg m(^{-3})</td>
</tr>
<tr>
<td>Dynamic viscosity [(\mu)] (Hyperphysics, n.d.)</td>
<td>8.99 (*\ 10^{-4}\ \text{kg m}^{-1}\text{s}^{-1})</td>
<td>8.94 (*\ 10^{-4}\ \text{kg m}^{-1}\text{s}^{-1})</td>
</tr>
<tr>
<td>Kinematic viscosity [(\nu)]</td>
<td>8.79 (*\ 10^{-7}\ \text{m}^{2}\text{s}^{-1})</td>
<td>8.75 (*\ 10^{-7}\ \text{m}^{2}\text{s}^{-1})</td>
</tr>
<tr>
<td>Median grain diameter (Engineering Consultants Limited, 2014b) [(D_{50})]</td>
<td>0.54 (*10^{-3}\ \text{m})</td>
<td>0.54 (*10^{-3}\ \text{m})</td>
</tr>
<tr>
<td>Density sediment [(\rho)]</td>
<td>2680 kg m(^{-3})</td>
<td>2680 kg m(^{-3})</td>
</tr>
<tr>
<td>Relative density [(s)]</td>
<td>2.619</td>
<td>2.625</td>
</tr>
<tr>
<td>Fall velocity ([w_s])</td>
<td>7.78 (*10^{-2}\ \text{m s}^{-1})</td>
<td>7.79 (*10^{-2}\ \text{m s}^{-1})</td>
</tr>
<tr>
<td>Omega</td>
<td>1.21</td>
<td>1.47</td>
</tr>
</tbody>
</table>

Table 11 Parameters dimensionless fall velocity and van Rijn (Bosboom and Stive, 2013)

Calculate fall velocity with Van Rijn (2007) when the sediment is between 100 µm and 1000 µm (Deltares, 2011);

$$w_s = \frac{10\nu}{D_{50}} \left(1 + \frac{0.01(s-1)gD_{50}^2}{\nu^2}\right)^{1/2} - 1 \quad \text{(eq. 4.8)}$$

Where:

$$\nu = \frac{\mu}{\rho} \quad \text{(eq. 4.9)}$$

\(w_s\) = Fall velocity \([\text{m s}^{-1}]\)

\(\nu\) = Kinematic velocity \([\text{m}^2\text{s}^{-1}]\)

\(D_{50}\) = Median grain diameter \([\text{m}]\)

\(s\) = Relative mass density \((\rho_s/\rho)\) [-]

\(T\) = Wave period \([\text{s}]\)

\(H_b\) = Wave height at breaking point \([\text{m}]\)

\(g\) = Gravitational acceleration \([\text{m s}^{-2}]\)
4.11 Transport capacity Hambantota Bay

To get a rough idea of the seasonal erosion and sedimentation within the Hambantota Bay the transport capacity will be calculated using the nearshore wave characteristics, the sediment properties and the Kamphuis formula.

Area of interest for SwanOne

To understand the sediment transport capacity within the Hambantota system the observed area is restricted. The area is defined from the Hambantota Fishery Harbour to the Pitawatan Point in the east. Due to restrictions from SwanOne the calculations can’t be executed for the entire bay, since SwanOne is limited by a maximal angle of 70° between the coastline orientation and the incoming waves. Location 0 is the most western point and no calculation can be executed at this place due to an angle larger than 70° between the coastline orientation and the incoming waves. Between location 0 and 1 is in reality wave action due to refraction. Waves, swell or sea from the south, will refract into the area near location 0. The transport capacity at location 1-5 can be described quantitatively by using SwanOne.

Figure 32 Area of interest SwanOne calculations
**Conclusion**

As can be seen from Figure 33 a positive transport is calculated for all cross-sections during the South-West monsoon, meaning a transport from the west towards the east. A transport towards the east is also dominant during the North-East monsoon, with an exception for the cross-section 4, where a transport towards the west is present. Detailed output can be found in Appendix D. During the North-East monsoon the wind and waves have an opposite direction. As a consequence the wave transformation is complex and the onshore wave conditions show a directional shift through the coast normal. Further elaboration on this topic can be Appendix E.

![Transport Capacity along Hambantota Bay](image)

*Figure 33 Transport Capacity for both monsoons per year; positive transport is towards the east (own illustration)*
4.12 Coastline changes

**Satellite images Hambantota bay period 1 (2003 – 2005)**
Period 1 contains three images of the Hambantota bay before construction of the harbour (Google Earth, 2014). The information and images belonging to this period are collected in Table 12 and Appendix F: Coastline changes Hambantota bay.

Number 1 and 2 are almost identical and no coastline changes can be observed. In number 3 can be seen that there is erosion on the west side of the bay.

<table>
<thead>
<tr>
<th>Number</th>
<th>Year</th>
<th>Date</th>
<th>Period [months]</th>
<th>Monsoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2003</td>
<td>14th of February</td>
<td></td>
<td>N-E (3/4)</td>
</tr>
<tr>
<td>2</td>
<td>2005</td>
<td>28th of January</td>
<td>24</td>
<td>N-E (2/4)</td>
</tr>
<tr>
<td>3</td>
<td>2005</td>
<td>7th of October</td>
<td>7</td>
<td>S-W (7/8)</td>
</tr>
</tbody>
</table>

Table 12 Information period 1

**Satellite images Hambantota bay period 2 (2009-2014)**
Period 2 starts three years after construction of the harbour (Google Earth, 2014). The information and images belonging to this period are collected in Table 13. Detailed images of the area just north of the breakwater and the Pitawatan Point are collected in Appendix F: Coastline changes Hambantota bay.

Number 5 shows that there is erosion direct above the northern breakwater. The beach near the Pitawatan Point in the northeast seems eroded as well but this can also be caused by high wave activity that particular day. The high wave activity creates large white spots in the satellite image and covers the beach.

Number 6 is nine months later and there seems to be sedimentation direct above the northern breakwater while other parts of the bay are unchanged.

Number 7 shows little accretion above the northern breakwater and the Pitawatan Point.

Number 8 shows an erosion area near the Pitawatan Point in the northeast. The beach is retreated for 30 m over a length of 500 m.

<table>
<thead>
<tr>
<th>Number</th>
<th>Year</th>
<th>Date</th>
<th>Period [months]</th>
<th>Monsoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>2009</td>
<td>9th of June</td>
<td></td>
<td>S-W (3/8)</td>
</tr>
<tr>
<td>5</td>
<td>2010</td>
<td>26th of July</td>
<td>14</td>
<td>S-W (4/8)</td>
</tr>
<tr>
<td>6</td>
<td>2011</td>
<td>30th of April</td>
<td>9</td>
<td>S-W (1/8)</td>
</tr>
<tr>
<td>7</td>
<td>2012</td>
<td>7th of May</td>
<td>12</td>
<td>S-W (2/8)</td>
</tr>
<tr>
<td>8</td>
<td>2013</td>
<td>10th of March</td>
<td>10</td>
<td>N-E (4/4)</td>
</tr>
<tr>
<td>9</td>
<td>2013</td>
<td>18th of March</td>
<td>-</td>
<td>N-E (4/4)</td>
</tr>
<tr>
<td>10</td>
<td>2014</td>
<td>10th of April</td>
<td>13</td>
<td>S-W (1/8)</td>
</tr>
</tbody>
</table>

Table 13 Information period 2
Number 8 and number 9 are taken eight days after each other and there can be clearly seen that the wave conditions are different. In number 9 is more wave attack at the northern part of the bay which lead to smaller beaches with white spots and rip current patterns can be seen.

Number 9 and number 10 are identical.

In Appendix F: Coastline changes Hambantota bay is the coastline measured compared to the coastline before construction of the Hambantota Fishery Harbour (red line). In general can be seen that the coastline is shifted landward and the beach above the northern breakwater and the Pitawatan point is accreted.

**Information fishermen**

During a site visit to Hambantota the local fishermen provided information about coastline changes. They declared that the beach in the Hambantota bay not suffered from erosion or accretion before construction of the harbour. If there was any seasonal change of the coastline was not confirmed.

After construction approximately 50 m erosion occurred in cross shore direction over the whole Hambantota bay.

An important statement was about the beach just north of the breakwater which moves seaward during the N-E monsoon and landward during the S-W monsoon. The siltation within the harbour starts to grow in the S-W monsoon (Engineering Consultants Limited, 2014a).

**Summary**

The limited amount of satellite images and information of the fishermen provide not enough evidence to come up with a consistent description of the behaviour of the Hambantota bay.

The satellite images and the fishermen confirm that the Hambantota bay is eroded after the construction of the harbour.

The behaviour of the area just north of the breakwater can not only be explained by satellite images. Taken the information of the fishermen into account can partly explain the behaviour. The fishermen affirm that during the S-W monsoon the area erodes and during the N-E monsoon accretes. Number 8 and 9 in Appendix F: Coastline changes Hambantota bay are taken at the end of the N-E monsoon and confirm this information. Number 4, 6, 7 and 10 are taken at the start of the S-W monsoon and erosion can’t be seen so early in the S-W monsoon. Number 5 is taken halfway the S-W monsoon and influences of erosion are noticeable.

The Pitawatan Point shows no clear accreting or eroding behaviour, it’s a mix of both.
Satellite images beach southwest of Hambantota period 1 (2005)

Period 1 contains two images of the beach in the southwest of the Hambantota bay (Google Earth, 2014). These two images are taken before the construction of the harbour. Information and images are collected in Table 14 and Appendix G: Coastline changes south of Hambantota.

On image number 2 can be seen that erosion took place on the west side and accretion on the east side of the beach. The order of magnitude is around 60 m erosion and accretion.

<table>
<thead>
<tr>
<th>Number</th>
<th>Year</th>
<th>Date</th>
<th>Period [months]</th>
<th>Monsoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2005</td>
<td>28th of January</td>
<td></td>
<td>N-E (2/4)</td>
</tr>
<tr>
<td>2</td>
<td>2005</td>
<td>7th of October</td>
<td>8</td>
<td>S-W (7/8)</td>
</tr>
</tbody>
</table>

Table 14 Information period 1 (Google Earth)

Satellite images beach southwest of Hambantota period 2 (2009 – 2012)

Period 2 starts approximately one year after the construction of commercial harbour. The effect of the construction of the breakwaters is investigated by five satellite images. Detailed information and images are collected in Table 15 and Appendix G: Coastline changes south of Hambantota.

The comparison starts with images number 3 and 4. Unfortunately a cloud blocks a large part of the beach on image number 3. After 14 months image number 4 is taken and on the east side of the breakwaters can be seen that erosion took place. There seems to be erosion as well on the west side of the breakwater but this can also be assigned to more wave attack that particular day.

Number 5 shows no large variations on the beach eastwards of the breakwater. The beach on the west side of the breakwater is more visible which can be assigned to accretion or less wave attack that particular day. There is no difference between number 5 and number 6 which can be assigned to the short period between both images.

Both beaches on the west and east side of the breakwater are clearly visible on image number 7. It doesn’t show any difference with images number 4, 5 and 6.

<table>
<thead>
<tr>
<th>Number</th>
<th>Year</th>
<th>Date</th>
<th>Period [months]</th>
<th>Monsoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>2009</td>
<td>9th of June</td>
<td></td>
<td>S-W (3/8)</td>
</tr>
<tr>
<td>4</td>
<td>2010</td>
<td>26th of July</td>
<td>14</td>
<td>S-W (4/8)</td>
</tr>
<tr>
<td>5</td>
<td>2011</td>
<td>30th of April</td>
<td>9</td>
<td>S-W (1/8)</td>
</tr>
<tr>
<td>6</td>
<td>2011</td>
<td>21th of June</td>
<td>2</td>
<td>S-W (3/8)</td>
</tr>
<tr>
<td>7</td>
<td>2012</td>
<td>7th of May</td>
<td>11</td>
<td>S-W (2/8)</td>
</tr>
</tbody>
</table>

Table 15 Information period 2 (Google Earth)

Summary

Period 1 contains too little images to come up with a reliable explanation. There might be a shift of sediment in the observed area to the west during the N-E monsoon and to the east in S-W monsoon.

After construction of the commercial harbour can be seen that a part of the beach on the east side of the area is eroded. Thereafter the beach seems constant and no large variations are observed.
4.13 Harbour
The area around the fishery harbour of Hambantota is the focus of this study. Unfortunately SwanOne is not able to perform the wave transformations for this part of the bay, so only an estimation can be made based on our gathered system knowledge and observations made during the site visit.

Processes entrance

Diffraction
Around the tip of the southern breakwater diffraction can be seen clearly, and it is expected this mechanism is a big contribution to the import of fine sediment into the harbour. The sediment is stirred up near the entrance due to breaking of waves and will flow into the harbour along with the diffraction. The circular pattern of sedimentation inside the harbour and the fine sediment causing most of the problems supports this idea.

Tide
The tide is resulting in a tidal flow in and out of the harbour. A calculation is made to check if the tidal flow is significant to cause inflow of sediment into the harbour basin. (Bosboom & Stive, 2013; Engineering Consultants Limited, 2014b)

\[
\text{Flow rate} = \frac{S \cdot a}{T} = 1.16 \, \text{m}^3 \text{s}^{-1} \quad \text{(eq. 4.10)}
\]

\[
\text{Flow velocity} = \frac{Q}{A} = 5.8 \cdot 10^{-3} \, \text{m s}^{-1} \quad \text{(eq. 4.11)}
\]

<table>
<thead>
<tr>
<th>Harbour basin ( [S] )</th>
<th>50,000 m(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum tidal range ( [a] )</td>
<td>0.5 m</td>
</tr>
<tr>
<td>Diurnal tide, period low to high water ( [T] )</td>
<td>21,600 s</td>
</tr>
<tr>
<td>Cross section harbour entrance area ( [A] )</td>
<td>200 m(^2)</td>
</tr>
<tr>
<td>Flow rate ( [Q] )</td>
<td>1.16 m(^3) s(^{-1})</td>
</tr>
<tr>
<td>Flow velocity ( [v] )</td>
<td>5.8*10(^{-3}) m s(^{-1})</td>
</tr>
</tbody>
</table>

Table 16 Flow velocity harbour entrance (Engineering Consultants Limited, 2014b)

The flow velocity is 5.8*10\(^{-3}\) m\(^1\) s\(^{-1}\). This is the flow velocity at the narrowest cross section between the two breakwaters. The flow velocity is even lower at other locations between the breakwaters.
The sedimentation of the harbour due to tidal filling depends on the concentration of sediment in the water and the flow velocity. If concentration is assumed to be equal over time a comparison can be made between the process tidal filling and diffraction. The flow velocity due to diffraction is much higher, so assumed is that diffraction is the dominant process which causes in flow of sediment into the harbour basin.

**Breaking waves**

After the construction of the breakwaters a shoal is formed in front of the harbour entrance. The shoal results in a lot of wave breaking in front of the harbour entrance due the decreasing depth. These breaking waves cause harsh navigation conditions for the fishermen.
Processes northern breakwater

Just outside the harbour an offshore directed current flows along the breakwater towards deeper water. This current is caused by a focused undertow in the cross-shore direction as well as set-up differences along the bay close to the northern breakwater.

Undertow can be explained by the wave setup in cross-shore direction. The ‘piling up’ of water at the coastline causes a water level gradient, and therefore a current directed against this gradient. Since waves dominate the surface of the water a return current is focused near the bed. A structure along a coastline acts as a guide for this flow, since a disturbance in the offshore direction is already present. The path with least resistance is therefore along the breakwater.

Strong refraction in the western part of the bay causes an uneven distribution of wave energy, and therefore an alongshore gradient of the water surface. This causes a current towards the west, where the water level is lowest. Close to the breakwater this is current is strengthened due to sheltering, since the coastline near the breakwater is protected against incoming waves by the construction. The water level at this location is lowest, so the alongshore current will be directed towards this point and will be diverted by the breakwater in offshore direction (Figure 35).

The return current in combination with the undertow and breaking waves near the entrance of the harbour create a shoal.

Figure 35 Set up differences (Google Earth, adapted)
5. Harbour analysis

5.1 Harbour location

Hambantota is located on the east side of the southern Sri Lankan coast, see Figure 36. The fishery harbour is of small scale and the location is evolved in time. Fishermen used the location of the harbour as a place to pull their ships onto the beach, long before the harbour was constructed.

Fishermen chose this beach because the headlands and the coastline orientation provided shelter against the incoming swell waves from the south. The western part of the coastal cell also experiences less erosion due to less exposure to the swell waves. After the city of Hambantota developed the location of the harbour was more or less fixed and the breakwaters were constructed to provide protection and enable the fishermen to use bigger ships.

![Figure 36 Location Hambantota on south coast Sri Lanka (Google Earth, 2014)](image)

5.2 Harbour usage

The livelihood of the people of Hambantota strongly depends on the fishery harbour. The population of Hambantota is approximately 55,249 (Disaster Management Centre, n.d.) people and most people work in the fishing industry. The harbour is a reliable source of food and generates income for the residents of Hambantota.

The harbour is state owned by the Ceylon Fishery Harbour Corporation and the harbour manager is in control. In the harbour two kind of fishing boats are operating, there are large multi-day vessels and traditional oruwa fishing boats with outboard engines. The large vessels are using the quay wall and have a length between 8 and 12 m and a maximal draught of 1.5 m. The oruwa fishing boats are using the slipway and have a length of approximately 6 m and a maximal draft of 0.3 m (Engineering Consultants Limited, 2014a).
The fish is processed inside the harbour and sold on a local fish market or at a fish market in Colombo. This process is handled by a few traders but some fishermen manage their own distribution especially the fishermen with the small vessels.

### 5.3 Approach channel

The orientation of the approach channel can be determined based on the breakwater orientation and dredging operations near the harbour. During the construction of the harbour a channel was dredged, shown in Figure 37. As can be seen a turn is present exactly at the harbour mouth, but the fishermen can postpone this turn to a point further inward of the harbour if the amount of anchored ships is limited.

![Figure 37 Dredging works approach channel (CFHC, n.d.)](image1)

![Figure 38 Alignment of approach channel (Google Earth, adapted)](image2)

Putting the alignment of the channel in a bigger perspective in Figure 38 shows the channel (blue line) is not oriented seaward (red lines), so another turn is required at a more offshore location.

The dominant wind and wave direction are summarized in Table 17 to give a clear view of the conditions.

<table>
<thead>
<tr>
<th></th>
<th>SW</th>
<th>NE</th>
</tr>
</thead>
<tbody>
<tr>
<td>wind direction</td>
<td>199</td>
<td>151</td>
</tr>
<tr>
<td>wave direction</td>
<td>248</td>
<td>45</td>
</tr>
</tbody>
</table>

*Table 17 Offshore wind and wave direction*

### 5.4 Channel width

To see if the channel is suitable for one- or two-lane traffic the required width for both cases is determined using benchmark figures from Table 18. For one-lane traffic the required width is seven times the vessels width, resulting in a required width of 28 m. A two-lane traffic channel needs ten times the vessels width, resulting in a required width of 40 m.
### Table 18 Channel width benchmark figures

<table>
<thead>
<tr>
<th>Description</th>
<th>required width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bank clearance</td>
<td>1.5 $B_i$</td>
</tr>
<tr>
<td>Outer channel lane width</td>
<td>3 $B_i$</td>
</tr>
<tr>
<td>Ship clearance</td>
<td>1 $B_i$</td>
</tr>
</tbody>
</table>

Measurements from both Google Earth and dredging maps show an entrance width of 40 m making it suitable for two-lane traffic. Assumptions with this calculations are favourable approach conditions and easy navigation. Since swell waves approach the coastline from the south throughout the year they move the ships sideways during the approach. This makes the conditions harsh to enter, and from practical point of view the entrance can only be seen as a single-lane.

Extra margins near hard structures like breakwaters are also lacking, so during harsh conditions the entrance can only be used as single-lane. This allows for extra margins of 6 m at both sides of the entrance channel, which doubles the clearance width.

### 5.5 Channel depth

The required channel depth is based on the factors described in Table 19, for which exact values are not available. To give an idea, estimations were made per component.

<table>
<thead>
<tr>
<th>Description</th>
<th>required depth [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximal ship draught</td>
<td>1.5</td>
</tr>
<tr>
<td>Ship motion due to waves</td>
<td>1</td>
</tr>
<tr>
<td>Sinkage due to squat</td>
<td>0.5</td>
</tr>
<tr>
<td>Minimum keel clearance</td>
<td>0.5</td>
</tr>
<tr>
<td>Bottom material</td>
<td>0.5</td>
</tr>
</tbody>
</table>

The estimated required depth is 4 m. Tidal components are not taken into account, since reference is made to Lowest Astronomical Tide (LAT). Inside the harbour a smaller depth can be accepted, since the ship motion due to waves is lower due to shelter provided by the breakwaters (Ligteringen & Velsink, 2012).
5.6 Breakwaters

Cross-section
Information about the cross-section is limited, but based on the information found in Appendix I: Breakwater design drawings an analysis is made. Some parts of the documents are hard to read due to bad coping quality, so cross-section four and five are ignored in this analysis.

The structure consists of three layers of rock on top of the seabed, of which three different cross-sections were designed. The cross-sections can be found in Appendix I: Breakwater design drawings.

The core consists of stones ranging from 2 – 100 kg, and the filter layer consists of stones from 400-900 kg. The armour layer is thickest at the breakwater head, with 4300 – 8400 kg. In the middle the size is 2800 – 5600 kg, and at the landward side 1600 – 3800 kg.

Since layer thickness and used stones varies along the breakwater the crest level is the highest near the land at 4.5 m above MSL, lowest at 4.0 m above MSL in the middle and 4.3 m above MSL at the head of the breakwater (Schiereck, 2012).

Alignment
The harbour is located near rocky headlands and the littoral transport is already naturally disrupted. If the assumption is made that there is ‘normal’ littoral transport both breakwaters are at the same offshore distance, suggesting no dominant sediment transport from either side. The breakwaters are also not long enough to block the transport in the entire breaker zone, so bypassing of sediment is inevitable.

The storage capacity is limited at the south side of the harbour since the breakwater is aligned parallel to the adjacent coastline. At the northern breakwater storage capacity is available and according to the local fishermen seasonal sedimentation and erosion is occurring.

Given the small depth of the vessels and based on drawings of the dredging activities during the construction phase the depth contour line of -5 m is very close to the port entrance and dredging further offshore is not required. Sedimentation of the approach channel is therefore not applicable for this case.

Sedimentation inside the harbour however is cause of the problems occurring. These processes are very hard to understand in detail and depend on local information about sediment concentration in the water due to wave stirring and current velocities into and out of the harbour. During a site-visit (Engineering Consultants Limited, 2014a) strong diffraction was observed, as well as breaking waves in front of the entrance. Suspended sediment therefore is present in front of the harbour and could be transported into the harbour by the diffraction or tidal flow.
5.7 Port layout

Appendix H: Port Layout shows a detailed map of the port layout. The function of each location will be described in this chapter.

Office building
The office building is the home of the port authority and the fishermen’s unions. All the administration is done at this place and there is room for gatherings, discussions and other activities for the fishermen and local people. In the harbour there is also a canteen and there are plans for an extra canteen where the fishermen can meet and rest.

Auction Hall
In the auction hall the fish is sorted, weighted and put in boxes. The fish is packed in ice during storage and transport, the ice comes from an ice-making plant close to the fishery harbour. There are a few traders who buy the fishes from the fishermen, some of these traders are also fishermen themselves.

Part of the fish is sold to local people at the local fish market close to the slipway and the other part is transported daily to a fish market in Colombo.

Navy hut
On the left side of the quay wall there is a navy hut. The navy checks all the boats and people that come into the harbour or set sail to sea.

Security office
At the entrance of the harbour there is a small security office with a barrier. Security officers check all the people that come and go over land to the fishery harbour.

Quay wall and slipway
In the south of the harbour there is quay wall located where the large boats can moor. The smaller boats use the slipway on the west side of the harbour. The slipway is partly interrupted by a revetment. This revetment is not placed on purpose but is a leftover from the quarry stone storage used during the building process of the breakwaters.

Repairing place for boats
The smaller boats are repaired on the slipway and the larger boats have a repairing area on the right side of the quay wall. At this repair there is a small slipway to pull the boats out of the water.

Fuel tank and fuel deposit
The oil storage is located at the right side of the quay wall, to guarantee a steady supply of fuel for the boats. Some boats have trips of few days which require a large amount of fuel so there should be enough in stock. Next to the fuel tank there is also a fuel deposit where fishermen can get rid of their waste oil.

Fishing gear storage and repair station
The fishing gear of the large boats that are using the quay wall is stored in the auction hall and the fishermen who are using the slipway dry and store their fishing gear on their boats or at the beach. In the harbour there is also a net mending hall to repair broken nets.
**Port process chain**

Three transport chains can be distinguished in the fishery harbour.

First there is the unloading and washing of the fish, the next step is sorting and weighting of the fish. Traders will buy the fish and store the fish in boxes filled with ice. After this part the fish is loaded into trucks to transport it to a fish market in Colombo. The other part of the fish is sold on the local fish market in Hambantota.

![Port process chain](image)

**Figure 39 Port process chain (Ligteringen and Velsink, 2012)**

Besides these two transport chains there is also a much shorter chain. There are also fishermen who sell their fish directly on the local fish market without intervention of a trader.

**Improvements**

It is possible to make a few adjustments to improve the design. The following improvements should be kept in mind during the brainstorm process for alternatives.

- Widen entrance or improve conditions near entrance to enable two-lane traffic into harbour during harsher wave conditions;
- Improve shape of breakwater to improve sediment bypassing due to natural processes;
- Elongate or reshape southern and northern breakwater to increase buffer capacity;
- Use uniform height & cross-section along breakwater to enable fast building process (Value Engineering can be used to find cost-optimum);
- Change breakwater head to minimize sedimentation into harbour;
- Consider building a wastewater treatment plant and garbage disposal waste inside the harbour;
- Change alignment of channel to have better navigation conditions.
6. Stakeholder Analysis

6.1 Part I: Development of the Hambantota Fishery Harbour

Identification of stakeholders

The stakeholders which were involved in the development and construction of the Hambantota Fishery Harbour can be divided into four role-groups: Government, Contractor, Financer and User. To which group a stakeholder belongs is set out in Table 20.

<table>
<thead>
<tr>
<th>Role-group</th>
<th>Stakeholders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Government</td>
<td>Central Government of Sri Lanka</td>
</tr>
<tr>
<td></td>
<td>Ministry of Fisheries and Aquatic Resources</td>
</tr>
<tr>
<td></td>
<td>Development</td>
</tr>
<tr>
<td></td>
<td>Department of Fisheries &amp; Aquatic Resources</td>
</tr>
<tr>
<td></td>
<td>Ceylon Fishery Harbour Corporation</td>
</tr>
<tr>
<td></td>
<td>District Assistant Directors’ Office</td>
</tr>
<tr>
<td></td>
<td>Fisheries Inspectorate Division</td>
</tr>
<tr>
<td></td>
<td>Harbour Manager</td>
</tr>
<tr>
<td></td>
<td>Project Director Team</td>
</tr>
<tr>
<td></td>
<td>Hambantota Fisheries Harbour Management Committee</td>
</tr>
<tr>
<td>Contractor</td>
<td>Halcrow International</td>
</tr>
<tr>
<td></td>
<td>Lanka Hydraulic Institute</td>
</tr>
<tr>
<td></td>
<td>Niras</td>
</tr>
<tr>
<td></td>
<td>CHEC</td>
</tr>
<tr>
<td>Financer</td>
<td>Asian Development Bank</td>
</tr>
<tr>
<td>User</td>
<td>Hambantota Fisherman Association</td>
</tr>
<tr>
<td></td>
<td>Hambantota Fisheries Traders Association</td>
</tr>
<tr>
<td></td>
<td>Hambantota Fisheries Harbour Management Committee</td>
</tr>
</tbody>
</table>

Table 20 Role-groups

Notice that the Hambantota Fisheries Harbour Management Committee has been assigned to two groups. This is due to the fact that this committee is staffed by people from the government as well as people from the two fishermen community associations.

Table 21 provides the objectives for each stakeholder that was involved in the development and construction of the harbour.

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Government of Sri Lanka</td>
<td>The construction of a fishery harbour in Hambantota, which contributes to the local and national economic development</td>
</tr>
<tr>
<td>Ministry of Fisheries and Aquatic Resources</td>
<td>The construction of a fishery harbour in Hambantota, which contributes to developments in the sector of Fisheries and Aquatic Resources for the benefit of the present and future generation.*</td>
</tr>
<tr>
<td>Development</td>
<td>The construction of a fishery harbour in Hambantota, which contributes to the sustainable development of the fishing industry.*</td>
</tr>
<tr>
<td>Department of Fisheries &amp; Aquatic Resources (DFAR)</td>
<td></td>
</tr>
<tr>
<td>Stakeholder</td>
<td>Objective</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Ceylon Fishery Harbour Cooperation (CFHC)</td>
<td>To deliver superior quality fishery harbour related services together with supporting infrastructure to provide all modern facilities to the fishing community, and achieve self-sustainability by upgrading the harbours through commercially viable ventures. * (Ceylon Fishery Harbours Corporation, n.d.)</td>
</tr>
<tr>
<td>District Assistant Directors’ Office</td>
<td>The construction of a fishery harbour in Hambantota, which contributes to the sustainable development of the fishing industry.</td>
</tr>
<tr>
<td>Fisheries Inspectorate Division</td>
<td>A well-designed harbour which does not hamper the inspectors during their inspections</td>
</tr>
<tr>
<td>Harbour Manager</td>
<td>A well-designed harbour which is safe and provides the fisherman with the required facilities to perform their job</td>
</tr>
<tr>
<td>Project Director Team</td>
<td>Construction of a well-designed fishery harbour, which is built within time and according to the budget</td>
</tr>
<tr>
<td>Hambantota Fisheries Harbour Management</td>
<td>A well-designed harbour which is safe and provides the fisherman with the required facilities to perform their job</td>
</tr>
<tr>
<td>Halcrow International</td>
<td>Providing a design for a safe and well-functioning fishery harbour</td>
</tr>
<tr>
<td>Lanka Hydraulic Institute</td>
<td>Providing a design for a safe and well-functioning fishery harbour</td>
</tr>
<tr>
<td>Niras</td>
<td>Redesigning the harbour so it will fit in the budget</td>
</tr>
<tr>
<td>CHEC</td>
<td>Construct the harbour within time and according to the budget</td>
</tr>
<tr>
<td>Asian Development Bank</td>
<td>Contribute to the (economic) development of the Hambantota region to fight poverty</td>
</tr>
<tr>
<td>Hambantota Fisherman Association</td>
<td>A well-designed harbour which is safe and provides the fisherman with the required facilities to perform their job</td>
</tr>
<tr>
<td>Hambantota Fisheries Traders Association</td>
<td>A well-designed harbour which is safe and provides the fisherman with the required facilities to perform their job</td>
</tr>
</tbody>
</table>

Table 21 Stakeholders and their objectives

*Based on the Vision and Mission statement of this organization (see Appendix J: Actors and core values)*

Looking at the various objectives of the stakeholders, it can be stated that there are no opponents to the development of a fishery harbour in Hambantota and all stakeholders want more or less the same thing: a well-designed harbour of which the fishing community in Hambantota can benefit.

**Interdependencies**

There are a lot of interdependencies between the various stakeholders. First the interdependencies between the stakeholders in the same group will be discussed and second the interdependencies between stakeholders of different groups.
**Interdependencies inside role-group**

The Central Government of Sri Lanka is at the top of all governmental organizations in Sri Lanka. The government is divided in various ministries, of which one is the Ministry of Fisheries and Aquatic Resources Development. The Department of Fisheries & Aquatic Resources Development (DFAR) and the Ceylon Fisheries Harbour Corporation (CFHC) are two of the six institutions which operate under the purview of the ministry (Ministry of Fisheries and Aquatic Resources, 2014). DFAR is the main implementation body of the ministry and is committed to the management, development and conservation of the fisheries and aquatic resources of Sri Lanka (Department of Fisheries and Aquatic Resources, 2012a). Sri Lanka is divided into a number of districts and each coastal district has a District Assistant Directors’ Office to support the DFAR. Inspection of the numerous harbours is done by the Fisheries Inspectorate Divisions, which falls under the District Assistant Directors’ Offices (Department of Fisheries and Aquatic Resources, 2012b).

The Ceylon Fishery Harbours Corporation has a main job of delivering good services related to the fishery harbours and assisting the fishing community by providing modern infrastructure and facilities. (Ceylon Fishery Harbours Corporation, n.d.). The CFHC also assigns a Harbour Manager to the fishery harbours in Sri Lanka (Fernando, 2014).

The Project Director Team is specially assigned by the Ministry to supervise the Hambantota Fishery Harbour project from the tender process to the opening of the harbour (Fernando, 2014).

Lanka Hydraulic Institute (LHI) and Halcrow International acted as associates on the Hambantota Fishery Harbour project. They jointly won the tender for the design of the new harbour.

The Hambantota Fisherman Association and the Hambantota Fisheries Traders Association consist of the fisherman and the traders in Hambantota, two groups who are very dependent on each other: the fishermen catch the fish and the traders sell them on local and non-local markets.

**Interdependencies between role-groups**

To obtain enough financial recourses the Central Government of Sri Lanka approached the Asian Development Bank (ADB), which decided to grant Sri Lanka the funds for building the harbour. The Project Director Team put out a tender for the design of the harbour, which was won by LHI and Halcrow. The ADB had to approve the decision of the Project Director Team before the contract could be awarded and therefore had a saying in the selection of the contractors, although the ADB is not directly connected to them (Fernando, 2014).

The Project Director Team and the engineering and construction companies are mutually dependent on each other, since the Project Director Team provides the companies with work and they are dependent on the companies to deliver good work. The contractors are also dependent on the CFHC, the Fisheries Inspectorate Division and the Hambantota Fisherman Association and the Hambantota Fisheries Traders Association to obtain useful data and information which the companies use as input for their work (Fernando, 2014).

The Hambantota Fisherman Association and the Hambantota Fisheries Traders Association are dependent on the CFHC and the Harbour Manager to deliver supporting services and infrastructure. They can express their thoughts and wishes through the Harbour Management Committee.
**Stakeholder network**

With the above information, the stakeholder network can be drawn up graphically. Figure 40 shows the different stakeholders and the connections between them.

Each role-group has been assigned with a different colour; blue for Government, green for Financer, purple for Contractor and orange for User. The black lines show the connections between the stakeholders. The stakeholders inside the boxed with the dotted lines act as one.
Stakeholders’ powers

Distribution of power
Every stakeholder obtains one or more types of power which they can use in a project. Table 22 sets out which powers the different stakeholders have in the Hambantota Fishery Harbour project.

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Type of power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Government of Sri Lanka</td>
<td>Legislative, blocking</td>
</tr>
<tr>
<td>Ministry of Fisheries and Aquatic Resources Development</td>
<td>Knowledge, blocking</td>
</tr>
<tr>
<td>Department of Fisheries &amp; Aquatic Resources Development</td>
<td>Knowledge</td>
</tr>
<tr>
<td>Ceylon Fishery Harbour Cooperation</td>
<td>Knowledge, services</td>
</tr>
<tr>
<td>District Assistant Directors’ Office</td>
<td>Knowledge</td>
</tr>
<tr>
<td>Fisheries Inspectorate Division</td>
<td>Knowledge</td>
</tr>
<tr>
<td>Harbour Manager</td>
<td>Knowledge, decision</td>
</tr>
<tr>
<td>Project Director Team</td>
<td>Knowledge, decision</td>
</tr>
<tr>
<td>Hambantota Fisheries Harbour Management Committee</td>
<td>Knowledge</td>
</tr>
<tr>
<td>Halcrow International</td>
<td>Productive</td>
</tr>
<tr>
<td>Lanka Hydraulic Institute</td>
<td>Productive</td>
</tr>
<tr>
<td>Niras</td>
<td>Productive</td>
</tr>
<tr>
<td>CHEC</td>
<td>Productive</td>
</tr>
<tr>
<td>Asian Development Bank</td>
<td>Financial, blocking</td>
</tr>
<tr>
<td>Hambantota Fisherman Association</td>
<td>Knowledge</td>
</tr>
<tr>
<td>Hambantota Fisheries Traders Association</td>
<td>Knowledge</td>
</tr>
</tbody>
</table>

Table 22 Distribution of power

The Central Government of Sri Lanka has legislative power, which means they can install new laws or change them, which could influence the other stakeholders. Along with the Ministry of Fisheries and Aquatic Resources Development, it has the power to stop the project if they want to. The other stakeholders which belong to the Government role-group mostly have knowledge about the Hambantota region as their main power related to this project. The CFHC also has the power to provide services to the fisherman. Decision power about which construction companies to contract lies with the Project Director Team, although the ADB has to approve this decision. The Fisherman Association and the Fisheries Traders Association have very specific knowledge about the coastal zone of Hambantota, as they are on its waters almost every day. The contractors have the power to develop the knowledge into a design and turn the design into a product, the harbour.

Power versus interest
All stakeholders who belong to the Government role-group are powerful in Sri Lanka. The interest in the project of the District Assistant Directors’ Office and the Fisheries Inspectorate Division is low compared to the other governmental stakeholders, as their job is more supporting and administrative. The ADB is also a powerful stakeholder as financer of the project. However, they do not have a high interest in this specific project, since for the ADB the project is just one of many. The construction companies do have some power, but in comparison to the governmental stakeholders it is relatively small, as they can be set aside and the government has a lot of other companies which would be glad to be on this project. The interest of Niras is low compared to the other companies, as their job was relatively small; adjust the design of Halcrow/LHI to meet the budget requirements.
For the Fisherman Association and the Fisheries Traders Association the project is very important, as it provides them a means of making a living. However, they do not have much power. See Table 23 Power-interest grid for a complete overview.

Table 23 Power-interest grid

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Players</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hambantota Fisherman Association</td>
<td>Central Government of Sri Lanka</td>
</tr>
<tr>
<td>Hambantota Fisheries Traders Association</td>
<td>Ministry of Fisheries and Aquatic Resources</td>
</tr>
<tr>
<td>Halcrow</td>
<td>Department of Fisheries &amp; Aquatic Resources</td>
</tr>
<tr>
<td>Lanka Hydraulic Institute</td>
<td>Ceylon Fishery Harbour Cooperation</td>
</tr>
<tr>
<td>CHEC</td>
<td>Project Director Team</td>
</tr>
<tr>
<td></td>
<td>Harbour Manager</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Crowd</th>
<th>Context Setters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Niras</td>
<td>Asian Development Bank</td>
</tr>
<tr>
<td></td>
<td>District Assistant Directors’ Office</td>
</tr>
<tr>
<td></td>
<td>Fisheries Inspectorate Division</td>
</tr>
</tbody>
</table>

**Storyline**

In the late nineties the Central Government of Sri Lanka deemed it necessary to build a fishery harbour in Hambantota in order to contribute to the local and national economic development. Until that time the Hambantota fisherman simply put their boats on the beach and would drag them into sea when they went fishing. The Central Government approached the Asian Development Bank for financial support on the development of the harbour, since it didn’t possess enough financial recourses itself. After following the required procedure, the ADB decided to grant the project a budget, which was based on some preliminary studies.

The Hambantota fisheries harbour project was delegated to the Ministry of Fisheries and Aquatic Resources Development. The Fisheries Department assigned a Project Director Team, who would supervise the project from the tender process to the opening of the harbour. The Project Director Team put out a tender for the design of the harbour, which was eventually won by Lanka Hydraulic Institute, a Sri Lankan company, and Halcrow International, a British firm, who acted as associates on the project. The ADB approved this decision and the design phase could commence.

LHI and Halcrow consulted the fisherman community to obtain specific information about the area, which the fisherman possessed because they had been on sea for most of their lives. They did not approach these stakeholders directly, but through the Harbour Manager and the inspectors of the Department of Fisheries, who had got to know the fisherman very well because of their profession. They used the fisherman’s’ knowledge to come up with a qualitatively good design which would satisfy the stakeholders. The final design of LHI and Halcrow had a bigger basin and larger breakwater constructions than originally planned, because this would result in a better harbour. However this design exceeded the budget set by the ADB and thus could not be realized.
The Project Director Team decided to put out a new tender for adapting the design by LHI and Halcrow so it would fit the budget. This tender was won by Niras, a Danish company, which placed two technical experts on the project. Unlike LHI and Halcrow, the people from Niras did not consult the fisherman and only looked at the technical aspects of the design. They managed to adapt the design so it would fit the budget, by reducing the size of the basin and the breakwaters drastically.

The Project Director Team approved the design and after another tender the contract for the construction of the harbour was given to CHEC, a Chinese construction company. They build the harbour according to the adapted design by Niras.

Within a year after construction, problems with sedimentation started to arise. From that point onwards the harbour’s basin has been dredged various times, but the problem turned out to be structural (Fernando, 2014).

**Conclusions and lessons learned**

Looking at the Hambantota fishery harbour project from a stakeholder point of view, it should be an easy project; all stakeholders have more or less the same objective and there are no opponents to the project which have to be dealt with.

So why then is the Hambantota fishery harbour dealing with a big sedimentation problem? It’s clear mistakes have been made in designing the harbour. LHI and Halcrow designed a harbour which was way above budget. Unfortunately there is no information available about why they did this; did they expect the government to assign extra funds or was it due to bad management?

Niras also made a mistake by not using the fisherman’s knowledge while making changes to the design. As mentioned earlier the fishermen have a very specific kind of knowledge about the area because they are on the water every day to make a living. Therefore, Niras should have used that knowledge in their redesign.

Besides the engineering companies that designed the harbour, blame can also be put on the Project Director Team. Their job is to manage the project properly and keeping it within budget and according to schedule. They should have noticed that the design on which LHI and Halcrow were working was going to be over budget, since it was of a much larger scale than originally planned. Also, they should have insisted that Niras consulted the fisherman and would take their specific knowledge into account.

Overall the failure of the project can be explained from bad communications between the various stakeholders. Improving the communication between stakeholders will be essential in future projects.
6.2 Part II: Adaption of the Hambantota Fishery Harbour

Identification of stakeholders

Similar to Part I, the stakeholders are divided into role-groups (see Table 24). In this new project of adapting the Hambantota Fishery Harbour, the Central Government acts as financier for the project, they don’t need the ADB for financial support. Royal HaskoningDHV and Engineering Consultants Ltd (ECL) act as associates during the project and will make the design for the adaption. The government wants a small adaption. After the design, a new tender will be put out to find a construction company to realize the design. The process will again be supervised by a Project Director Team, however this team is not the same team as in Part I.

<table>
<thead>
<tr>
<th>Role-group</th>
<th>Stakeholders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Government</td>
<td>Central Government of Sri Lanka</td>
</tr>
<tr>
<td></td>
<td>Ministry of Fisheries and Aquatic Resources</td>
</tr>
<tr>
<td></td>
<td>Department of Fisheries &amp; Aquatic Resources</td>
</tr>
<tr>
<td></td>
<td>Ceylon Fishery Harbour Corporation’</td>
</tr>
<tr>
<td></td>
<td>District Assistant Directors’ Office</td>
</tr>
<tr>
<td></td>
<td>Fisheries Inspectorate Division</td>
</tr>
<tr>
<td></td>
<td>Harbour Manager</td>
</tr>
<tr>
<td></td>
<td>Project Director Team</td>
</tr>
<tr>
<td></td>
<td>Hambantota Fisheries Harbour Management Committee</td>
</tr>
<tr>
<td>Contractor</td>
<td>Royal HaskoningDHV</td>
</tr>
<tr>
<td></td>
<td>Engineering Consultants Ltd.</td>
</tr>
<tr>
<td>Financer</td>
<td>Central Government of Sri Lanka</td>
</tr>
<tr>
<td>User</td>
<td>Hambantota Fisherman Association</td>
</tr>
<tr>
<td></td>
<td>Hambantota Fisheries Traders Association</td>
</tr>
<tr>
<td></td>
<td>Hambantota Fisheries Harbour Management Committee</td>
</tr>
</tbody>
</table>

Table 24 Role-groups

Table 25 sets out the stakeholders that will play a role in the adaption of the harbour. The objective for each stakeholder is specified in the second column.

<table>
<thead>
<tr>
<th>Actor</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Government of Sri Lanka</td>
<td>Address the issues of the fishing community using the Hambantota Fishery Harbour and take necessary remedial measures to make sure the harbour will function properly again (ECL, 2014). The preferred design change is making a small scale change to the existing breakwaters.</td>
</tr>
<tr>
<td>Ministry of Fisheries and Aquatic Resources</td>
<td>Address the issues of the fishing community using the Hambantota Fishery Harbour and take necessary remedial measures to make sure the harbour will function properly again (ECL, 2014). The preferred design change is making a small scale change to the existing breakwaters.</td>
</tr>
<tr>
<td>Department of Fisheries &amp; Aquatic Resources (DFAR)</td>
<td>Address the issues of the fishing community using the Hambantota Fishery Harbour and take necessary remedial measures to make sure the harbour will function properly again (ECL, 2014).</td>
</tr>
</tbody>
</table>
The preferred design change is making a small scale change to the existing breakwaters.

<table>
<thead>
<tr>
<th>Ceylon Fishery Harbour Cooperation</th>
<th>To deliver superior quality fishery harbour related services together with supporting infrastructure to provide all modern facilities to the fishing community, and achieve self-sustainability by upgrading the harbours through commercially viable ventures (Ceylon Fishery Harbours Corporation, n.d.).</th>
</tr>
</thead>
<tbody>
<tr>
<td>District Assistant Directors’ Office</td>
<td>The reconstruction of a fishery harbour in Hambantota, which contributes to the sustainable development of the fishing industry.</td>
</tr>
<tr>
<td>Fisheries Inspectorate Division</td>
<td>A well-designed harbour which does not hamper the inspectors during their inspections</td>
</tr>
<tr>
<td>Harbour Manager</td>
<td>A well-designed harbour which is safe and provides the fisherman with the required facilities to perform their job</td>
</tr>
<tr>
<td>Project Director Team</td>
<td>Address the issues of the fishing community of Hambantota Fishery Harbour and take necessary remedial measures to make sure the harbour will function properly again (ECL, 2014). The project has to be due in time and according to budget.</td>
</tr>
<tr>
<td>Hambantota Fisheries Harbour Management Committee</td>
<td>A well-designed harbour which is safe and provides the fisherman with the required facilities to perform their job</td>
</tr>
<tr>
<td>Royal HaskoningDHV</td>
<td>Analyse the existing harbour and use that knowledge to redesign the harbour so it will function properly and be safe to use for the fisherman. This has to be done within time and according to budget.</td>
</tr>
<tr>
<td>Engineering Consultants Ltd. (ECL)</td>
<td>Analyse the existing harbour and use that knowledge to redesign the harbour so it will function properly and be safe to use for the fisherman. This has to be done within time and according to budget.</td>
</tr>
<tr>
<td>Hambantota Fisherman Association</td>
<td>Reconstruction of the harbour so it will function properly and be safe to use for the fisherman</td>
</tr>
<tr>
<td>Hambantota Fisheries Traders Association</td>
<td>Reconstruction of the harbour so it will function properly and be safe to use for the fisherman</td>
</tr>
</tbody>
</table>

Table 25 Stakeholders and their objectives

The objectives of the stakeholders have changed, but all stakeholders still want the same: reconstruction of the harbour so it will function properly and be safe to use for the fisherman. Although the government prefers a small scale change of the existing breakwater structures, it may not be enough to deal with the existing problems. Royal HaskoningDHV and ECL will try to meet this request by the government.
Interdependencies
There are not many changes in the interdependencies between the stakeholders, compared to Part 1. Royal HaskoningDHV and ECL are mutually dependent on each other, similar to LHI and Halcrow in Part I. The project is not financed by an external party anymore, but by the government of Sri Lanka.

Stakeholder network
Since there are not many changes in the stakeholders involved and their objectives and interdependencies, the stakeholder network looks quite similar to the network in Part I.

For each role-group a different colour is used; blue for Government, green for Financer, purple for Constructor and orange for User. The black lines show the connections between the stakeholders. The stakeholders inside the boxed with the dotted lines act as one.
Stakeholders' powers

Distribution of power
Table 26 shows the powers of the various stakeholders in the project of adapting the Hambantota Fishery Harbour.

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Type of power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Government of Sri Lanka</td>
<td>Legislative, blocking, financial</td>
</tr>
<tr>
<td>Ministry of Fisheries and Aquatic Resources</td>
<td>Knowledge, blocking</td>
</tr>
<tr>
<td>Development</td>
<td></td>
</tr>
<tr>
<td>Department of Fisheries &amp; Aquatic Resources</td>
<td>Knowledge</td>
</tr>
<tr>
<td>Ceylon Fishery Harbour Cooperation</td>
<td>Knowledge, services</td>
</tr>
<tr>
<td>District Assistant Directors’ Office</td>
<td>Knowledge</td>
</tr>
<tr>
<td>Fisheries Inspectorate Division</td>
<td>Knowledge</td>
</tr>
<tr>
<td>Harbour Manager</td>
<td>Knowledge, decision</td>
</tr>
<tr>
<td>Project Director Team</td>
<td>Knowledge, decision</td>
</tr>
<tr>
<td>Hambantota Fisheries Harbour Management Committee</td>
<td>Knowledge</td>
</tr>
<tr>
<td>Royal HaskoningDHV</td>
<td>Productive</td>
</tr>
<tr>
<td>Engineering Consultants Ltd.</td>
<td>Productive</td>
</tr>
<tr>
<td>Hambantota Fisherman Association</td>
<td>Knowledge</td>
</tr>
<tr>
<td>Hambantota Fisheries Traders Association</td>
<td>Knowledge</td>
</tr>
</tbody>
</table>

Table 26 Distribution of power

Royal HaskoningDHV and ECL are now the stakeholders with the productive power: they will provide the design for the adaption of the harbour. The financial power has shifted from the ADB to the Central Government of Sri Lanka. The powers of the other stakeholders have remained the same.

Power versus interest
Similar to the distribution of power, there have not been much changes to the power versus interest diagram. The new contractors, Royal HaskoningDHV and ECL, have little power but high interest in the project. For Royal HaskoningDHV a good delivery could open doors for them to the Sri Lankan market and for ECL a good delivery on a domestic project would be beneficial for their reputation.
Participation planning

This Participation Planning Matrix will differ from the one described by Bryson (2004). There are no stakeholders opposing the project and therefore it is not about building a winning coalition and coming up and implementing strategic interventions, but more about making sure the various stakeholders are heard and no important knowledge will be overseen. Since the Project Director Team is in charge of the project, the participation planning is made from their perspective.

Bryson (2004) distinguishes five levels of stakeholder participation, as set out in Table 28.

<table>
<thead>
<tr>
<th>Level of involvement</th>
<th>Promise to stakeholder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inform</td>
<td>We will keep you informed</td>
</tr>
<tr>
<td>Consult</td>
<td>We will keep you informed, listen to you, and provide feedback on how your input influenced the decision</td>
</tr>
<tr>
<td>Involve</td>
<td>We will work with you to ensure your concerns are considered and reflected in the alternatives considered, and provide feedback on how your input influenced the decision</td>
</tr>
<tr>
<td>Collaborate</td>
<td>We will incorporate your advice and recommendations to the maximum extent possible</td>
</tr>
<tr>
<td>Empower</td>
<td>We will implement what you decide</td>
</tr>
</tbody>
</table>

Table 28 Levels of stakeholder participation

The Project Director Team has to assign a certain level of participation to each individual stakeholder. It is assumed that the Central Government and the Ministry believe in the competence of the Project Director Team they assign to the project and therefore only need to be informed. Table 29 shows the level of participation for the different stakeholders.

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Level of participation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Government of Sri Lanka</td>
<td>Inform</td>
</tr>
<tr>
<td>Ministry of Fisheries and Aquatic Resources</td>
<td>Inform</td>
</tr>
<tr>
<td>Development</td>
<td></td>
</tr>
<tr>
<td>Department of Fisheries &amp; Aquatic Resources</td>
<td>Consult</td>
</tr>
<tr>
<td>Ceylon Fishery Harbour Cooperation</td>
<td>Consult</td>
</tr>
<tr>
<td>District Assistant Directors’ Office</td>
<td>Consult</td>
</tr>
<tr>
<td>Fisheries Inspectorate Division</td>
<td>Consult</td>
</tr>
<tr>
<td>Harbour Manager</td>
<td>Involve</td>
</tr>
<tr>
<td>Hambantota Fisheries Harbour Management Committee</td>
<td>Involve</td>
</tr>
<tr>
<td>Royal Haskoning DHV</td>
<td>Collaborate</td>
</tr>
<tr>
<td>Engineering Consultants Ltd.</td>
<td>Collaborate</td>
</tr>
<tr>
<td>Hambantota Fisherman Association</td>
<td>Involve</td>
</tr>
<tr>
<td>Hambantota Fisheries Traders Association</td>
<td>Involve</td>
</tr>
</tbody>
</table>

Table 29 Participation planning

The governmental bodies should be consulted during the project to ensure all their knowledge is incorporated. The stakeholders which are focussed solely on the Hambantota Fishery Harbour (the Harbour Manager, the associations and the Management Committee) need to be on a higher
participation level. These stakeholders have suffered directly from the sedimentation problems and to keep them on your side it is essential to make them feel their concerns are considered. Furthermore they have specific knowledge about the existing harbour and its problems, which will be essential for the contractors to make a design that will work.

The Project Director Team has awarded the contract for this project to Royal HaskoningDHV and ECL and will incorporate their advice and recommendations, which consists of a redesign of the existing harbour.

**Conclusions and recommendations**

Comparing the project of adapting the harbour to its original construction project, not much has changed from a stakeholder perspective. The Central Government is now the financer of the project and the Project Director Team and the contractors have been replaced. However the interdependencies between the stakeholders and the powers of the stakeholders have not changed.

To make sure the adaption of the existing Hambantota Fishery Harbour will be a success the Project Director Team should make use of the participation planning matrix provided above. This way every stakeholder will participate to that extend that no valuable information will be lost and the stakeholders will stay in support of the project.

The Project Director Team should have proper communication with the contractors, to make sure that the new design is up to their demands and they won’t need a third party to adjust the design. It is also important that the Project Director Team is open to really incorporating the advice and recommendations of the contractors to maximum extend. The Project Director Team has required a small change to the existing harbour, but when Royal HaskoningDHV and ECL believe that this won’t solve the problems and a bigger change is needed, the Project Director Team should be open to changing this requirement.
7. Conclusion of the analysis

The Hambantota bay was in a natural equilibrium before the construction of the breakwaters of the fishery harbour. The breakwaters have disturbed the equilibrium and currently the harbour traps sediment in the harbour basin, the entrance channel and the entrance. The research question for this first part of the report was: *Which processes are responsible for the sedimentation and harsh navigability conditions at the Hambantota Fisheries Harbour and why aren’t those processes dealt with in the existing design?* This chapter provides an answer to this question.

The coastal cell, equal to the natural shaped Hambantota bay, starts at the rocky headland south of the Hambantota Fishery Harbour and ends in the northeast at the Pitawatan Point. The Hambantota Fishery Harbour is located in the west of this coastal cell.

The coastal cell contains an input sediment flux and an output sediment flux. The input sediment flux is on the west side of the coastal cell. In the northeast of the coastal cell, at the Pitawatan Point, there is sediment output due to the eastward direction of the sediment transport, the shape of the headland and the adjacent bay to the east.

![Coastal system, coastal cell and Hambantota Fishery Harbour](image)

**Figure 42 Coastal system, coastal cell and Hambantota Fishery Harbour**

**Source**
The siltation within the harbour basin, entrance channel and the entrance is caused by sediment from the adjacent coast to the west of Hambantota and the Hambantota bay.
The sediment transport on the south coast of Sri Lanka is directed eastwards. On the west of the Hambantota bay the sediment transport encounters the breakwater of the commercial harbour. The breakwater extends up to the -12 m depth line and blocks the bed load transport in the littoral zone. This prevents coarse sediment from bypassing this point. Only fine sediment will be able to bypass the breakwater through suspended load transport. Subsequently the sediment transport will take the sediment around the corner into the Hambantota bay.

Satellite images show no significant change of the beach on the east side of the commercial harbour. This makes it more likely that the source of the sediment input from the west lies more to the west of the commercial harbour.

Another important source of the sediment is the Hambantota bay itself. The sediment in the harbour basin, entrance channel and the entrance contains fine and coarse material. Sediment transport within the Hambantota bay is influenced by its oval shape, seasonal behaviour and hydraulic processes that will be explained in the next paragraph about the processes in the Hambantota bay. Satellite images taken just after the S-W monsoon show accretion on the east side of the Hambantota bay. On the other hand, images taken just after the N-E monsoon show small accretion on the west side of the Hambantota bay. The seasonal accretion and erosion just north of the northern breakwater causes sediment transport towards the harbour of coarse and fine sediment.

 Processes outside the harbour
The climate in Sri Lanka is determined by the S-W monsoon and the N-E monsoon. The wind direction during the S-W monsoon is predominantly from the southwest and during the N-E monsoon from the northeast. Swell waves are year-round from the south while sea waves vary with the monsoon. Sea waves during the S-W monsoon come from the southwest and have the same direction as the swell waves. During the N-E monsoon sea waves are from the N-E and do not have the same direction as the swell waves. The configuration of the wind and waves cause a year-round sediment transport eastwards on the Sri Lankan south coast.

Calculations of the transport capacity within the Hambantota bay show a transport towards the east during the entire year. The magnitude of the transport is larger during the S-W monsoon and smaller in the N-E monsoon due to the configuration of the waves and wind.

Information of fishermen and satellite images show that after the N-E monsoon the area just north of the northern breakwater is accreted. This accretion is caused by the configuration of the wind and waves during the N-E monsoon and the lee area of this spot for swell waves from the south.

Around the rocky headland in the south waves bend towards the coastline. Within the west side of the Hambantota bay also refraction occurs near the harbour. During the site visit and on satellite images (Figure 42) refracting waves were seen that break on the southern breakwater.

The area just north of the northern breakwater is in a lee side due to the rocky headland in the south and the dominant direction of the waves from the south. The difference in wave breaking on the beach causes a current from the high wave breaking area to the area with low wave breaking. The low wave breaking area is just above the northern breakwater and attracts a current from the east that will flow along the northern breakwater to the entrance of the harbour.
Continuity requires a return current near the bottom. This undertow is constant over the whole Hambantota bay and flows in opposite direction of the approaching and breaking waves.

**Processes inside the harbour**
The waves that break on the tip of the southern breakwater are not fully blocked and will turn the harbour due to diffraction. This diffraction around the tip of the southern breakwater is also the mean contributor to the siltation within the harbour is the diffraction.

**Siltation entrance channel and entrance**
The current driven by set up differences along the northern breakwater and the undertow contribute to the siltation in front of the entrance which results in a shoal.

**Stakeholders**
It’s clear mistakes have been made in designing the harbour, since it doesn’t deal well with the processes that cause the sedimentation problems. LHI and Halcrow designed a harbour which was way above budget. Niras also made a mistake by not using the fisherman’s knowledge while making changes to the design. Blame can also be put on the Project Director Team. They should have noticed that the design on which LHI and Halcrow were working was going to be over budget, since it was of a much larger scale than originally planned. Also, they should have insisted that Niras consulted the fisherman and would take their specific knowledge into account. Overall the failure of the project can be explained from bad communications between the various stakeholders. Improving the communication between stakeholders will be essential in future projects.
8. Alternatives

Ten possible solutions are described in this chapter. A first selection is made based on the constructability, effectiveness, building costs, maintenance costs and if the design is a small adjustment. After the first selection some of the alternatives will be combined to get the three most promising alternatives. These alternatives will be evaluated by a Multi Criteria Analysis in chapter 8.

8.1 Possible solutions

Alternative 1
This alternative makes no adjustments to the northern breakwater and extends the southern breakwater up to the six meter depth line, at this depth the longshore transport is nearly reduced to zero. The extension is shaped towards the north and is beyond the entrance. The diffraction point is at the head of the breakwater, with this adjustment the diffraction point is shifted towards deeper water. This will result in less diffraction of waves into the harbour basin and so reducing the sedimentation of the basin.

The longshore sediment current follows the shape of the breakwater, this reduces the amount of sand coming into the harbour. Most of the sand goes offshore and a part of the sand goes back in the system. The sand that comes back into the system is picked up by the longshore sediment current to the north of the harbour. Some of sediment never reaches the longshore sediment current because it settles in the approach channel. Besides this, the extension is also an improvement to the navigability because the wave action behind the extension is reduced and this improves the navigability conditions.

Like already mentioned before a small amount of sand will settle in the approach channel, so maintenance dredging is required to keep the channel deep enough.

Figure 43 Alternative 1
Alternative 2
The northern breakwater remains the same. A small extension on the southern breakwater is made, the small extension is placed perpendicular to the current breakwater up to the 6 meter depth line. The diffraction point is shifted towards deeper water which reduces the diffraction into the harbour. Furthermore most of the sand is trapped in front of the extension, this is called the buffer zone. Occasionally some of the sand bypasses buffer zone and settles in the approach channel.

The sand is either trapped behind the breakwater or settles in the approach channel so the sediment coming into the harbour will be negligible. Maintenance dredging is required to remove the trapped sand and the small amount of sand that settles in the approach channel.

This adjustment will also block the waves near the entrance which increases the navigability conditions and reduce the wave penetration into the harbour.

Alternative 3
This alternative builds a third breakwater behind the northern breakwater this creates a settlement basin. Sediment that would normally go into the harbour will settle in the basin, reducing the amount of sediment that settles in the harbour basin. Maintenance dredging is necessary to keep the settlement basin deep enough for the grains to settle. The coast inside the settlement basin can be used as slipway for smaller vessels.

The southern breakwater remains the same so the wave conditions and navigability conditions at the entrance are still the same as with the current design.
**Alternative 4**  
Both of the breakwaters remain the same in this alternative. A dredging pit is made to the southeast of the fishery harbour. The dredging pit traps the sediments coming from the south so it won’t reach the entrance of the harbour and the harbour basin. Maintenance dredging of the dredging pit is required to keep the system working. The navigability and wave conditions will not improve in this alternative.

![Figure 46 Alternative 4](image)

**Alternative 5**  
This alternative is based on the successful sediment traps along the coast of Indonesia (Ceylon Fishery Harbour Cooperation, n.d.).

There are no adjustments to the breakwaters in this design. To the southeast of the fishery harbour there is a fence with wooden piles driven into the bottom. These wooden piles are connected with wire and prunings. This porous dam catches the sediment and reduces wave action behind it. Due to reduce wave action sediment that passes the porous dam will settle behind it. The sand will form a part of the dam or settle behind it.

Maintenance dredging is required to remove the sand behind the fences to keep the system working. The navigability and wave conditions remain the same as in the current design.

![Figure 47 Alternative 5](image)
**Alternative 6**
No adjustments will be made to the current layout of the harbour and nothing will prevent sediment from coming into the harbour. Continuous dredging is required to keep the harbour and entrance channel deep enough to continue harbour operations. The sediment settles in the harbour and the harbour basin is getting to shallow a dredging machine deepens the area, this is an ongoing process.

![Figure 48 Alternative 6](image)

**Alternative 7**
This alternative presents the optimal solution when a total redesign of the harbour is possible.

The southern breakwater is bending towards deeper water and passing the entrance of the harbour. The breakwater extends till the 6 meter depth line. This will result in a redirection of the sediment current to offshore waters. Most of the sediment is trapped behind the southern breakwater. Some of the sediment goes offshore or bypasses the entrance and is picked up by the alongshore sediment current in the north. A small amount will settle in the approach channel and a negligible amount of the sediment will diffract into the harbour.

The alignment of the northern breakwater is to the east with a small extension perpendicular to the breakwater to catch the sediments coming from the north. The small extension is not placed at the end of the breakwater if this was the case waves would reflect on to the extension and this would create hard navigation conditions.

Maintenance dredging is required at the buffer zone to prevent sedimentation in the harbour basin.

![Figure 49 Alternative 7](image)
**Alternative 8**
This alternative is based on the vision of the fishermen. A large breakwater should be built perpendicular to the coast beneath the current breakwater in the south. According to the fishermen this breakwater will capture sediment from the south and block the incoming waves. The tip of the northern breakwater will be extended perpendicular and create a T-shaped breakwater. This T-shaped breakwater traps the sediment which is coming from the north. The created buffer areas in the north and the south should be dredged periodically to maintain its function.

![Figure 50 Alternative 8](image)

**Alternative 9**
This alternative makes a small adjustment to the northern breakwater and the southern breakwater remains the same. The northern breakwater will make a curve into the sea in order to redirect the return current along the north breakwater. The sediment in the return current will flow into deeper water. The entrance channel will be shifted more to the north due to the adjustment of the northern breakwater. The wave action is not reduced in front of the entrance so the navigability conditions remain the same.

![Figure 51 Alternative 9](image)
**Alternative 10**

This alternative makes a minor adjustment to the northern breakwater and the southern breakwater remains the same. A perpendicular extension into the sea will be made on the northern breakwater. The extension is on a safe distance from the harbour entrance to prevent reflecting waves into the entrance channel. At the same time the extension will block the return current and sediment will accrete between the breakwater and the adjacent beach. This buffer zone should be dredged periodically to maintain its function.

*Figure 52 Alternative 10*
8.2 First selection

Aspects
To get to the three most promising alternatives a selection will be made based on:

- technical feasibility
  - Constructability;
  - Effectiveness to prevent harbour sedimentation.
- Costs
  - Building Costs;
  - Maintenance Costs.

The technical feasibility is divided into constructability and effectiveness. This shows the difference between effective solutions which are hard to build and easy solutions with a low score on effectiveness.

The costs are separated in costs during the building phase of the harbour, and costs after completion of the construction. This division will show which solutions are expensive during the entire lifetime, or have a lot of costs during construction.

To stay within the scope of the project a hard requirement is added to make sure the solution is a small adjustment to the current situation.

Comparison
Since the scores given are an estimation the used scale is ++ (best), + (good), 0 (average), - (bad), -- (worst).

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Technical Feasibility</th>
<th>Costs</th>
<th>cumulative</th>
<th>small adjustment</th>
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<td>Maintenance Costs</td>
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<td>+</td>
<td>+</td>
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<td>10</td>
<td>+</td>
<td>++</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

| Table 30 Scorecard for all alternatives |
**Constructability**

Alternative 3 has best building conditions, since the new breakwater is constructed inside the current harbour. Alternative 9 and 10 are small adjustments in shallow water, and this area is partly sheltered by the existing harbour structures. Alternative 1 and 2 can partly be constructed from the existing breakwater or near the current location. All alternatives which involve dredging are considered to have a bad workability, since the incoming swell waves result in small workable periods for dredging vessels. Especially the construction of the wooden dams is very difficult, which is why alternative 5 scores lowest.

**Effectiveness**

Alternative 7 is considered to be the optimal design assuming a ‘clean start’. We expect this solution to be very effective, and try to approximate the design with alternative 1 and 2. The fishermen’s solution is also effective, but due to refraction waves can still reach the harbour entrance. With alternative 3 the entrance orientation has changed, but sedimentation in front of the entrance is still a possible problem.

For alternative 9 and 10 the focus is on the sediment transport approaching from the north. With a smooth alignment the sediment will pass by the entrance. Blocking as in alternative 10 is expected to be more effective, since no sediment will pass the head of the breakwater.

The effectiveness of alternative 4 is hard to determine since the settling of sediment required calm waters. Coarse sediment is more likely to be trapped, but the finer sediment can stay in suspension and flow over the pit.

**Building costs**

Lowest building costs are easily reached by implementing an intense dredging program. This can be in ways of dredging a pit or by frequently dredging the harbour basin. Regardless the method, an obvious consequence is higher maintenance costs. The dredging of the dredging pit is considered as building costs.

Expensive solutions like alternative 7 and 8 involve a lot of new structures. All small adjustments are similar in size except for alternative 3, where a longer breakwater has to be constructed.

**Maintenance costs**

Soft solutions which involve a lot of dredging automatically have high maintenance costs. Smoothening of the breakwater alignment as in alternative 1, 3, 7 and 9 minimises dredging efforts since the transport is diverted past the entrance and pushed further offshore.

Alternative 2, 4, 5 and 10 enable the dredging to take place in one location making it less expensive and less conflicting with day to day harbour operations.

Alternative 6 required continuous dredging in the entire harbour basin, this is most disturbing and expensive.
Conclusion

As can be seen in the comparison above alternative 1, 2, 3, 7, 9 and 10 are the best options from the ten alternatives described. Option 7 can be seen as an undesired solution since current structures are not re-used in this design. Big adjustments are needed, and this conflicts with requirements.

Option 1, 2 and 3 prevent sediment from the south to enter while option 9 and 10 are effective against sediment from the north. Since sediment is coming from both directions the best design is obtained by a combination of these solutions. Option 9, redirecting the northern sediment, conflicts with increased safety for approaching fishing ships. Therefore option 10 will be combined with 1, 2 and 3 resulting in three alternatives to compare in the Multi Criteria Analysis.
8.3 Alternatives MCA

After the first selection three alternatives are tested by a Multi Criteria Analysis. First a short description of these three alternatives will be given.

Redirect
This alternative is a combination of alternative 1 and 10.

The extension on the northern breakwater traps all the sand coming from the north that’s transported due to set up and the return current. The extension on the north breakwater is not placed on the top of the breakwater to prevent reflection of waves into the harbour. The southern breakwater is smoothly bending to the six meter depth line so it redirects the sediment offshore and traps part of the sediment behind the breakwater. The sediment that is redirected offshore is picked up by the northern sediment current or lost into the deep sea. At both breakwaters maintenance dredging is required in the buffer zone to maintain its function.

The swell waves coming from the south are partly blocked on the southern breakwater. Because of the smooth shape not all the energy is dissipated on this breakwater, some of the waves will be redirected and diffract around the head of the breakwater. The swell waves are causing most of the problems for the navigability due to harsh wave conditions. The southern breakwater blocks these waves partly so the navigation conditions improve.

The alignment of the approach channel and entrance channel is chosen to reach the deep water as soon as possible but considering the location of the turning basin. The turning basin is in front of the revetment to prevent ships which are out of control to hit the slipway.
**Block**

This alternative combines alternative 2 and 10.

An extension nearly perpendicular to the southern breakwater is built up to the six meter depth line. The extension traps most of the sediments coming from the south. The sediment that is coming from the north due to set up and a return current is trapped by a small perpendicular extension on the north breakwater. These extensions prevent sediments from coming into the harbour. The buffer zones behind the breakwaters have to be dredged periodically to maintain their function.

The southern breakwater blocks the waves coming from the south, this improves the navigation conditions in front of the harbour.

The approach and entrance channel is made parallel to both extensions. This way the ships will reach deep water as fast as possible considering the place of the turning basin in front of the revetment and the navigability. Another benefit is that the dredged area is minimized when the approach channel is connected in the shortest possible way.

---

*Figure 54 Block*
**Basin**

Alternative ‘Basin’ is a combination of alternative 3 and 10.

The southern breakwater remains the same so the wave conditions and navigability conditions at the entrance are still the same as with the current design.

The new breakwater will create a settlement basin for sediment that passes the tip of the southern breakwater into the harbour. The basin and beach within the new breakwater and the current breakwater can be used for smaller vessels as slipway.

A perpendicular extension into the sea will be made on the northern breakwater. The extension is on a safe distance from the harbour entrance to prevent reflecting waves into the entrance channel. At the same time the extension will block the return current and sediment will accrete between the breakwater and the adjacent beach. This buffer zone should be dredged periodically to maintain its function.

The entrance channel will be adjusted more parallel to the beach. This results in a longer approach channel but this is necessary to have a sufficient channel width at the entrance.

---

*Figure 55 Basin*
9. Evaluation of alternatives

The three alternatives will be evaluated with the Permutation MCA as described in Chapter 3 and Appendix K: MCA Permutation method. First the criteria and weight factors will be provided. Next the rating of the alternatives will be discussed per criterion. The ratings will be the input of the analysis, which will provide the best alternative.

9.1 Criteria

The alternatives will be evaluated against eleven criteria:

- Construction cost;
- Maintenance cost;
- Construction time;
- Sedimentation of the harbour basin;
- Sedimentation of the approach channel;
- Wave intrusion;
- Alignment of the approach channel;
- Wave conditions near entrance;
- Capacity;
- Durability;
- Stakeholder nuisance.

An elaboration on these criteria can be found in Appendix L: Criteria MCA.

9.2 Weight factors

The weight factors are provided by the Project Director Team (2014). Construction cost, Sedimentation of the approach channel and Durability prove to be the most important criteria, while Stakeholder nuisance is not important at all.

<table>
<thead>
<tr>
<th>Criteria</th>
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<td>Wave intrusion</td>
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<td>Alignment of the approach channel</td>
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<tr>
<td>Wave conditions near entrance</td>
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<td>Capacity</td>
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<td>Durability</td>
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<tr>
<td><strong>Total</strong></td>
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</tr>
</tbody>
</table>

Table 31 Weight factors
9.3 Ratings

Construction cost
Alternative Basin is the cheapest solution, since the new breakwater can be constructed inside the harbour. Land-based equipment and a sheltered worksite provide good building conditions, and the required stone sizes inside the harbour are relatively small. Due to the demolition of a big part of the southern breakwater alternative Redirect is most expensive. The re-use of armour stones is an advantage, but the amount of new stones to be acquired is similar for alternative Redirect and Block. Alternative Block requires bigger armour stones since more energy will be dissipated. The cost of dredging during the construction is expected to be equal.

Maintenance cost
Alternative Redirect required the least amount of dredging, since the sediment flow along the southern breakwater is redirected towards deeper water, where the sediment will settle due to the absence of breaking waves. The expected damage due to storm events is higher for alternative Block since the breakwater is aligned more perpendicular to the incoming waves. This will result in more energy dissipation and is bigger change of damage. Dredging activities are focussed on one location for alternative Block, which results in more effective dredging operations. Alternative Basin has the highest maintenance cost, because the effectiveness of the settling basin is doubtful. Dredging through the entire harbour basin is most expensive.

Construction time
Implementing alternative Basin can be done within a small building period, since the working conditions are favourable and land based equipment can be used. Alternative Redirect requires the most time, since demolition and rebuilding of the southern breakwater can’t be executed simultaneously. The northern breakwater adjustment could be constructed while the southern breakwater is build, but this will result in a similar advantage for alternative Redirect and Block.

Sedimentation of the harbour basin
Sedimentation rate of the harbour basin is the highest for alternative Basin, because it is uncertain whether the sediment will only settle in the settling basin. The required dredging interval is also highest, since a large volume of sediment enters the harbour with the current entrance. It is expected alternative Block results in the smallest sedimentation inside the harbour, since no sediment will pass the head of the breakwater head. This in contrast with alternative Redirect, where a small part of the sediment will enter the harbour when it is pushed offshore.

Sedimentation of the approach channel
The sedimentation of the approach channel is expected to be most for alternative Basin, since no effort is taken to block or divert a portion of the sediment transport. The approach channel for alternative Redirect is located in more shallow areas, which results in faster sedimentation. A larger amount of sediment passing the breakwater head will also result in faster sedimentation for alternative Redirect.

Wave intrusion
The harbour basin is best sheltered from incoming waves with alternative Redirect, since the head of the southern breakwater is furthest towards the north. This prevents refracting waves from entering
the harbour. With alternative Basin no changes are made for the harbour entrance, so wave intrusion will be worst but it will mostly enter the settling basin.

Alignment of the approach channel
The approach channel is most convenient with alternative Redirect, since the waves are in the back when you leave the sheltered area. A sharp turn is inevitable for all alternatives, so this is less important for this comparison. With alternative Block ships will have incoming waves from the side, which makes it hard to navigate to the sheltered area behind the breakwater.

Wave conditions near the entrance
Alternative Block provides the best sheltering near the harbour entrance, since the breakwater is very close to the entrance. Most wave energy is also dissipated with this alternative, so less wave energy is present to worsen the wave climate. Alternative Basin is worst, since no changes are made to the current situation

Capacity
Alternative Basin is clearly worst on this aspect, since a part of the slipway will be abandoned and used as settling basin. The harbour basin is also reduced, with less anchor space as a consequence. Alternative Redirect and Block are quite similar, but alternative Redirect is a bit more spacious.

Durability
Alternative Block is determined to be the best because in this adjustment the sediment loss in the system can be estimated the most exact. The sediment loss in alternative Redirect is not easy to predict and may harm the adjacent beaches in the Hambantota bay. Alternative Basin doesn’t change anything compared to the current system. The lifetime of alternative Block will be the largest because the changes in the processes around the harbour are the best predictable.

Stakeholder nuisance
Both construction and maintenance dredging will take place outside of the harbour for alternative Block, this avoids conflicts with normal harbour operations. Alternative Redirect is a bit worse, since demolition of a part of the southern breakwater results in a partly unprotected harbour basin. In addition, dredging has to take place inside the harbour and at the approach channel. This is relatively small compared to the situation with alternative Basin. The construction inside the harbour causes most inconvenience, combining this with frequent dredging inside the harbour basin results in the worst alternative for this aspect.
9.4 Analysis
The information provided above is combined in Table 32, in which * indicated the best rated alternative and *** the worst.

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<tr>
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<td>Sedimentation of the approach channel</td>
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<tr>
<td>Wave intrusion</td>
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<tr>
<td>Alignment of approach channel</td>
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<td>Wave conditions near entrance</td>
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<tr>
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</table>

Table 32 MCA ratings

Table 32 is used as input for the MCA, which results have been provided in below in Table 33.

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<td>-1</td>
<td>+1</td>
<td>+3</td>
<td>-1</td>
<td>+1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>R3</td>
<td>-1</td>
<td>+1</td>
<td>-1</td>
<td>+3</td>
<td>+3</td>
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<td>+3</td>
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<tr>
<td>R4</td>
<td>+1</td>
<td>-1</td>
<td>+1</td>
<td>+1</td>
<td>-1</td>
<td>-3</td>
<td>+1</td>
<td>-1</td>
<td>+1</td>
<td>+1</td>
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</tr>
<tr>
<td>R5</td>
<td>+1</td>
<td>-1</td>
<td>+1</td>
<td>-3</td>
<td>-3</td>
<td>-1</td>
<td>+1</td>
<td>-3</td>
<td>-1</td>
<td>-3</td>
<td>-3</td>
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<tr>
<td>R6</td>
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<td>+3</td>
<td>-1</td>
<td>-1</td>
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<td>-1</td>
<td>-1</td>
<td>-3</td>
<td>-1</td>
<td>-1</td>
</tr>
</tbody>
</table>

Table 33 MCA results

9.5 Conclusion
From the MCA follows that R3 is the preferred order of alternatives Appendix K: MCA Permutation method. This means alternative Block is the best, then alternative Redirect and alternative Basin comes out worst.
10. Discussion

This chapter will discuss the limitations on data and methods used and the results that follow from our research.

Data limitations
The assessment of the harbour in general is mostly based on observations and personal experience since detailed measurements are not available. Consequently the results should be interpreted as such, since our knowledge and experience is limited to college lectures. Master students however have spent multiple years studying Hydraulic Engineering topics and are expected to understand the system and the ongoing processes.

Calculations in this report range from nearshore wave conditions to sediment transport capacities and the outcome is taken as a fact. In reality this is not to certain, since assumptions in input parameters and simplifications for the calculation method not necessarily mean reality is still approached. Wave and sediment transport data were unavailable and therefore not used to calibrate calculations and validate the results. Due to this limitation the outcome of the various calculations can only be seen as benchmark figures which are not applicable for specific locations.

For this report ARGOSS-data was used as input for the transformation to nearshore wave conditions. This data does not contain any storm events which may be useful to include in an accurate research. Wave data is collected from a grid of 200 by 200 km around an offshore point. This data is used at one specific input point on the cross-shore profile for the calculation of the nearshore wave conditions. The conversion from a square to one specific point is done by taking the centre of the square, but further attention is needed since the wave height is sensitive to the profile length.

Because there are no documents available from the time the Hambantota Fishery Harbour was designed and constructed, it is hard to say what went wrong and who is to blame. A large part of the input for the stakeholder analysis was obtained through personal communications with mister Channa Fernando. It would have been very valuable to be able to speak to people who were directly involved in the project, but unfortunately this was not possible.

Method limitations
Using SwanOne to calculate the nearshore wave conditions implies a uniform and straight coastline, so the circular shape of the Hambantota Bay is not taken into account. Differences in wave height due to this effect are not taken into account.

As input only the total of incoming waves in considered due to time constraints. A separation into the different contributions of swell and sea for sediment transport would give more detailed information. Local details where sheltering for one of the component is occurring could be better described and insight is gained into local processes.

Changes of the bed slope are not taken into account over time, so the estimated coastline changes can not directly be connected to sedimentation or erosion. Since a yearly average of the slopes is fairly constant this level of detail is sufficient for this report.

The comparison of satellite images is limited due to the lack of available images of Google Earth. The period between consecutive images is too long or too short to conduct a consistent pattern.
Comparison of the alternatives is done on a relative basis because detailed figures of effectiveness, cost and building time were hard to come by. To show the implied uncertainty a relative comparison is made, but with this method significant differences are neglected leading to a false comparison. To correct for this effect a quantitative comparison is preferred if the required data can be collected with acceptable certainty.

Results
The results of the SwanOne calculation show an unexpected wave transformation. This is ascribed to the local wind used as input as described in Appendix A: Wave characteristics and Appendix C: Nearshore conditions. It remains very uncertain whether this is true, since it could be a modelling error as well. A more detailed look is required for this issue.

Calculations of the sediment transport capacity were executed, and not for the actual sediment transport. Sediment availability is therefore not taken into account in this research. This could be a point for further research.

The failure of the project is explained from bad communications between the stakeholders, which is not an uncommon problem in an undeveloped country as Sri Lanka. However because of the limited information available it is uncertain if bad communication is the main problem which leads to the mistakes in the design.
11. Conclusion

Since the construction of the Hambantota Fishery Harbour there have been problems with sedimentation. To solve these problems the following research question has been formulated:

*Which adjustments of the current design will prevent future sedimentation inside the harbour and improve navigability conditions for the fishermen and to what extend should the different stakeholders be involved to achieve this?*

One of the major problems in the Hambantota Fishery Harbour is siltation of the harbour basin. Sediment that passes the commercial harbour enters the Hambantota bay on the south side. The sediment is carried along the southern breakwater by the breaking swell waves. At the tip of the southern breakwater there is a lot of diffraction. The sediment is diffracted into the harbour basin and settles there due to the lack of wave action.

The block alternative will solve this problem due to a small adjustment that is made on the southern breakwater. The diffraction point of the breakwater is shifted to deeper water (the six meter water depth contour line) by placing a perpendicular extension at the head of the breakwater. The sedimentation into the harbour is reduced since less diffracted wave energy can reach the harbour basin. Aside from the reduced diffraction, the extension is also trapping sediment. The amount of sediment that is coming from the south remains the same and most of it is trapped in the buffer zone. This sediment should be removed periodically for the buffer zone to maintain its function.

Besides the sediment from the south there is also a sediment supply from the north. The source of this sediment is the Hambantota bay itself. The sediment is carried towards the entrance of the harbour by a current due to set up difference and the undertow. To avoid this sediment coming into the harbour the same procedure is used at the northern breakwater as at the southern breakwater. A small perpendicular extension is built at the northern breakwater. The extension creates a buffer zone where the sediment is trapped.

The other main problem is the navigability since fishermen encounter breaking waves when they enter the harbour. These breaking waves are the result of a shoal, which is formed in front of the harbour by the sediment that is coming from the north and the south. Since the breakwater extensions prevent the passing of sediment the shoal can no longer be formed. The extension of the northern breakwater is located on some distance from the entrance so reflecting waves won’t cause hazardous conditions. Due to the fact that the southern breakwater will be located further offshore a sheltered area is created in front of the entrance which will enable the fishermen to enter the harbour in a safe manner.

Overall the failure of the Hambantota Fishery Harbour project can be explained from bad communications between the various stakeholders. Improving the communication between the stakeholders will be essential for the new project of adapting the harbour to be successful. Therefore the Project Director Team should collaborate with Royal HaskoningDHV and ECL, involve the Hambantota Fisherman Association, Hambantota Fisheries Traders Association, the Harbour Manager and the Hambantota Fisheries Harbour Management Committee and consult most of the governmental stakeholders. It should be sufficient to inform the Central Government and the Ministry of Fisheries and Aquatic Resources Development.
With a small adjustment to the existing harbour constructions an improved harbour design can be realised. This will result in improved navigability conditions and a decrease in siltation. The decrease in harbour siltation and the prevention of shoal-forming can only be achieved in combination with periodic dredging, since the improved breakwaters do not prevent the accumulation of sediment, only block the flow of sediment in a convenient location.
12. Recommendations

Finalize the design
The proposed alternative is rather an advised solution direction than a ready-to-use preliminary design. To convert our rough solution to an actual design more in depth knowledge should be acquired.

The processes at the harbour entrance are very detailed in both space and time. This requires very detailed measurements and a detailed approach, while only the overall results and processes are discussed in this report. A detailed model of the harbour entrance should be processed to validate the assumed dominant processes and confirm whether our alternatives are indeed effective at solving the problems experienced by the Hambantota fishermen.

The proposed layout of the breakwaters should be optimized to find the best breakwater length, angle with the existing structures and depth at the breakwater head. The Hambantota Fishery Harbour is also vulnerable to wave penetration. This is not part of our research questions since it is less problematic and it does not create hazardous situations for the fishermen. If however the breakwaters are adapted wave penetration should be considered as well.

Independent of the final alternative, initial dredging is required to meet harbour requirements such as the channel depth and the harbour basin depth. Besides, dredging will be required in every solution because no harbour can be fully protected against siltation.

Stakeholder involvement
To make sure the adaption of the existing Hambantota Fishery Harbour will be a success the Project Director Team should make use of the participation planning matrix provided in Chapter 6. This way every stakeholder will participate to that extend that no valuable information will be lost and the stakeholders will stay in support of the project.

The Project Director Team should have proper communication with the contractors, to make sure that the new design is up to their demands and they won’t need a third party to adjust the design. It is also important that the Project Director Team is open to really incorporating the advice and recommendations of the contractors to maximum extend. The Project Director Team has required a small change to the existing harbour, but when Royal HaskoningDHV and ECL believe that this won’t solve the problems and a bigger change is needed, the Project Director Team should be open to changing this requirement.
List of references

Bosboom, J., & Stive, M. J. F. (2013). Coastal Dynamics I lecture notes CIE4305 (version 0.4 ed.). Delft, the Netherlands: VSSD.
Ceylon Fishery Harbour Cooperation. (n.d.). Dredging works approach channel.
ECL (2014). [Minutes of the Stakeholder Meeting No.1 held on 28th July 2014].
Project Director Team. (2014). Weight factors MCA.
Schiereck, G. J. (2012). Introduction to bed, bank and shore protection (2nd ed.). Delft, the Netherlands: VSSD.
Appendix A: Wave characteristics

Wave characteristics as discussed in Chapter 4 ‘Waves’ are obtained from ARGOSS data. As an example Table 1 and Table 2 show the output from ARGOSS for the South-West monsoon for both wind waves and swell waves. The wave direction and wave period are shown per wave height. To get to a representative value the ten most frequent values are averaged using their relative weight. This resulted in representative values for the wave direction, wave period and wave height. Wave height is calculated twice, so the value of the first table is used.

### Table 34 Wave Height vs Wave direction during South-West monsoon for total wave conditions

<table>
<thead>
<tr>
<th>lower</th>
<th>upper</th>
<th>123.75</th>
<th>146.25</th>
<th>168.75</th>
<th>191.25</th>
<th>213.75</th>
<th>236.25</th>
<th>258.75</th>
<th>average value per bin</th>
<th>occurrence of frequent values</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>0.00</td>
<td>0.00</td>
</tr>
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<td>0.5</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>0</td>
<td>0.75</td>
<td>0.75</td>
</tr>
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<td>1.25</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2.25</td>
<td>2.25</td>
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<td>0</td>
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<td>0</td>
<td>7667</td>
<td>7667</td>
</tr>
<tr>
<td>total</td>
<td></td>
<td>0</td>
<td>135</td>
<td>5553</td>
<td>14986</td>
<td>5871</td>
<td>383</td>
<td>0</td>
<td>26928</td>
<td>26928</td>
</tr>
</tbody>
</table>

### Table 35 Wave height vs Peak Period during South-West monsoon for total wave condition

| lower | upper | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   | 13   | 14   | 15   | 16   | 17   | 18   | 19   | 20   | 21   | 22   | 23   | 24   | 25   | total |
|-------|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 0     | 0.5   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 0.5   | 1     | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 1     | 1.5   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1.25 | 0   | 0   |
| 1.5   | 2     | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 115965 | 2.25 | 0   | 0   |
| 2     | 2.5   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 2.5   | 3     | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1  | 0   | 0   | 0   |
| 3     | 3.5   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 3.5   | 4     | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 4     | 4.5   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| total |       | 0   | 108   | 416   | 91    | 168   | 867   | 1602  | 2564  | 3795   | 5516   | 5845   | 0   | 3367   | 1387   | 0   | 273   | 0   | 25   | 0   | 0   | 1   | 0   | 28523  | 18290   |

Table 34 Wave Height vs Wave direction during South-West monsoon for total wave conditions

Table 35 Wave height vs Peak Period during South-West monsoon for total wave condition
Appendix B: Wave transformation of shelf break and alongshore current

The figures below show the wave transformation with and without shelf break and alongshore current as discussed in Chapter 4 ‘Waves’
Appendix C: Nearshore conditions

South-West monsoon

<table>
<thead>
<tr>
<th></th>
<th>Offshore value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Significant wave height</td>
<td>1.85</td>
<td>[m]</td>
</tr>
<tr>
<td>Dominant wave direction</td>
<td>199</td>
<td>['']</td>
</tr>
<tr>
<td>Peak period</td>
<td>13.4</td>
<td>[s]</td>
</tr>
<tr>
<td>Wind</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind speed</td>
<td>6.5</td>
<td>[ms⁻¹]</td>
</tr>
<tr>
<td>Dominant wind direction</td>
<td>248</td>
<td>['']</td>
</tr>
</tbody>
</table>

Table 36 Offshore data South-West monsoon

The depth profile is obtained from nautical maps and is listed in Table 8. The starting point is fixed on the –1000 m depth line and the Hambantota coast is at 0 m, see Figure 30.

<table>
<thead>
<tr>
<th>Distance from offshore point [m]</th>
<th>Depth [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-1000</td>
</tr>
<tr>
<td>6250</td>
<td>-100</td>
</tr>
<tr>
<td>18750</td>
<td>-50</td>
</tr>
<tr>
<td>25750</td>
<td>-30</td>
</tr>
<tr>
<td>30750</td>
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</tr>
<tr>
<td>32417</td>
<td>-10</td>
</tr>
<tr>
<td>32917</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 37 Depth profile dominant direction South-West monsoon
**North-East monsoon**

<table>
<thead>
<tr>
<th>Offshore value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave</td>
<td></td>
</tr>
<tr>
<td>Significant wave height</td>
<td>1.25  [m]</td>
</tr>
<tr>
<td>Dominant wave direction</td>
<td>151  ['']</td>
</tr>
<tr>
<td>Peak period</td>
<td>12.6  [s]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wind</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind speed</td>
<td>4.8  [m s⁻¹]</td>
</tr>
<tr>
<td>Dominant wind direction</td>
<td>45  ['']</td>
</tr>
</tbody>
</table>

Table 38 Offshore data North-East monsoon

The depth profile is obtained from nautical maps and is listed in Table 10. The starting point is fixed on the –1000 m depth line and the Hambantota coast is at 0 m, see Figure 31.

<table>
<thead>
<tr>
<th>Distance from offshore point [m]</th>
<th>Depth [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-1000</td>
</tr>
<tr>
<td>12500</td>
<td>-100</td>
</tr>
<tr>
<td>31250</td>
<td>-50</td>
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<td>35250</td>
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</tr>
<tr>
<td>47083</td>
<td>-10</td>
</tr>
<tr>
<td>47583</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 39 Depth profile dominant direction North-East monsoon

**South-West monsoon**

<table>
<thead>
<tr>
<th>Breaker point</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water depth</td>
<td>7.5  [m]</td>
</tr>
<tr>
<td>Significant wave height</td>
<td>1.5  [m]</td>
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<tr>
<td>Wave direction</td>
<td>165  ['']</td>
</tr>
<tr>
<td>Peak period</td>
<td>13.9  [s]</td>
</tr>
</tbody>
</table>

Table 40 Output SwanOne South-West monsoon

**North-East monsoon**

<table>
<thead>
<tr>
<th>Breaker point</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water depth</td>
<td>10.5  [m]</td>
</tr>
<tr>
<td>Significant wave height</td>
<td>1.2  [m]</td>
</tr>
<tr>
<td>Wave direction</td>
<td>155  ['']</td>
</tr>
<tr>
<td>Peak period</td>
<td>12.4  [s]</td>
</tr>
</tbody>
</table>

Table 41 Output SwanOne North-East monsoon
Determining dominant wave direction, depth and distance to the shore

**South-West monsoon**

For the South-West monsoon a dominant wave direction is taken around 202°. This is mainly based on the dominant ‘Total and Swell waves’.

<table>
<thead>
<tr>
<th>SW monsoon</th>
<th>Hs [m]</th>
<th>T [s]</th>
<th>Phi [°]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swell</td>
<td>1.7</td>
<td>13.9</td>
<td>189</td>
</tr>
<tr>
<td>Sea</td>
<td>1.1</td>
<td>5.2</td>
<td>234</td>
</tr>
<tr>
<td>Total</td>
<td>1.2</td>
<td>14.2</td>
<td>202</td>
</tr>
</tbody>
</table>

Table 42 Wave characteristics during South-West monsoon

The distance from -1000 m line to the shore is measured on nautical depth charts from the TU Delft Library, see Figure 30.

<table>
<thead>
<tr>
<th>Distance from offshore point [m]</th>
<th>Depth [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-1000</td>
</tr>
<tr>
<td>6250</td>
<td>-100</td>
</tr>
<tr>
<td>18750</td>
<td>-50</td>
</tr>
<tr>
<td>25750</td>
<td>-30</td>
</tr>
<tr>
<td>30750</td>
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</tr>
<tr>
<td>31750</td>
<td>-10</td>
</tr>
<tr>
<td>33750</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 43 Depth measurements

Figure 59 Depth chart Hambantota (1:1.500.000 and 1:75.000) during S-W monsoon
North-East monsoon
For the North-East monsoon a dominant wave direction is taken around 134°. This is mainly based on the dominant ‘Total and Swell waves’.

<table>
<thead>
<tr>
<th>NE monsoon</th>
<th>H_s [m]</th>
<th>T [s]</th>
<th>Phi ['']</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swell</td>
<td>1.1</td>
<td>13.0</td>
<td>161</td>
</tr>
<tr>
<td>Sea</td>
<td>0.5</td>
<td>4.3</td>
<td>59</td>
</tr>
<tr>
<td>Total</td>
<td>1.3</td>
<td>12.4</td>
<td>134</td>
</tr>
</tbody>
</table>

Table 44 Wave characteristics during North-East monsoon

The distance from -1000 m line to the shore is measured on nautical depth charts from the TU Delft Library, see Figure 31.

<table>
<thead>
<tr>
<th>Distance from offshore point [m]</th>
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<td>48250</td>
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</table>

Table 45 Depth measurements

Figure 60 Depth chart Hambantota (1:1.500.000 and 1:75.000) during N-E monsoon
Appendix D: Transport capacity
Table 22 and Table 23 demonstrate the input and output of the transport capacity calculations.

<table>
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<td>160</td>
<td>175</td>
<td>170</td>
</tr>
<tr>
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<td>309</td>
<td>325</td>
<td>340</td>
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<tr>
<td>$\phi_{\text{offshore}}$</td>
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<td>199</td>
<td>199</td>
<td>199</td>
<td>199</td>
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<tr>
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<td>$H_s$ offshore</td>
<td>1.85</td>
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<td>$\phi_{\text{on to coastline}}$</td>
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<td>987934.5</td>
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Table 46 Sediment transport per cross-section during SW-monsoon

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<td>160</td>
<td>175</td>
<td>170</td>
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<tr>
<td>Notation in SwanOne</td>
<td>309</td>
<td>325</td>
<td>340</td>
<td>355</td>
<td>350</td>
</tr>
<tr>
<td>$\phi_{\text{offshore}}$</td>
<td>151</td>
<td>151</td>
<td>151</td>
<td>151</td>
<td>151</td>
</tr>
<tr>
<td>$\phi_{\text{off to coastline}}$</td>
<td>22</td>
<td>6</td>
<td>-9</td>
<td>-24</td>
<td>-19</td>
</tr>
<tr>
<td>$H_s$ offshore</td>
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<td>1.25</td>
<td>1.25</td>
<td>1.25</td>
<td>1.25</td>
</tr>
<tr>
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<td>155</td>
<td>165</td>
<td>174</td>
<td>172</td>
</tr>
<tr>
<td>$H_s$ onshore</td>
<td>1.15</td>
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<td>1.2</td>
<td>1.18</td>
<td>1.2</td>
</tr>
<tr>
<td>$T_p$</td>
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<td>$\phi_{\text{on to coastline}}$</td>
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<td>$S$ in N-E</td>
<td>225694.7</td>
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<td>213100.7</td>
<td>-94699.2</td>
<td>137108.4</td>
</tr>
</tbody>
</table>

Table 47 Sediment transport per cross-section during NE-monsoon.
Appendix E: Wave transformation opposite waves

The results from SwanOne for position 3 and 5 during the NE-monsoon show an offshore wave direction of 151°/151° and an onshore direction of 165°/172°, while the coast normal has an orientation of 160°/170°. This seems unnatural, since refraction or shoaling cannot be responsible for a turn in wave direction through the coast normal.

To investigate these unexpected results the results were checked using a mirrored input into SwanOne. The same output was expected, except the signs for the wave directions. Besides the mirrored input a run was conducted excluding wind as an input-parameter to see whether this could explain the phenomena. Both results can be seen in Table 1 to Table 3.

The mirrored run does not show a similar output with changed signs. With our current knowledge of SwanOne we can’t explain the difference, so this direction can’t help us solve the issue.

The run without taking wind into account does give us the expected results which can be explained by refraction and shoaling. This comparison suggests the local wind causes unexpected transformations. To further investigate the influence of the wind the directional spreading of waves is calculated before and after transformation with and without taking wind into account.

Table 4 is a graphical comparison of this directional spreading of waves. The situation assessed is cross-section 3 with total waves during the North-East monsoon. Table 4 shows the directional spreading of the wave approaching before transformation (high) and after transformation (low). The influence of wind can be seen by comparing the images for the transformations with (left) and without wind (right).

The more detailed information about the directional spreading of the waves does not provide an explanation for the unexpected transformation. Since the effects of wind can’t be neglected the transformation including wind will be used. This will also provide a correct comparison for transport between the different monsoons, since both have wind effects taken into account.
### Table 48: 'Normal' run

<table>
<thead>
<tr>
<th>normal</th>
<th>coastline orientation</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<th>5</th>
</tr>
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<tr>
<td>coastnormal</td>
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<td>110</td>
<td>129</td>
<td>145</td>
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<td>1,25</td>
<td>1,25</td>
<td>1,25</td>
<td>1,25</td>
<td>1,25</td>
<td></td>
</tr>
<tr>
<td>Dominant wave direction</td>
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<td>151</td>
<td>151</td>
<td>151</td>
<td>151</td>
<td>151</td>
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<td>wave off vs coast</td>
<td>41</td>
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<td>-19</td>
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<tr>
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<td>12,6</td>
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<td>12,6</td>
<td>12,6</td>
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<td>4,8</td>
<td></td>
</tr>
<tr>
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<td>165</td>
<td>174</td>
<td>172</td>
<td></td>
</tr>
<tr>
<td>wave on vs coast</td>
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<td>15</td>
<td>10</td>
<td>5</td>
<td>-1</td>
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### Table 49: 'Mirrored' run

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<th>3</th>
<th>4</th>
<th>5</th>
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<tbody>
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<td>129</td>
<td>145</td>
<td>160</td>
<td>175</td>
<td>170</td>
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<td>1,25</td>
<td>1,25</td>
<td>1,25</td>
<td>1,25</td>
<td></td>
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<tr>
<td>Dominant wave direction</td>
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<td>139</td>
<td>169</td>
<td>199</td>
<td>189</td>
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<td>wave off vs coast</td>
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<td>-22</td>
<td>-6</td>
<td>9</td>
<td>24</td>
<td>19</td>
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<tr>
<td>Peak period</td>
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<td>12,6</td>
<td>12,6</td>
<td>12,6</td>
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<td>Windspeed</td>
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<td>4,8</td>
<td>4,8</td>
<td>4,8</td>
<td>4,8</td>
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<tr>
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<td>213</td>
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### Table 50: Excluding wind

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<th>2</th>
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<th>5</th>
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<td>129</td>
<td>145</td>
<td>160</td>
<td>175</td>
<td>170</td>
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<td>1,25</td>
<td>1,25</td>
<td>1,25</td>
<td>1,25</td>
<td>1,25</td>
<td></td>
</tr>
<tr>
<td>Dominant wave direction</td>
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<td>151</td>
<td>151</td>
<td>151</td>
<td>151</td>
<td>151</td>
<td></td>
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<tr>
<td>wave off vs coast</td>
<td>41</td>
<td>22</td>
<td>6</td>
<td>-9</td>
<td>-24</td>
<td>-19</td>
<td></td>
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<tr>
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<td>12,6</td>
<td>12,6</td>
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<td>12,6</td>
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<tr>
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<td>0</td>
<td>0</td>
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<td></td>
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<td>2</td>
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<td>-9</td>
<td>-7</td>
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</tbody>
</table>
Table 51: Transformation including wind (left) and excluding wind (right)
Appendix F: Coastline changes Hambantota bay

Coastline changes period 1 (2003 - 2005)

Figure 61 Coastline Hambanota bay period 1 (2003-2005)
Coastline changes period 2 (2009-2014)

3. (7-10-2005) S-W (7/8)
4. (9-6-2009) S-W (3/8)
5. (26-6-2010) S-W (3/8)
6. (30-4-2011) S-W (1/8)
7. (7-5-2012) S-W (2/8)
8. (10-3-2013) N-E (4/4)
9. (18-3-2013) N-E (4/4)
10. (10-4-2014) S-W (1/8)

Figure 62 Coastline Hambantota bay period 2 (2009-2014)
Coastline changes period 2 (2009-2014)

Figure 63 Coastline changes with coastline before construction of Hambantota Fishery Harbour as red line

3. (7-10-2005) S-W (7/8)
4. (9-6-2009) S-W (3/8)
5. (26-6-2010) S-W (3/8)
6. (30-4-2011) S-W (1/8)
7. (7-5-2012) S-W (2/8)
8. (10-3-2013) N-E (4/4)
9. (18-3-2013) N-E (4/4)
10. (10-4-2014) S-W (1/8)
Figure 64 Pitawatan Point period (2005 – 2013)
Hambantota Fishery Harbour

Figure 65 Harbour period (2005—2014)
Satellite images beach southwest of Hambantota period 1(2005)


2. (7-10-2005) S-W (7/8)

Satellite images beach southwest of Hambantota period 2(2009-2012)

3. (9-6-2009) S-W (3/8)

4. (26-7-2010) S-W (4/8)

5. (30-4-2011) S-W (1/8)

6. (21-6-2011) S-W (3/8)

7. (7-5-2012) S-W (2/8)
Appendix G: Coastline changes south of Hambantota

Satellite images beach southwest of Hambantota period 1 (2005)
Period 1 contains two images of the beach in the southwest of the Hambantota bay. These two images are taken before the construction of the harbour. Information and images are collected in Table 1 and Figure 6.

<table>
<thead>
<tr>
<th>Number</th>
<th>Year</th>
<th>Date</th>
<th>Period [months]</th>
<th>Monsoon</th>
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<tr>
<td>1</td>
<td>2005</td>
<td>28th of January</td>
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<td>N-E (3/5)</td>
</tr>
<tr>
<td>2</td>
<td>2005</td>
<td>7th of October</td>
<td>8</td>
<td>S-W (7/7)</td>
</tr>
</tbody>
</table>

Table 52 information period 1 (2005)

On image number 2 can be seen that erosion took place on the west side and accretion on the east side of the beach.

Satellite images beach southwest of Hambantota period 2 (2009 – 2012)
Period 2 starts approximately one year after the construction of commercial harbour. The effect of the construction of the breakwaters is investigated by five satellite images. Detailed information and images are collected in Table 2 and Figure 2.

The comparison starts with images number 3 and 4. Unfortunately a cloud blocks a large part of the beach on image number 3. After 14 months image number 4 is taken and on the east side of the breakwaters can be seen that erosion took place. There seems to be erosion as well on the west side of the breakwater but this can also be assigned to more wave attack that particular day.

Number 5 shows no large variations on the beach eastwards of the breakwater. The beach on the west side of the breakwater is more visible which can be assigned to accretion or less wave attack that particular day. There is no difference between number 5 and number 6 which can be assigned to the short period between both images.

<table>
<thead>
<tr>
<th>Number</th>
<th>Year</th>
<th>Date</th>
<th>Period [months]</th>
<th>Monsoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>2009</td>
<td>9th of June</td>
<td>S-W (3/7)</td>
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</tr>
<tr>
<td>4</td>
<td>2010</td>
<td>26th of July</td>
<td>14</td>
<td>S-W (4/7)</td>
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<td>5</td>
<td>2011</td>
<td>30th of April</td>
<td>9</td>
<td>S-W (1/7)</td>
</tr>
<tr>
<td>6</td>
<td>2011</td>
<td>21th of June</td>
<td>2</td>
<td>S-W (3/7)</td>
</tr>
<tr>
<td>7</td>
<td>2012</td>
<td>7th of May</td>
<td>11</td>
<td>S-W (2/7)</td>
</tr>
</tbody>
</table>

Table 53 information period 2 (2009 – 2012) Both beaches on the west and east side of the breakwater are clearly visible on image number 7. It doesn’t show any difference with images number 4, 5 and 6.
Satellite images period 1 (2005)

1. (28-1-2005) N-E (3/5)
2. (7-10-2005) S-W (7/7)

Figure 68 Beach southwest of Hambantota period 1 (2005)

Satellite images period 2 (2009-2012)

3. (9-6-2009) S-W (4/7)
4. (26-7-2010) S-W (3/7)
5. (30-4-2011) S-W (1/7)
6. (21-6-2011) S-W (3/7)
7. (7-5-2012) S-W (2/7)

Figure 69 Beach southwest of Hambantota period 2 (2009 – 2012)
Appendix I: Breakwater design drawings

Various drawings are obtained by Royal HaskoningDHV and this appendix will elaborate on the design.

Top view

Figure 70 Design drawing Hambantota Fishery Harbour
Breakwater cross-sections

Section H1

Figure 71 Design drawing breakwater section H1

H1: slopes 1:2(harbour) – 1:2(sea)

<table>
<thead>
<tr>
<th>Layer thickness (harbour)</th>
<th>Layer thickness (sea)</th>
<th>level top [to MSL]</th>
<th>name</th>
<th>stone size [kg]</th>
</tr>
</thead>
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<td>-</td>
<td>-</td>
<td>??</td>
<td>sea bed</td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>+0.5</td>
<td>core material</td>
<td>2 – 100 kg</td>
</tr>
<tr>
<td>1.2</td>
<td>1.8</td>
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<td>2.6</td>
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<td>4300-8400 kg</td>
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</table>

Section H2

Figure 72 Design drawing breakwater section H2

H2: 2:3(harbour) – 1:2(sea)

<table>
<thead>
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<th>Layer thickness (harbour)</th>
<th>Layer thickness (sea)</th>
<th>level top [to MSL]</th>
<th>name</th>
<th>stone size [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>-</td>
<td>??</td>
<td>sea bed</td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>+0.5</td>
<td>core material</td>
<td>2 – 100 kg</td>
</tr>
<tr>
<td>1.2</td>
<td>1.8</td>
<td>+ 1.7</td>
<td>Filter M600</td>
<td>400-900 kg</td>
</tr>
<tr>
<td>2.3</td>
<td>2.3</td>
<td>+4.0</td>
<td>2 Layers M4000</td>
<td>2800-5600 kg</td>
</tr>
</tbody>
</table>
**Section H3**

Figure 73 Design drawing section H3

H3: 2:3(harbour) – 1:2(sea)

<table>
<thead>
<tr>
<th>Layer thickness (harbour)</th>
<th>Layer thickness (sea)</th>
<th>level top [to MSL]</th>
<th>name</th>
<th>stone size [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>-</td>
<td>??</td>
<td>sea bed</td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>+1.3</td>
<td>core material</td>
<td>2 – 100 kg</td>
</tr>
<tr>
<td>1.2</td>
<td>1.2</td>
<td>+ 2.5</td>
<td>Filter M600</td>
<td>400-900 kg</td>
</tr>
<tr>
<td>2.0</td>
<td>2.0</td>
<td>+4.5</td>
<td>2 Layers M2500</td>
<td>1600-3800 kg</td>
</tr>
</tbody>
</table>

**Section H4**

Figure 74 Design drawing section H4

H4: 2:3(harbour) – 1:2(sea)

<table>
<thead>
<tr>
<th>Layer thickness (harbour)</th>
<th>Layer thickness (sea)</th>
<th>level top [to MSL]</th>
<th>name</th>
<th>stone size [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>sea bed</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>core material</td>
<td>2 – 100 kg</td>
</tr>
</tbody>
</table>
**Section H5**

Figure 75 Design drawing section H5

H5: 2:3(harbour) – 1:2(sea)

<table>
<thead>
<tr>
<th>Layer thickness (harbour)</th>
<th>Layer thickness (sea)</th>
<th>level top [to MSL]</th>
<th>name</th>
<th>stone size [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>sea bed</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>core material</td>
<td>2 – 100 kg</td>
</tr>
</tbody>
</table>
## Appendix J: Actors and core values

<table>
<thead>
<tr>
<th>Actor</th>
<th>Vision</th>
<th>Mission</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ministry of Fisheries and Aquatic Resources Development</td>
<td>Sri Lanka to be the leader of conservation and sustainable utilization of Fisheries and Aquatic Resources in the South Asian Region.</td>
<td>Managing the utilization of Fisheries and Aquatic Resources for the benefit of the present and future generation</td>
<td>(Ministry of Fisheries and Aquatic Resources, 2014)</td>
</tr>
<tr>
<td>Department of Fisheries &amp; Aquatic Resources (DFAR)</td>
<td>To provide an optimum contribution to the national economy through strengthening the socio-economic status of the fisher communities while maintaining the fisheries and aquatic resources in a sustainable manner.</td>
<td>Management of fisheries and aquatic resources by adopting new technologies in compliance with the national and international laws and treaties for the productive contribution to the Sri Lankan economy through sustainable development of fishing industry.</td>
<td>(Department of Fisheries and Aquatic Resources, 2012c)</td>
</tr>
<tr>
<td>Ceylon Fishery Harbour Cooperation</td>
<td>To be the fundamental resource of the fisheries Industry and the inspiration of the local fishing community whilst striving to become the top facilitator of the regions maritime enterprise.</td>
<td>To deliver superior quality fishery harbour related services together with supporting infrastructure to provide all modern facilities to the fishing community, and achieve self sustainability by upgrading the harbours through commercially viable ventures.</td>
<td>(Ceylon Fishery Harbours Corporation, n.d.)</td>
</tr>
</tbody>
</table>

*Table 54 Actors and core values*
Appendix K: MCA Permutation method

Every possible arrangement of alternatives will be tested on the degree of accordance with the effectiveness scores and weights of the different criteria. Through simultaneous application of preference scores and ordinal solutions based on a series of permutations, the preferred ranking of alternatives can be deduced.

The data material must be in compliance with the following conditions to be able to use the permutation method:

- Every alternative can be valued towards a defined set of criteria;
- The effectiveness of the alternatives with regard these criteria can be measured on an ordinal scale;
- The importance of each criterion in the decision-making process must be translated into weight factors.

For the MCA three alternatives will be used and hence there will be six possibilities to arrange the alternatives:

R1: A1 > A2 > A3
R2: A1 > A3 > A2
R3: A2 > A1 > A3
R4: A2 > A3 > A1
R5: A3 > A1 > A2
R6: A3 > A2 > A1

All possible orders will be tested with the help of an effect matrix. Every orders receives a valuation based on the comparison of partial orders and the data in the matrix. When the partial order is in accordance with the ordinal score order in the matrix, the valuation is +1. When this is not the case the partial order receives -1. The valuation of the total order is the sum of the valuations of the partial orders. The resulting valuations will be multiplied with the weight factors to see which order of alternatives is preferred.
Appendix L: Criteria MCA

Construction cost

- required length of additional breakwater;
- stones sizes needed;
- wave conditions at worksite;
- required equipment;
- demolition of undesired constructions;
- recycling of building materials;
- required dredging volume.

Maintenance cost

- amount of dredging material per period;
- interval between required dredging periods;
- wave conditions at dredging site (workability);
- required equipment;
- damage due to storm events.

Construction time

- required length of additional breakwater;
- required length of undesired breakwater;
- land based or water based operations;
- wave conditions at worksite;
- opening of double work fronts.

Sedimentation of the harbour basin

- expected dredging volume;
- expected dredging interval between dredging operations;
- disturbance of harbour operations.

Sedimentation of the approach channel

- expected dredging volume;
- expected dredging interval between dredging operations;
- disturbance of harbour operations.

Wave intrusion

- Ship motion due to incoming waves;
- Erosion of slipway inside of the harbour.

Alignment of the approach channel

- alignment of approach channel in relation with direction of incoming waves.
Wave conditions near entrance

- wave conditions near the harbour entrance.

Capacity

- anchor space inside harbour;
- meters slipway.

Durability

- expected lifetime of the solution.

Stakeholder nuisance

- construction conflicts with harbour operations;
- maintenance conflicts with harbour operations;
- land- or water based operations.
Appendix M: Stakeholder meeting Hambantota Fisheries Harbour

Fishermen’s response to information request of Royal HaskoningDHV

Date: 26th of August 2014
Place: Head office Hambantota Fishery Harbour

Participants:
- Mark Klein: Royal HaskoningDHV
- Bart-Jan van der Spek: Royal HaskoningDHV
- Four employees: Engineering Consultants Limited
- Harbour Manager of Hambantota Fishermen
- Siemen Everts: TU Delft
- Eric Julianus: TU Delft
- Mark Marijnissen: TU Delft
- Bas Voorend: TU Delft

Problem definition
The fishermen came with two main problems:

1. Siltation within the harbour basin and near the entrance (Figure 80 and Figure 81);
2. The conditions near the entrance are dangerous due to breaking waves.

Area analysis
Beaches eastwards of the harbour (Figure 78):

- Erosion at the beaches towards the Peacock Beach Hotel. In cross shore direction is 50 meter eroded since the construction of the harbour (2006) and steep slopes. Bedrock exposed during South-West monsoon.

Beaches southwards of the harbour (Figure 78):

- Not much changed, was already a rocky coastline;
- No influence by the commercial harbour noticed;
- Beaches between the commercial harbour and Hambantota are not eroded or accreted since the construction of the commercial harbour.

Harbour basin (Figure 79):

- The north-east part of the beach within the harbour is exposed to incoming swell waves and erosion occurs. The beach is partly protected by left-overs from the stone storage during the construction stage. 5-6 people wide erosion, (9,6 m seems a big number);
- Near quay erosion occurs;
- Main dredging location is in the corner between quay and breakwater;
- Current dredger does ‘half a job’;
- Expected cycle time is one month according to the fishermen.
Various information

Siltation
- Siltation problems occurred within one year after construction of the breakwaters;
- During May – September most problems occur because of a difference in direction between swell waves and wind (sea waves). During this period the siltation within the harbour grows;
- Causes reduced depth within the harbour and breaking waves near the entrance;
- Sand origin: northern beaches, northern part within the harbour;
- After N-E monsoon beaches just north of northern breakwater are wider;
- Is sediment going through the breakwater? (big rocks -> big pores);
- Fishermen do not expect the siltation to be connected to the siltation within the harbour.

Dredging period
- 2011 February – 2011 October (3500 m³);
- 2012 August – 2013 May;

Nautical conditions
- Current is Northern directed during the entire year;
- During September – January the sea is calm ;
- During January – April waves and wind have same direction.
Fishermen’s solution
The fishermen prefer solutions that contain at least:

- No continuous dredging, since it is very expensive;
- Preferred solution is a breakwater modification.

**Option 1:**
- Construction of an additional breakwater;
- Block sand transport completely;
- Port entrance sheltered for incoming waves.

**Option 2:**
- Construction of a T-breakwater;
- Prevention of incoming sediment for the Northern direction;
- Better sheltered against incoming swell waves.

**Quick assessment RHDHV:**
- Dredging will always be part of the solution, both with construction and with periodic maintenance.
Erosion and sedimentation

The shaded areas just give a rough indication and doesn’t give a precise outline of the eroded or accreted areas.

Figure 78: Erosion and sedimentation in Hambantota bay according to the fishermen

Figure 79: Erosion and sedimentation in harbour according to the fishermen
Figure 80 Site visit shoal near entrance

Figure 81 Site visit shoal near entrance