Puerto San Vicente, Chile

Evaluation of a Port Expansion

Group 297

Technische Universiteit Delft

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PUERTO SAN VICENTE, CHILE

EVALUATION OF A PORT EXPANSION

by

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An analysis of the Port of San Vicente and a proposed port expansion design through land reclamation.

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PREFACE

This report presents a study on the expansion of San Vicente port in Concepción, Chile. The study is conducted by six students from Delft University of Technology (DUT) with the following backgrounds; *Civil Engineering*, *Mechanical Engineering* and *System Engineering and Policy Analysis*. The members of the group are currently MSc students with the specialisations *Hydraulic Engineering* and *Transport Engineering*. The study is performed as a part of their masters program under the name of a Multidisciplinary Project, Civil Engineering Consultancy Project.

A collaboration between Universidad Católica de la Santísima Concepción (UCSC) and DUT made this project possible. Puertos De Talcahuano and San Vicente Terminal Internacional (SVTI), which are the port authority and port operator, are regarded as the clients for this project.

We would like to thank Mauricio Villagrán, Rafael Aránguiz, Jan van Overeem and Adam Pel who were our supervisors from UCSC and DUT. They supported us throughout the project and gave us advice when necessary. Special thanks to Omar Salgado Oportus, Rodrigo Vidal González, Claudio Fernándes Alarcón and Pablo García Astete for providing us with a lot of (technical) information about the San Vicente port. Thanks to Valentina Valdivia who provided us with data from earthquake simulations and thanks to Matías Felipe Gómez who helped us a lot with Delft3D modelling. Finally, we would like to thank our sponsor Movares for their financial support!

Victor, Tim, Hilco, Hugo, Niels and Alex
Concepción, October 2019

Executive Summary

This summary is written with the purpose to give a concise overview of this report. For a full explanation on the matter one is referred to the corresponding Chapters and/or Appendices.

The port of San Vicente is located in the Biobío region in Chile, also called the VIII region. The zone of influence however comprises regions VII, VIII and IX. The main industry that drives the port is timber products, agriculture and fishing. The port of San Vicente is characterised as an export port. The port experiences competition from the ports of Lirquén and Coronel. The market share has shown a decrease for the past decennial. The ambition of the port is to turn this trend around and regain market share.

The port of San Vicente comprises a total surface of 33 hectares. The storage yard covers about 20.7 hectares of which approximately 8 hectares is located external. The port of San Vicente is a state port and it is therefore obligated to handle all kinds of cargo. Accordingly, in the port of San Vicente there is room reserved to handle containers, bulk and break bulk. Within the port the container yard comprises the largest area. The port categorises three types of containers: empties, import and export. The port operations can be subdivided into several sub-processes. Namely vessel operations at the quay, internal transport, the stacking system and the continental transport. The port currently has a throughput of a bit less than half a million TEU per year. The port has a TEU factor of 1.86. Therefore the amount of handled containers equals approximately 260.000. The containers arrive in the port on a vessel, the port of San Vicente can accommodate for various ship sizes. After the vessel has moored at the depicted berth, the unloading process of the vessel starts. The port of San Vicente has recently purchased two new Ship-to-Shore gantry cranes. These cranes, occasionally assisted by mobile harbour cranes, are used to unload the containers from the vessel and load them onto trucks that are waiting on the quay. The internal transport in the port is done by trucks. When the container is loaded onto the truck, the truck drives to the right location in the port. Once the truck arrives at the right location within the port, the container is transferred to the port stacking system. A reach stacker lifts the container from the truck and stacks it in the storage yard. The container remains in the storage yard until it is requested again. When a container is requested, a reach stacker lifts the container from the storage yard and onto a truck. The truck transports the container to the next location. From the imported containers 85% is empty. Therefore a large part of the containers is transported from the storage yard to the consolidation centers. In the consolidation centers the empty containers are filled with bulk for export.

Various issues can be identified concerning the operations inside the port of San Vicente. The port of San Vicente aims to reach 100 container movements per hour per ship. In theory this is possible since they posses two gantry cranes. Yet in practise 100 moves are not reached. The crane operators are still rather inexperienced because the cranes are relatively new. The gantry cranes do therefore not operate at full handling capacity, limiting the efficiency of the port operations. The internal transport is limited by the current layout. Most containers are not stacked directly behind the cranes. The stacking area in the port of San Vicente is organised quite well. Containers are separated based on various criteria such as weight, length, function and destination to make stacking operations more efficient. However, the port of San Vicente has some difficulties to accommodate for the container throughput, especially during peak moments. The port is forced to rent external locations in order to stack containers.

The port of San Vicente is located at the west coast of South-America which can be classified as a leading-edge coast. This kind of coast is characterised by rugged and cliffed coastlines. The water depth inside the port is around 16.5 meters. Currently vessels ranging from 100 to 350 meters in length and a draught up to 15 meters enter the port. A leading-edge coast is tectonically unstable, meaning that earthquakes occur on a regular basis. It is worth mentioning that in 2010 a catastrophic earthquake and tsunami damaged the port significantly. In 2019, repair works are still underway. The tidal motion inside the port of San Vicente is a semi-diurnal tide, meaning that there are two nearly equal high and low tides every day. The maximum difference between high astronomical tide (HAT) and low astronomical tide (LAT) is 1.78m. The currents inside the bay were measured and found to be very small, in the order of a few cm/s.

The port of San Vicente expects a significant rise in container throughput for the coming years. A demand forecast for the Biobío region was used to predict the required container storage yard area for the future. This calculation shows that with the current market share the container yard area will reach is maximum capacity by the year of 2025. If the port regains market share it will reach its capacity even earlier. Thus therefore an urgent need to expand. Future problems include:

1. Quay: In the future multiple vessels need to be served at the same time. The port only has 2 gantry cranes. It is therefore not possible to achieve 100 container moves per hour per ship.
2. Internal transport: The layout of the port is inefficient. This problem will become more evident once the container throughput starts to grow.
3. Stacking system: The storage yard becomes rather unorganised. When container throughput will start to grow less time between calls is expected leading to less time to organise the storage yard. Moreover, it is expected that the stacking equipment will not be able to keep up with the predicted increase in throughput.
4. Continental transport: The capacity of the port gates is expected to be too low with respect to the predicted container throughput.

A land reclamation is needed. It will be beneficial for the supply side as well as for the demand side. A land reclamation will result in a higher storage capacity and it will result in a higher handling efficiency. As a result the port will be prepared for the increasing throughput and become more attractive for shipping lines. If the port has more clients, the market share increases as well. This will automatically lead to the port's main goal which is financial growth.

As was stated in the previous paragraph a land reclamation is required as the port will not be able to accommodate the expected increase in container throughput. The following set of criteria has been selected to test different alternatives:

1. Storage capacity
2. Handling capacity
3. Costs
4. Flexibility
5. Hindrance to port operations (landside)

The storage capacity is a very important criterion for the port, as it is strongly correlated with the throughput that the port can handle. By increasing its capacity, it will immediately impact the increase of shareholder value and thus the financial growth. The handling capacity is another very important criterion for the port, as it affects the efficiency of the port. With an increased handling capacity it also impacts the increase of stakeholder value and thus the financial growth of the port. The cost criterion is related to three aspects; the CapEx, initial CapEx and the OpEx. These aspects all coincide in the criterion costs. The flexibility is an important factor when considering the port expansion since it is beneficial for the port to maintain its freedom in flexibility. With respect to hindrance to port operations it is desirable to keep the hindrance as low as possible. In most cases hindrance will be inevitable, minimisation of the hindrance should then be prioritised.

The amount of land reclamation is strongly related to the demand forecast. To avoid many uncertainties the future brings, 2025 is picked as a reference year. With the reference year and an expected market share of 45%, the minimal surface of land is estimated at roughly 23 hectares. With the port having a current area of 20.7 hectares, this it would mean that a total of 2.3 hectares still remains to be reclaimed. However, given the uncertainties a high safety margin is advised. Moreover, there will be high startup costs when performing the reclamation. For this reason it is not attractive to reclaim small areas of land. Therefore a total of 4 hectares is suggested for reclamation. Apart from knowing the amount of surface for the land reclamation, the engineering challenges for this project are analysed. The main (engineering) challenges that need to be taken into account for an alternative are listed below:

1. Amount and type of sand for land reclamation
2. Amount and type of revetment at reclaimed land
3. Length of connection at the jetty construction

The proposed alternatives for land reclamation are listed below. Figure 2 shows the 8 options for land reclamation. The alternatives can be categorised in 4 different groups:

1. 0 Hectare land reclamation - Alternative A
2. 4 Hectare land reclamation - Alternative B to D
3. 6 Hectare land reclamation - Alternative E to G
4. 13 Hectare land reclamation - Alternative H

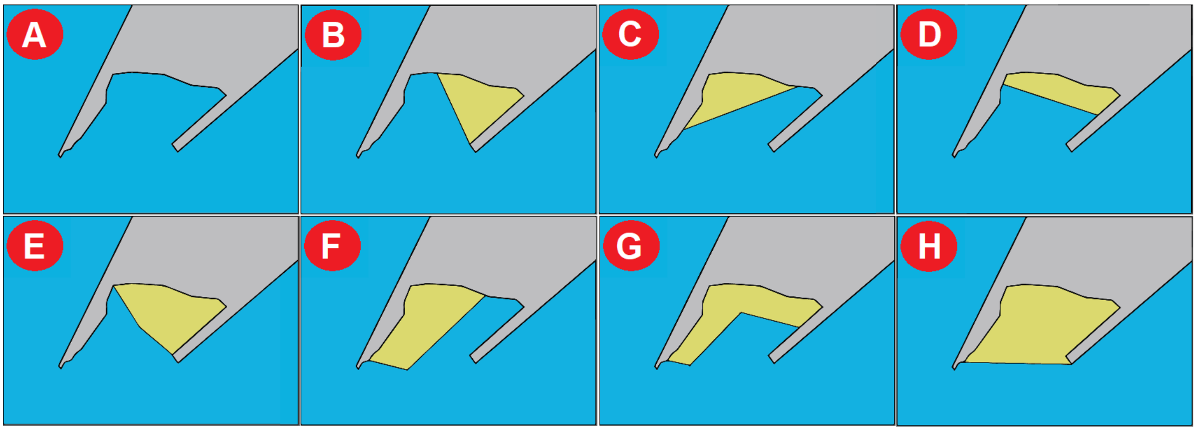

Figure 2: Overview of all proposed alternatives

A Multi Criteria Analysis (MCA) was conducted on the proposed alternatives. The MCA is depicted in Table 1 below.

Criteria	**Weight Factor**	**Alternatives**							
			4 Hectare			**7 Hectare**			
	WF [%]	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Storage Capacity	30	1	4	4	4	5	5	5	7
Handling Capacity	30	1	7	1	4	7	2	4	7
Flexibility	20	7	5	6	6	3	3	4	1
Costs	13.3	7	4	6	4	3	5	2	1
Hindrance to Port Operations	6.7	7	2	6	4	2	6	4	1
Scores MCA	-	3.4	**4.97**	3.9	4.4	**4.73**	3.77	4.6	4.6

Table 1: Scores of the alternatives for each criterion

The MCA shows that alternative B is the best option for land reclamation. A few small modifications were made to the selected alternative. A land reclamation at the tip of the jetty should be avoided in order to avoid hindrance in the manoeuvring area of the seaside operations. Small movement at the connection to the jetty construction should be allowed in order to facilitate movement of the jetty during the mooring of a vessel. With the modifications taken into consideration the modified alternative B looks as depicted in Figure 3:

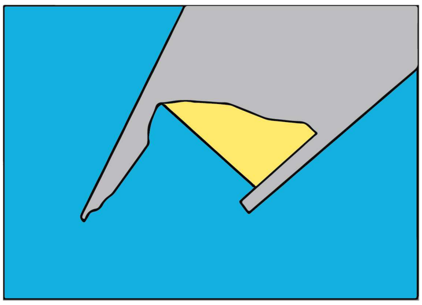

Figure 3: Alternative B with some adaptations made in accordance with the client

It was decided to design a riprap revetment with natural rock armour. It was calculated that a d_{n50} of $0.21m$ would be big enough to withstand the incoming waves. The old revetment consisted of riprap with a d_{n50} of $1.00m$. Since large part of the old revetment would be removed it was decided to reuse the rocks for the new revetment. The armour layer therefore consists of a double layer of rock with a d_{n50} of $1.00m$. The under layer consists of a double layer of rock with a d_{n50} of $0.50m$. Between the under layer and the core a non-woven geotextile is applied. A cross section of the revetment is given in Figure 4.

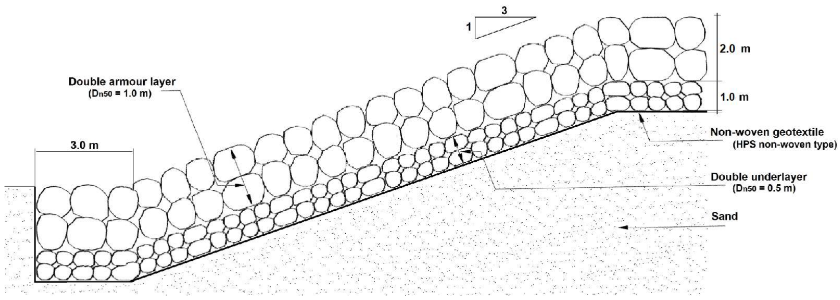

Figure 4: Overview of the designed revetment at the land reclamation

The jetty connection is designed with the purpose to connect the reclaimed land to the jetty. Two main elements are important for the jetty connection; a retaining structure or method to prevent the sediment from flowing into the berth and a connection piece to link the land reclamation to the existing port infrastructure. The design is assessed for the following design criteria: vertical stability, horizontal stability and rotational stability. Using MatrixFrame structural analysis software, the designed components are evaluated for internal forces and deflections. Various solution strategies were found for retaining the sediment: a caisson wall, a cantilever wall, an underwater mound and a jetty connection. An evaluation of the alternatives is conducted based on the following criteria: cost, hydrodynamics, availability of material and construction convenience. A comparison between the options has proven that a cantilever wall would be the best solution for retaining the sediment as it uses the weight of the landfill to increase resistance against the lateral pressure from the landfill. Figure 5 below shows a cross-section of the jetty connection.

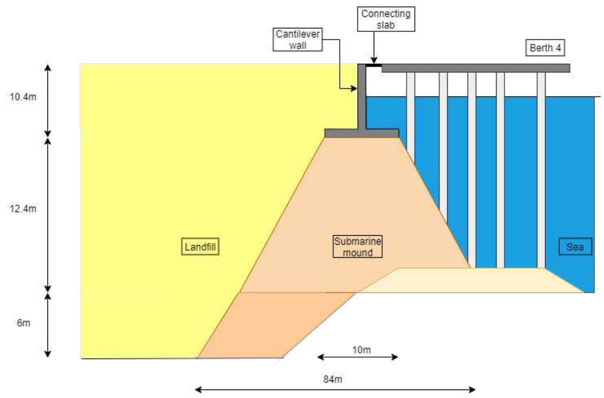

Figure 5: Overview of the designed connecting structure at the jetty

Stability checks were executed on the cantilever wall. The results from the stability checks are depicted in Table 2 below. The section 'required' indicates the required strength and the section 'resistance' indicates the strength of the cantilever wall.

Stability check	**Required**	**Resistance**
Vertical stability	$14kPa$	$54kPa$
Horizontal stability	$633kN$	$671kN$
Rotational stability	$0.38m$	$1.66m$

Table 2: Stability checks

The connection slab is designed to carry the loads imposed by heavy vehicles that are used in port operations. A proposed cantilever wall design is shown in Figure 6.

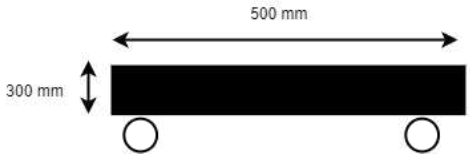

Figure 6: Proposed cantilever wall design

The maximum allowable deflections were compared with the deflections under loading. Table 3 below depicts the results.

Stability check	Maximum allowable deflection [m]	Deflection under loading [m]
Connecting slab	0.002	0.0002
Cantilever wall	0.0376	0.0228

Table 3: Deflections in jetty connection

The new port layout is designed for the situation in 2025. The import containers and a surplus of the empty containers remain to be stored in the external area. The design is made with the aim to improve port operations and make them more efficient. The container yard is therefore located directly behind the cranes and the traffic lanes are straight. Moreover, there are quite some paths between the containers inside the storage yard. This will improve container separation and container accessibility, increasing the efficiency of the operations. The newly proposed design is depicted in Figure 7.

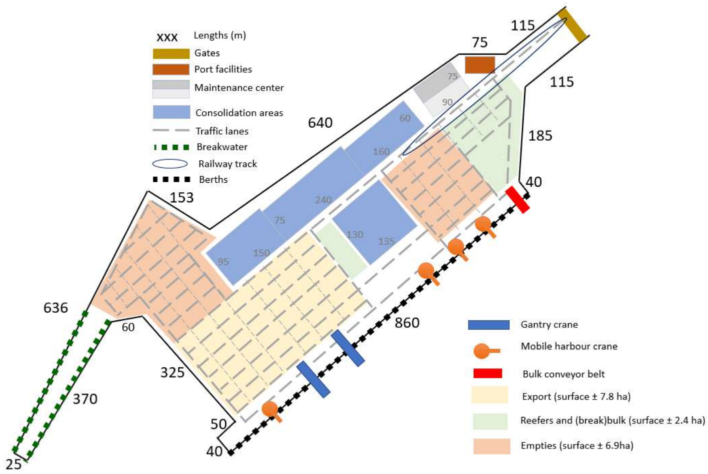

Figure 7: Final design of the new port layout

The operations in the San Vicente port after the land reclamation will be very similar to the current operations. The only difference in the port operations with the land reclamation and without, is the container handling between the cranes and the storage area. With the land reclamation the containers are stored directly behind the cranes along the entire length of the quay. This improves the handling of containers as the shape is more efficient. The optimisation of the port operations will be mentioned separately for each sub process. Quay: During the event that multiple vessels require service, the mobile harbour cranes and two gantry cranes are not efficient enough to reach the desired handling capacity. Therefore additional gantry cranes should be purchased to optimise port operations in the future. Internal transport should also be upgraded in order to deal with the event of multiple vessels mooring at once in combination with the establishment of extra gantry cranes. This could be done by investing in a multi trailer system or automated guided vehicles. As a result the internal transport would be optimised making the port more future proof. An optimal stacking system is achieved using stacking equipment such as straddle carriers, rubber tired/rail mounted gantry cranes or overhead traveling cranes. Such stacking equipment speeds up the stacking activities, making the stacking system more efficient. In order to minimise the queues, the gate operations should be optimised. Continental transport operations in the San Vicente port could become more efficient if the truck appointment system is improved. In the optimal situation the cargo flows are smoothed over the entire day, lowering the pressure on the port gates.

The hydrodynamics inside the port should not be influenced by the land reclamation in such a way that the manoeuvring and mooring conditions for vessels will not be negatively affected. This is set as a strict requirement for the land reclamation. Only then the downtime of the port will not be affected in a negative way. The two main aspects that determine manoeuvring and mooring conditions inside the port are the wave climate and the currents. As was mentioned before the currents are negligible inside the port. In order to investigate the wave climate after land reclamation the software Delft3D-Flow is used. The outcome for the wave heights shows that there is hardly any difference when the land reclamation was included in the model compared to the model without the land reclamation. The largest difference has a value of $9.5mm$.

As the hydrodynamics are simulated for a relatively normal state, it is interesting to analyse if the reclaimed land will be heavily damaged in case of a tsunami. With the results of the earthquake simulations, an analysis is made on what kind of tsunami will be generated that could damage the port. From the analysis it is concluded that the risk that the port floods from an earthquake with the magnitude of 9.0 is very low, with a return period of roughly 800 years.

The purpose of the reclaimed land and the new port layout is to make port operations more efficient and to be able to accommodate for the predicted container throughput. Table 4 below provides an overview of the expected problems in the future that may or may not be prevented by reclaiming the land.

Expected problems in the future, no land reclamation	**Prevented by reclaiming land?**
Crane capacity	NO
Inefficient shape of the port	YES
Road capacity inside the port	YES
Organising containers	YES
Storage space inside the port	YES
Stacking equipment	NO
Gate capacity	NO

Table 4: Overview of problems and effect of land reclamation

The land reclamation will be a success as it solves issues the port is currently facing or will face in the future. The land reclamation can prevent most of the expected problems. Yet not all expected problems can be prevented by reclaiming land. This implies that the cranes, the stacking equipment and the gates will cause issues in the future, even though the ports area has been expanded.

Once the land has been expanded, the port wants to prepare itself in order to accommodate for future expansion. In that way it will be able to deal with the expected demand. This will be examined according to the following questions: What is the amount of extra truck movements? In what way will these movements be divided across the different roads? Do the extra truck movements have a significant influence on the traffic flows? For 2025 it is expected that a total of 450 trucks will move into the port every day. These are 150 trucks more compared with the current situation. In order to obtain the amount of vehicles per hour the amount of trucks is multiplied by a factor of 2.5. The result, 375 vehicles, is the extra amount of vehicles that will move into the port each day. The extra traffic flow is therefore equal to 375 vehicles per day. If the same calculation is performed for 2045 (in case of a 50% market share) this would give an extra traffic flow of 1250 vehicles per day. The situation for the connecting routes is different than the situation for route 160. The traffic flows on these roads are not critical. Almost all extra traffic merges on these roads which have a relatively low capacity. The expectation is that the access roads should be able to accommodate the extra 375 expected vehicles for 2025. The situation for 2045 is different. It heavily depends on the ability of the port authority to spread the incoming traffic across the day.

The port has a lot of stakeholders. The first group of stakeholders is identified as a group that has the same interest as the port authority. It is therefore expected that they will not stand in the way of a possible land expansion. The first group of stakeholders comprises the port operator SVTI, Arauco Mill and the shipping lines. Another stakeholder, CRUBC, is responsible for managing initiatives along the Chilean shoreline. This will be an important stakeholder to manage closely. The second group of stakeholders consists of stakeholders that are regarded as opponents to the port expansion. The SAE Chile (environmental organisation) is one of the most important stakeholders that is regarded as an opponent. The second stakeholder that is regarded as an opponent is the municipality and community of Talcahuano.

The expansion of San Vicente port will be a drawback for the competitive ports Lirquén and Coronel. The layout of San Vicente port already is more efficient than the other ports. With the expansion, the storage yard can be located directly behind the STS gantry cranes, increasing the difference in container handling efficiency with the other ports.

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List of Abbreviations

AGV	Automated Guided Vehicles
CDF	Cumulative Distribution Function
CRUBC	Comisión Regional de Uso del Borde Costero *English: Regional Coastal Edge Use Commission*
DUT	Delft University of Technology
FEU	Forty Feet Equivalent Unit
GDP	Gross Domestic Product
HPS	High Performance Square
KPI	Key Performance Indicator
MAPA	Modernizacion y Ampliacion Planta Arauco *English: Modernization and Extension of Arauco Mill*
MDP	Multidisciplinary Project
MHC	Mobile Harbour Cranes
MSC	Mediterranean Shipping Company
MSL	Mean Sea Level
MTS	Multi Trailer System
NEOWAVE	Non-hydrostatic Evolution of Ocean Waves
PTHA	Probabilistic Tsunami Hazard Assessment
RMG	Rail Mounted Gantry Cranes
RS	Reach Stackers
RTG	Rubber Tired Gantry Cranes
SAE	Sistema de Alerta de Emergencia *(English: Emergency Alert System)*
SPT	Standard Penetration Test
STS	Ship-to-Shore
SVTI	San Vicente Terminal Internacional
TEU	Twenty foot Equivalent Unit
UCSC	Universidad Católica de la Santísma Concepción *English: Catholic University of Santísma Concepción*

1
Introduction

This Chapter contains a short introduction on the San Vicente port and its geographical location. Next, a brief description of the problem analysis is given. Subsequently the objectives of the report are described and a readers guide is provided.

1.1. Geographical location

The port of San Vicente is located in the VIII (eighth) region in the middle of Chile, often referred to as the Biobío region. The country of Chile is divided into twelve regions, region I (one) being in the far north moving down to region XII (twelve) in the absolute south. The port is located 520 km south of Santiago de Chile and 18 km from Concepción. Concepción is the capital of the Biobío region which is the second largest region in Chile in terms of population (San Vicente Terminal Internacional, 1999). Figure 1.1 shows the Biobío region with respect to the rest of Chile and the port of San Vicente with respect to the Biobío region.

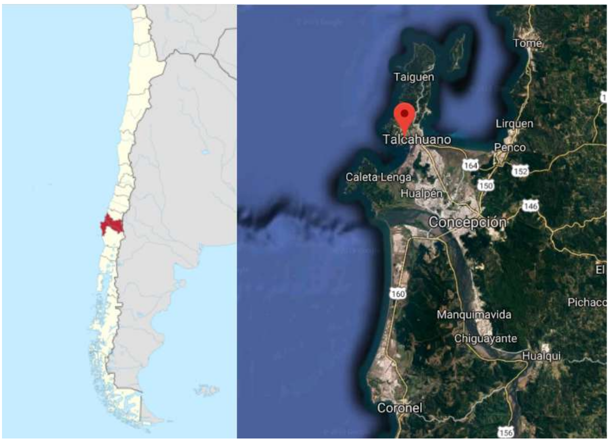


Figure 1.1: Location of the San Vicente Port in the Biobío region (Google Maps), scale xx

1.2. Problem description

San Vicente port is not the only port present in the Biobío region. For example north of Concepcíon, in the Concepcíon Bay, the port of Lirquén is situated and in the south the port of Coronel (Figure 1.1). These two ports are the biggest competitors of the San Vicente port in the region. Currently the port of San Vicente is ranked in the top 20 largest ports on the west coast of South America (WorldAtlas, 2018). In the past the San Vicente port was ranked higher than the other two ports, but in the last decade this changed. In order to regain their competitive position the port of San Vicente has the intention to address some of the problems it faces right now.

The port authority together with San Vicente Terminal Internacional (SVTI) are expecting future growth due to increased inland economic activities. Most importantly the MAPA project being carried out near Arauco in the south. It is expected that these developments and national trends will make additional container handling space desirable. In recent years, a large contract with Mediterranean Shipping Company (MSC) was lost because of lack in container handling speed. Since then, SVTI invested in two Ship-To-Shore (STS) cranes that were installed in May 2019.

In order to compete with the other ports in the Biobío region, the port needs to increase efficiency and therefore SVTI has set a Key Performance Indicator (KPI) for itself, consisting of handling 100 container movements per hour per ship (compared to 60 moves per hour it currently handles, (Empresa Portuaria Talcahuano San Vicente, 2017)). In order to be able to reach this target the port authority is looking for options to increase capacity inside the port, along with improving the port operations. They concluded that it is necessary to expand the port. As the port is surrounded by hills and houses, expanding landwards is not possible. This means that the port is forced to expand towards the sea by reclaiming land.

1.3. Objective and research question

As mentioned before, the port of San Vicente aims to improve their competitive position. A possible solution that the port has in mind in order to achieve this objective is by reclaiming land. In this report several options for land reclamation will be proposed and one of the options will be investigated in more detail. The reclaimed land will be used to suggest a new port layout in order to improve operations. This new layout will be based on evaluations of the current operations.

The objective of this project is to investigate the proposed land reclamation and elaborate on the improved port operations which can be established after the expansion. Along with the research objective the following research question is identified:

What is an optimal design for land reclamation to enhance port operations in order to facilitate future growth?

1.4. Theoretical framework

Figure 1.2 visualises the theoretical framework which explains the essence of the project. It must be read from left to right as it starts with analysis of the current situation of the port and ends with evaluating the proposed final design for the port expansion. The framework indicates what is inside the project scope, namely a seaside and landside design for the port expansion and effects of the expansion. Furthermore it indicates in which way the research will be conducted in order to find an answer to the research question.

The research exists of two phases. The first phase in this research is to examine what the expansion should look like. The preliminary designs represents this first phase. There are two important questions belonging to this phase:

- *What is the surface of land that should be reclaimed?*
- *What is the best location to reclaim the land?*

Once the first phase is finished, the second phase will consists of designing the chosen expansion. This has two important elements:

- *Designing the reclamation*
- *Designing the new port layout*

Naturally, the expansion should contribute to the main goal of San Vicente port and therefore generate more capacity at the supply side and higher efficiency at the demand side (Chapter 3). This will prepare the port for the higher throughput of containers in the future and make the port more attractive to costumers. These two things together will result in financial growth for the port of San Vicente.
The port expansion will have other effects that need to be evaluated. From the landside perspective it is interesting to examine what the effect of an expansion will be on the problems in the port operations, on the traffic in the hinterland of the port and how stakeholders will react to an expansion.
Furthermore, the expansion will have some seaside effects. It could have influence on wave conditions inside the port area, resulting in undesirable mooring and manoeuvring conditions for incoming vessels which will increase the downtime of the port. Since the port is situated in a seismic active area the effects of a tsunami event should also be investigated.

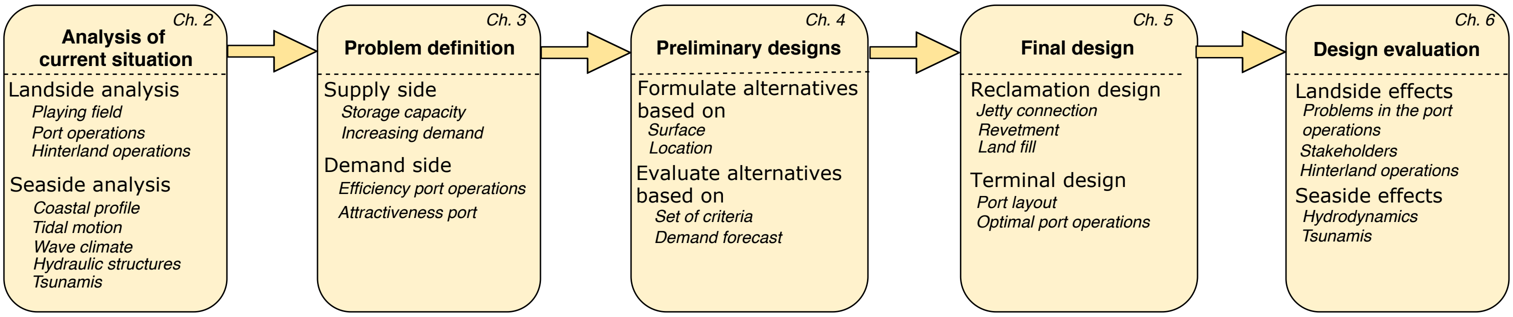


Figure 1.2: Theoretical framework of research

1.5. Readers guide

Chapter 2 describes the current situation of the port from a landside and a seaside perspective. From a landside perspective the playing field of San Vicente is laid out, the port operations are described and information about the hinterland operations is given. From a seaside perspective the coastal profile, the tidal motion, the wave climate, the infrastructure of the port, the subsoil and the possible influence of tsunamis is described.

In Chapter 3 the reason for the port expansion is elaborated in detail. This chapter fulfils as a more extensive problem description.

Chapter 4 is the first step in developing the expansion itself. Multiple preliminary designs for a possible expansion are elaborated. After a meeting with the port authority and SVTI (the port operating company) a choice is made for the preferred expansion.

Subsequently a design is made concerning this expansion in Chapter 5. This design consists of a landfill, revetment and a jetty-connection part.

Chapter 6 consists of the evaluation of the design. The effect on the hydrodynamics inside the port is investigated. Furthermore the effects on the port operations, on the hinterlands operations and on different stakeholders are described.

At the end of the report a conclusion and recommendations can be found.

2
Current Situation

In this chapter more information about the port of San Vicente is given. The current situation of the port is discussed from a landside and a seaside perspective. From a landside perspective the playing field of San Vicente is laid out, the port operations are described and information about the hinterland operations is given. From a seaside perspective the boundary conditions are described such as the coastal profile, the tidal motion, the wave and wind climate, the infrastructure of the port, the subsoil and the possible influence of tsunamis

2.1. Landside

The current situation from a landside perspective includes information about the playing field, the port operations and hinterland operations.

2.1.1. Playing field

As stated in the introduction, San Vicente port is located in the VIII region. However, its zone of influence is comprised of regions VII, VIII and IX. The port's hinterland zone contains a diversified mix of industries. The main industry is timber products (VIII and IV region), agriculture (VII region) and fishing (VIII region) (San Vicente Terminal Internacional, 1999). As San Vicente is mainly an export port, it is widely used by companies in the hinterland to export their products. Section 2.1.3 will elaborate further on the products handled in the port.

The Chilean port system can be characterised by a relatively large amount of medium-sized ports of which ten port authorities run twelve public ports (Merk, 2016). The port of San Vicente is one of these public ports, and all public ports are considered of strategic importance to the economy of Chile. The port of San Vicente is the third largest public port of Chile and, since it was outperformed by the private port of Coronel in 2018, the fourth largest port of Chile (United Nations, 2019). The top 5 Chilean ports (in terms of throughput) make up approximately 40% of the market in Chile, which is low compared to other South American countries (Merk, 2016). This highlights the competitive port environment in Chile.

The Biobío region counts a total of 3 container ports: the port of San Vicente, the port of Coronel and the port of Lirquén (San Vicente Terminal Internacional, 1999). Traditionally the port of San Vicente used to be the biggest port in the Biobío region and in 2006 its market share was almost 70% (Merk, 2016). Since then its market share has been steadily decreasing to approximately 40% in 2017 (Appendix A). Figure 2.1 shows the market shares of the container ports in the Biobío region from 2000 until 2014. The downward trend can be clearly observed from 2006 onwards.

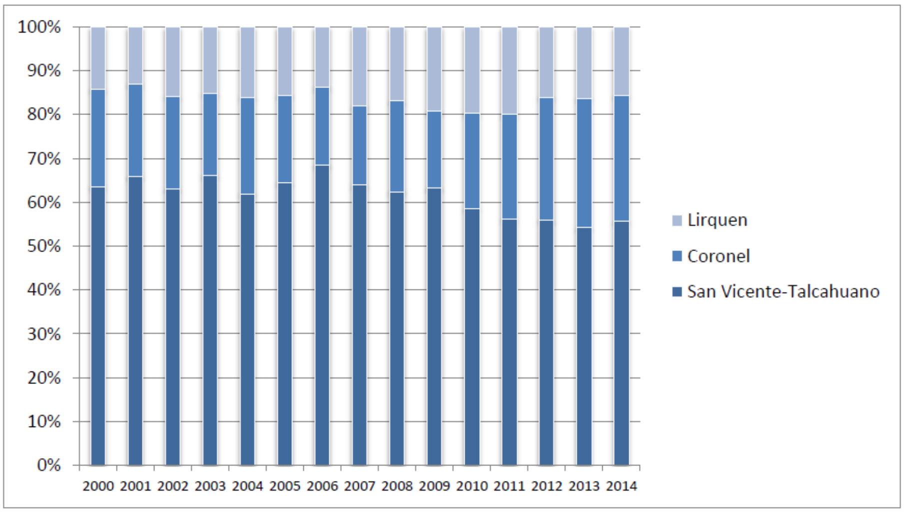


Figure 2.1: Market shares (in tonnes) public and private ports in VIII region, (Merk, 2016)

Port organisation

The port of San Vicente is part of the public port system. It is owned by one of the ten port authorities that own public ports in Chile (Merk, 2016). The port authority in San Vicente is called Puertos De Talcahuano. They also own the port of Talcahuano which is situated very close to San Vicente port.

The fact that the port of San Vicente is a public port means that the port is state-owned. Therefore the port is not an independent commercial organisation and it must apply state rules and regulations. This implies that the port of San Vicente cannot focus solely on handling goods that are most profitable. According to the law state ports must handle container cargo, bulk and break bulk. Therefore the variety of goods in the port of San Vicente is quite large. In state ports the landlord model is used (Merk, 2016). This means that the port authority owns the land and that they are responsible for the regulation and administration in the port. They assign concessions to private operating companies that will operate inside the port. San Vicente Terminal Internacional (SVTI) is the current port operator in San Vicente.

Stakeholders

The port authority is in charge of decisions considering the total area of the port. Consequently, the authority would be the party to initiate developments around the San Vicente port area. To illustrate, they could initiate an expansion of the port or an extra jetty with more room for berths. However, this does not mean that everything the authority initiates will be executed. There are lots of other parties which will be influenced by these kind of decisions and should therefore also be involved in the decision-making process. In order to establish which parties are important to consider an analysis is made which can be found in Appendix B. Those parties that have an interest in changes around the port are the so-called stakeholders. Not all stakeholders have the means to influence decisions. In this section only stakeholders are depicted which could influence the decision process. These are the critical stakeholders of the port of San Vicente.

Firstly, SVTI is determined as a critical stakeholder since they perform all operations inside the port. The port authority benefits from a close relationship with this stakeholder. SVTI has won the concession until 2029, so it is favourable to (at least) maintain a good relationship until that year. In 2029 the port authority could reconsider the cooperation and decide to proceed the cooperation or to opt for another commercial party.

Second critical stakeholder is CRUBC which is responsible for managing initiatives along the shoreline. This stakeholder gives advice to the National Committee and the Navy on whether they should give permission for the execution of projects that concern the shoreline. The advising role that CRUBC has involves managing stakeholders that might be influenced by the project. Stakeholders that normally have no influence on the decision process can make objections at the CRUBC. The CRUBC will analyse all assets, for example economic growth for the region and compare this with the drawbacks. Based on this they will form an objective opinion that they share with the national committee. The advice that CRUBC gives to the Navy is more on a technical basis. This concerns giving away territory in the sea. Based on an hydraulic analysis the CRUBC will advise the Navy about threats that might occur on the seaside (CRUBC, 2019). The National Committee and Navy will follow developments around the port with less interest because they have a nationwide function. Still, because these parties give a final permission about executing projects, they must be kept satisfied at all times.

Most of the developments inside the port area are focused on increasing the amount of operations. Therefore it is likely that the environment is affected. More operations could for instance mean more vessel movements, which will have influence on air pollution in the area. El Sistema de Alerta de Emergencia (SAE) Chile is an independent and decentralised organ that gives environmentally based evaluations on project plans. They test projects on a lot of criteria which are all formulated by ministries and governmental authorities (SAE). So, when planning developments the port authority has to keep in mind these criteria.

With the San Vicente port being situated in Talcahuano, the municipality of Talcahuano will also be involved in most decisions concerning developments around the port. The municipality will have as its main objective to protect their inhabitants. This also means protecting them against negative external effects due to developments around San Vicente port. An example of a negative external effect would be extra truck movements towards the port due to higher throughput or the execution of new projects.

Additionally, the Arauco Mill is an important stakeholder as this is the initiator of the MAPA project. The MAPA project will significantly enlarge the market for the forest industry in the Biobío region (ARAUCO, 2018). Consequently, it is likely that the MAPA project will increase the throughput of the ports in the region. It is therefore important that a positive relationship between the port of San Vicente and this business partner is maintained.

The last critical stakeholder to point out are the shipping lines. The shipping lines are of great importance to the port of San Vicente. When shipping lines decide to use other ports, the port of San Vicente loses market share. Considering the amount of competitive ports in the area, the shipping lines have enough alternatives for the port of San Vicente. Therefore, the port authority must retain a good relationship with the shipping lines.

Competition

The stakeholder analysis presented in Appendix B, shows that the competitive ports Coronel and Lirquen are not acknowledged as critical stakeholders. This is due to the fact that the competitive ports do not have the means to influence decisions made by the port authority of San Vicente. However, they can react on the developments of the San Vicente port. Considering the competitive environment of ports in Chile and the fluctuations in market shares in the BioBío region in the past (Figure 2.1), it is likely they will. The three ports are quite similar, this makes it worthwhile to analyse possible threats for San Vicente and its opportunities compared to its competitors. An extensive analysis is performed in Appendix B.5.

As mentioned before the San Vicente port is a public port, whereas Coronel and Lirquén are private ports. This means that Coronel and Lirquén can focus solely on profitable cargo, contrary to San Vicente that, by Chilean law, must handle all cargo types. As a result Coronel and Lirquén can increase market share more quickly by focusing on the most profitable products. Moreover, both private ports have invested a lot of money lately. Public infrastructure investments for the port of San Vicente reached USD 61 million from 1994 till 2016. In the same period Lirquen invested USD 104 million and Coronel USD 132 million dollar (Merk, 2016). Coronel has recently invested in four new gantry cranes and can therefore achieve more than 100 moves per hour per ship. This makes the port more attractive to shipping lines. San Vicente has lost big clients to Coronel in the recent years due to these investments. A few years ago Lirquén invested in an expansion of the container terminal. With this investment the Lirquén port became more attractive for shipping lines. Furthermore, Lirquén has recently been acquired by DP World, a large global port company with a large network of investors.

As a result of these investments of the private ports, the market share of San Vicente decreased from close to 70% in 2006 to about 55% in 2014 (Merk, 2016). San Vicente must take action to keep competing with the two private ports in the Biobío region.

Yet hope is not lost for the San Vicente port as they have a few important advantage over the other ports. Where the two private ports have a port layout with a storage yard not located directly behind the cranes, as the cranes are positioned on a jetty (Figure 2.2a and 2.2b), in the San Vicente port the storage area is partly located behind the cranes (Figure 2.2c). Consequently, the operations in the San Vicente port can be executed more efficient compared to the other two ports. Furthermore, the San Vicente port is better protected from wave action than the other two ports.

Moreover, creating a storage area behind the jetties of the Coronel and Lirquén port is less practical than in the San Vicente port. The San Vicente port could expand more effectively than the other two ports since it has a small sea area which is surrounded by the breakwater, the jetty and land. This area is already territory of the port authority, making decision about expansion less complicated.
Besides that the port of Coronel can not easily expand, it also suffers from a bad relationship with the surrounding city. (Villagrán, 2019).

Finally, the port of San Vicente and Lirquén are very strategically located regarding the main hinterland roads. This makes the ports more attractive for a lot of hinterland companies to export their products compared to the Coronel port. Yet the Coronel port has a better location with respect to the Arauco Mill. The Arauco Mill will in the future generate a lot of throughput for the ports because of the MAPA project. l

(a) Berth layout Coronel port (b) Berth layout Lirquén port (c) Berth layout San Vicente port

Figure 2.2: Berth layouts port in the Biobío region (Google Maps) (equal scale for all figures)

2.1.2. Port operations

Port layout

The San Vicente port has a total surface area of 33 hectares. The storage yard covers about 20.7 hectares of which a part is located outside the port (external storage is estimated to be roughly 8 hectares). In Figure 2.3 the layout of the port is displayed, a further elaboration is given in Appendix C.

As mentioned before San Vicente is a Chilean state port and is therefore obligated by law to handle all kinds of cargo. Accordingly, in the San Vicente terminal there is space required to handle containers, bulk and break bulk. Figure 2.3 indicates the locations in the port where containers are stacked and (break)bulk is stored. Furthermore, in this Figure 2.3 the consolidation centers where (break)bulk is consolidated in containers are illustrated. The port categorises three types of containers, namely empties, import and export containers. For efficiency the port has separate locations to stack the categories as is shown in Figure 2.3.

Additionally, the San Vicente port rents an external area outside the port in order to store more containers. In this area the surplus of empty containers, for which no place is available inside the port, and all import containers are stored.

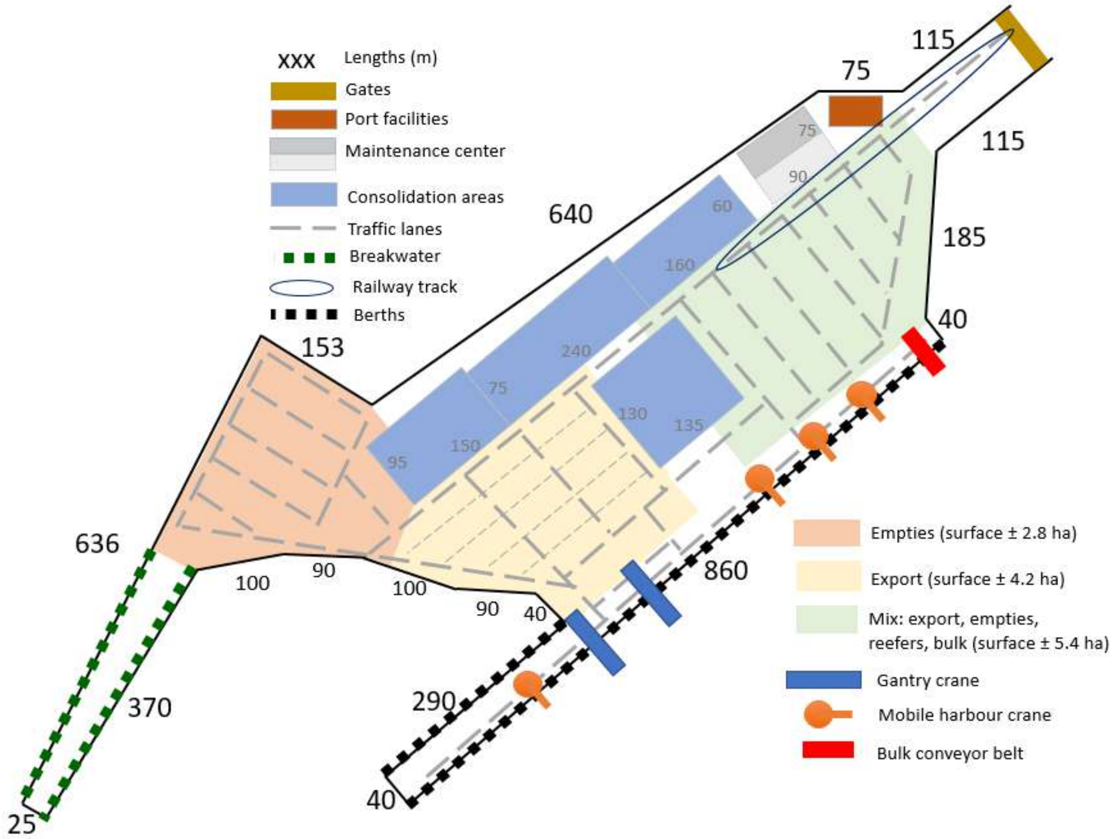


Figure 2.3: Layout of the San Vicente port

Operations

The port operations in the San Vicente port are equivalent to port operations in general. The port operations can be divided into several sub-processes, namely the vessel operations at the quay, internal transport, the stacking system and the continental transport (Rijsenbrij, 2018b). In Appendix D there is a more extensive description about these processes.

Currently the San Vicente port has a throughput of a bit less than half a million TEU per year (Empresa Portuaria Talcahuano San Vicente, 2017). With a TEU factor of 1.86 (Appendix A) this means that roughly 260.000 containers are handled in the San Vicente port each year. The journey of these containers in the port from seaside to landside is summarised below (in Appendix D a more extensive description is given). As the operations in the port are divided in multiple sub-processes, the container is moved around several times during its journey. Unfortunately, the average moves per container is unknown since the lack of information about the shuffling of containers in the storage yard.

The containers arrive in the port on a vessel, the San Vicente port can accommodate for various ship sizes. After the vessel has moored at the depicted berth with the help of tugboats, the unloading process of the vessel starts. The San Vicente port has recently purchased two new Ship-to-Shore gantry cranes on the quay. These cranes, occasionally assisted by mobile harbour cranes, are used to unload the containers from the vessel and load them unto trucks that are waiting on the quay for the internal transport.

The internal transport in the port is done by trucks. When the container is loaded unto the truck, the truck drives to the right location in the port. When arrived on the right location in the port, the container continues to the port stacking system.

A reach stacker lifts the container from the truck and stacks it in the storage yard. The container remains in the storage yard until it is requested again (for exact dwell times see Appendix A). When a container is requested, a reach stacker lifts the container from the storage yard and onto a truck. The truck transports the container to the next location. This location can be found internally or externally of the port.

From the containers that are imported, 85% is empty (Empresa Portuaria Talcahuano San Vicente, 2017). This implies that a large part of the containers is transported from the storage yard to the consolidation centers. In the consolidation centers the empty containers are filled with bulk for export. Transporting those containers from the stack to the consolidation center is part of the internal transport.

Full imported containers and the surplus of empty imported containers are transported by trucks to the hinterland or to the external rented area immediately after arriving in the port. By doing this the port creates a push system, which prevents containers from remaining in the port unnecessary (Negenborn, 2018).
Using the truck appointment system in the port, trucking companies can reserve an arrival time online via the SVTI website to bring and pick up containers (Maritimo, 2015). When entering and leaving the port for transporting containers, the truck loaded with container passes the gates at the beginning of the port. At the gates the truck driver is manually checked by a gate employee for legitimate documents and if the correct container is entering or leaving the port.

Problem analysis

The port operations are sequential, yet all operation steps are coherent and all affect the handling capacity of the containers in the port. Therefore it is not possible to pinpoint one problem in the San Vicente port operations as the absolute bottleneck. For that reason the all problems in the port operations are analysed. Various issues can be identified concerning the operations inside the San Vicente port (Garcia, 2019). These issues are found to be the limiting factors for the efficiency in the San Vicente port. By dealing with these limiting factors the terminal operations can become more efficient, making the San Vicente port more attractive for shipping lines. Problems are identified for each sub-process of the port operations from seaside to landside. The limiting factors are listed below per sub-process. Moreover, there is little information available to quantify the port operations in the San Vicente port. Therefore the problems are described in a more qualitative way.

- **Quay:** the port of San Vicente aims to reach 100 container movements per hour per ship. In theory this is possible since they possess two gantry cranes. Yet in practise the 100 moves are not reached. The crane operators are still rather inexperienced because the cranes are relatively new. Therefore the gantry cranes do currently not operate at full handling capacity, limiting the port operations in efficiency.
- **Internal transport:** the internal transport in the port is limited by the current shape of the port. The containers are not everywhere stacked directly behind the cranes. When large container ships moor at berth 3 and 4, the trucks that are loaded with containers at the quay travel an inefficient route to the storage yard (Figure 2.4) compared to when the containers would be stacked directly behind the cranes. The shape of the port therefore causes a problem in the port operations.

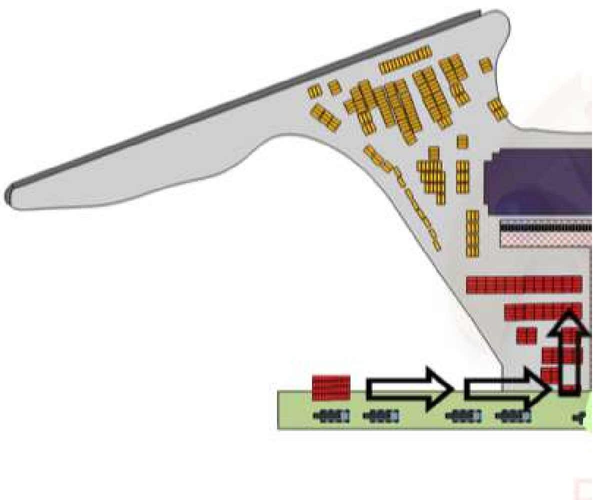


Figure 2.4: Inefficient internal transport because of container travel route

- **Stacking system:** the stacking area in the San Vicente port is organised quite well. Containers are separated based on various criteria such as weight, length, function and destination to make stacking operations more efficient (Garcia, 2019). However, the San Vicente port has some difficulties to accommodate for the container throughput, especially during peak moments. The port is forced to rent an external location to stack containers. Sometimes even roads inside the port area are used to create more storage place. Also many containers are stacked five high with little space in-between in order to allow for enough storage space. Despite the proper separation of containers, the container accessibility is quite poor due to the high stacking density. Therefore stacking operations are limited in efficiency.
- **Continental transport means:** the San Vicente port has to deal with a lot of peak and trough moments. Even though the port uses a container pick up system, large queues can form at the port gates during peak moments. Currently the queues do not affect the port operations as such, yet it can not be denied to be an issue for the port because it stimulates waiting times and congestion around the port.

Even though no absolute bottleneck can be identified in the San Vicente port operations,the issues described in the problem analysis can be traced back to the lack of storage yard capacity and the shape of the port. In the future the current problems are expected to enlarge and new issues might occur, in Chapter 3.3 it will be more elaborated how land reclamation will be beneficial for the efficiency in the port. Expected is that especially the problems in the internal transport and the stacking system are problems that may be solved by reclaiming land. The prospect is that the reclaimed land will solve the storage capacity issues as more land becomes available for the port. Furthermore, by reclaiming the land at the right location, the issue with inefficient shape of the port might disappear.

2.1.3. Hinterland operations

Products

The San Vicente port transports several product categories, this is discussed in more detail in Appendix E. The product that is most handled in the San Vicente port is wood. Wood is exported by the port in various forms: wood, chips, pulp, cellulose and paper. In the Chilean hinterlands large manufacturers of these wood products are located. These wood processing companies transport their product, among other ports in the Biobío region, via the San Vicente port to the global market.

Transport

From the report of Merk (2016) it arises that the Chilean ports are very dependent on trucks for connections to the hinterland and that multi-modality hinterland transport is needed to reduce congestion on the main roads. This is also the case with the San Vicente port.

The San Vicente port has connections with the hinterland by two modes, namely truck and train. Yet exclusively trucks transport imported containers to the hinterlands. The train only transports bulk into the port for consolidation. Moreover, of all transported hinterland products in tonnes, the share of truck transport is 80% compared to only 20% train transport. The focus in the hinterland transport analysis is therefore on trucks.

The San Vicente port (red pin in Figure 2.5) is very strategically located since it has a very good connection to the hinterland roads. San Vicente has multiple access roads, for most other Chilean state ports this is not the case (Empresa Portuaria Talcahuano San Vicente, 2017). There are four main locations where hinterland transport originates from (Figure 2.5), namely Nueva Aldea (green dot), Cabrero (orange dot), the south of Chile (black dot) and Arauco (blue dot). These four locations use four different highways for hinterland transport, respectively to the mentioned locations, the 152 route, the 146 route, the 156 route and the 160 route. This implies that the San Vicente hinterland transport is quite scattered on the Chilean highways around the port.

Figure 2.5: Overview of road connections of San Vicente

The San Vicente port is located in an urban area. Where as the hinterland traffic is spread out on the highways, in the urban area close to the port the trucks are merged. The port authority wants to minimise the traffic hindrance for the inhabitants of the Concepcion urban area. Therefore, the port authority has restricted the hinterland traffic to use two standard routes to approach the port. In Appendix E.1.3 there is elaborated more in depth how the port is accessible, including a visual representation.

Because the access routes use secondary roads, with lower capacity (1400 vehicle/hour), it is interesting to see if these roads can accommodate for all traffic towards the port. In Appendix E.2 there is done an extensive analyses of current traffic conditions on the hinterland routes as well as the Urban routes.

Route 160 is the only hinterland route that currently faces problems. On the 160 route the speed on the road is usually low, especially during the rush hours. The congestion is in particular an issue near the bridge that crosses the Biobio river south of Concepcion. An explanation for the congestion on the Coronel route (160 route) is that the road is damaged and very badly maintained. Additionally to the damaged road, truck traffic is only allowed to use one of the bridges to cross the river since the other bridge is too weak to support heavy truck traffic (Villagrán, 2019). Traffic towards the port, passing through the urban area of Concepcion, should avoid peak hours. Especially in the evening peak, there will always be some congestion passing the main roads. Fortunately, the approaching routes show free flowing conditions throughout the day. Although the approaching routes only have a few accessibility issues it is important to keep in mind that this area is most vulnerable for more throughput of containers in the future. These roads have smaller capacity and all traffic going to the San Vicente port is obligated to use these roads.

2.2. Seaside

This section describes the coastal profile, tidal motion, wave climate and wind climate that are present in the San Vicente port area. The most important hydraulic structures that can be found inside the port are also depicted below.

2.2.1. Coastal profile

San Vicente port is located at the west coast of South-America which can be classified as a leading-edge coast. This kind of coast is characterised by rugged and cliffed coastlines. Mountain ranges can be found near the coast and volcanic ranges (Andes) somewhat further inland. The steep coastal profile is visualised in Figure 2.6, on average it has a slope of roughly 1:100. A negative value for the water depth in this figure means the presence of land since the depth is measured from Mean Sea Level (MSL) with the positive axis going downward. The water depth inside the port is around 16.5 meters. Currently vessels ranging from 100 to 350 meters in length and a draught up to 15 meters enter the port.

A leading-edge coast is also tectonically unstable, meaning that earthquakes occur on a regular basis. It is worth mentioning that in 2010 a catastrophic earthquake and tsunami damaged the port significantly. In 2019, repair works were still underway.

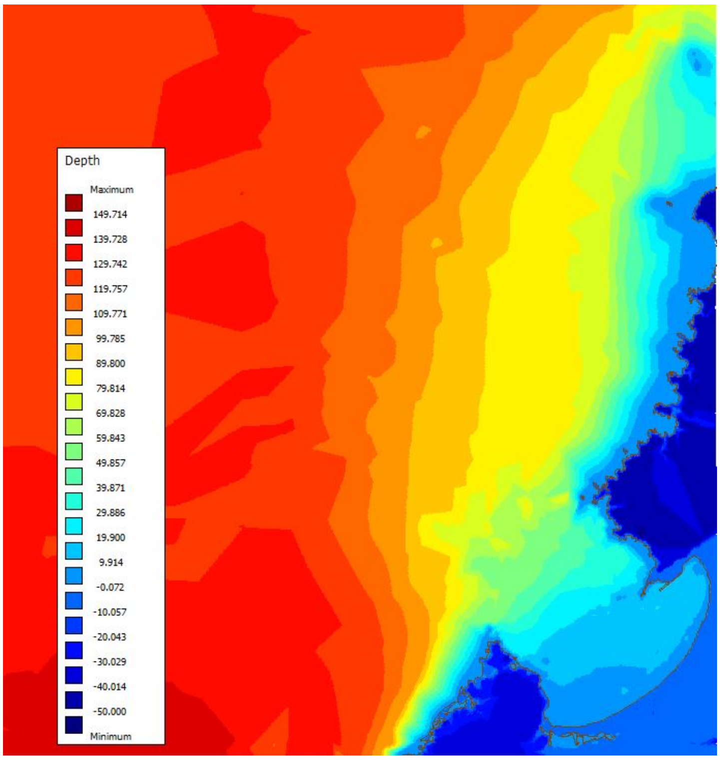


Figure 2.6: Coastal area San Vicente port

2.2.2. Tidal motion

The tidal motion inside San Vicente port is a semi-diurnal tide, meaning that there are two nearly equal high and low tides every day. The tidal level at Talcahuano is given in Table 2.1 below.

Tide	Water level [m]
HAT	1.09
MHWS	0.96
MSL	0
LAT	-0.69

Table 2.1: Tidal currents Talcahuano, obtained from (Sea Level Station Monitoring Facility (IOC))

A study on currents has been conducted (San Vicente Terminal Internacional, 2017). The results show that in the top layer of the bay the average flow velocity is equal to 5.0 cm/s, with a maximum of 20.8 cm/s. In the middle layer an average flow velocity of 3.4 cm/s prevails with a maximum of 20.0 cm/s. The average flow velocity in the bottom layer is equal to 3.8 cm/s with a maximum of 10.8 cm/s. A possible explanation for the small tidal currents inside the bay can be the relatively large water depth (16.5m) compared to the maximum tidal elevation (2m) and the wide entrance of the San Vicente bay compared to the length. Since there is also no river discharge in the San Vicente bay area, currents hardly play any role in the hydrodynamics.

2.2.3. Wave climate

In order to establish the governing wave climate an analysis has been performed on the wave data that was gathered by an offshore wave buoy which lies approximately 40 km away from the port of San Vicente. The data set that is used represents 21 years of measurements, for each 3 hours the wave buoy has given significant wave height H_s, peak period T_p and peak direction Θ. The purpose of this analysis is to establish several offshore wave conditions that represent the prevailing wave climate the best. These conditions will be used as input parameters in the Delft3D model which is described in chapter 6. Figure 2.7 gives a graphical representation of the significant wave heights from 1997 to 2018.

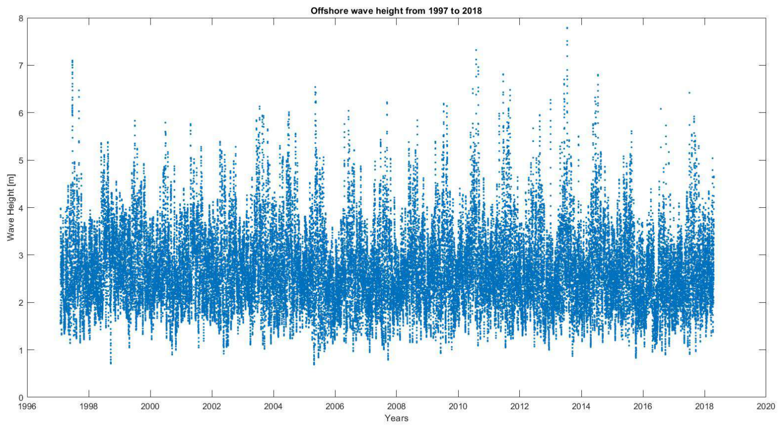


Figure 2.7: Significant wave height 1997 to 2018

Figure 2.8 is a graphical representation of the same data. Only now the wave height is plotted against the direction. It is clearly visible that waves mainly come from the direction between 200° and 320°.

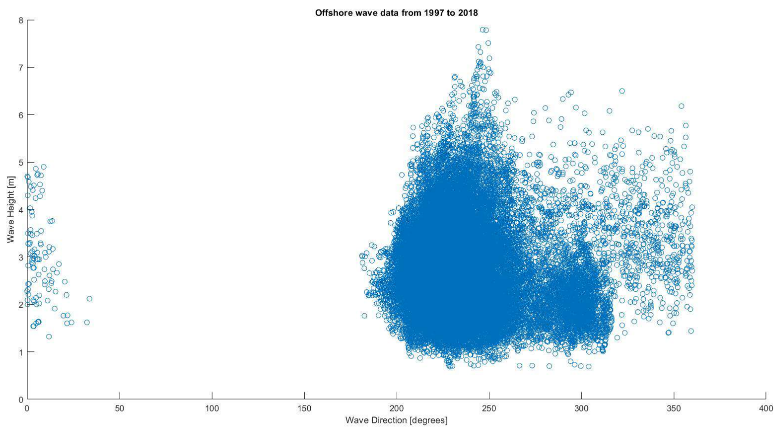


Figure 2.8: Significant wave height vs peak direction

Figure 2.9 gives a graphical representation of the significant wave height plotted against the peak wave period. This figure shows that there is not a clear separation when it comes to wave period, most values lie between 5 and 20 s.

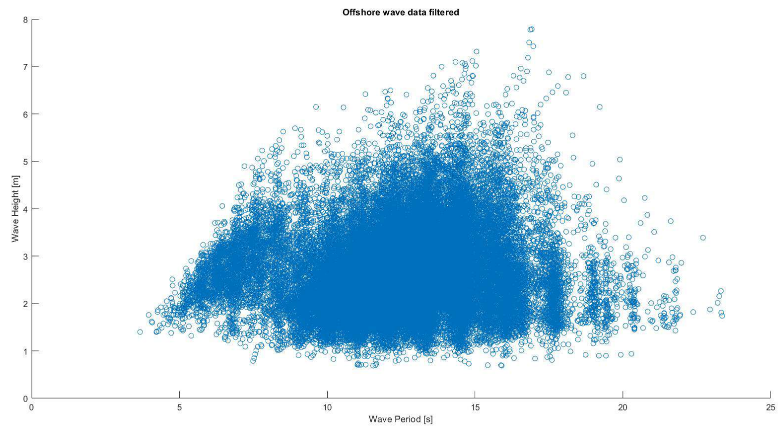


Figure 2.9: Wave height vs peak wave period

From Figure 2.8 it is concluded to filter out the wave data coming from a direction of less than 200°. The remaining wave data is separated into four directional bins, as is visualized in Figure 2.12. A more graphical representation of the filtered wave data is given in Figures 2.10 and 2.11. Figure 2.10 shows the wave height with respect to the direction of the waves. Figure 2.11 shows the wave period with respect to the direction of the waves.

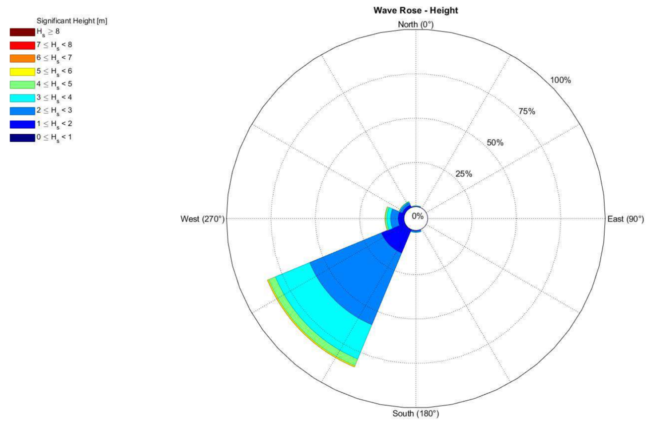


Figure 2.10: Waverose - Significant height

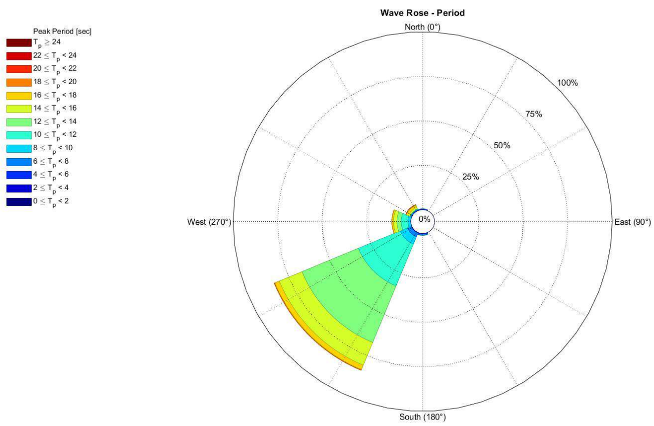


Figure 2.11: Waverose - Peak period

Figure 2.12 is the same plot as in Figure 2.8, only now the part outside 200° and 320° is excluded because almost all waves come from this direction. Furthermore, the plot is divided into 4 bins. The first bin being between 200° and 230°, second between 230° and 260°, third between 260° and 290° and the fourth one between 290° and 320°.

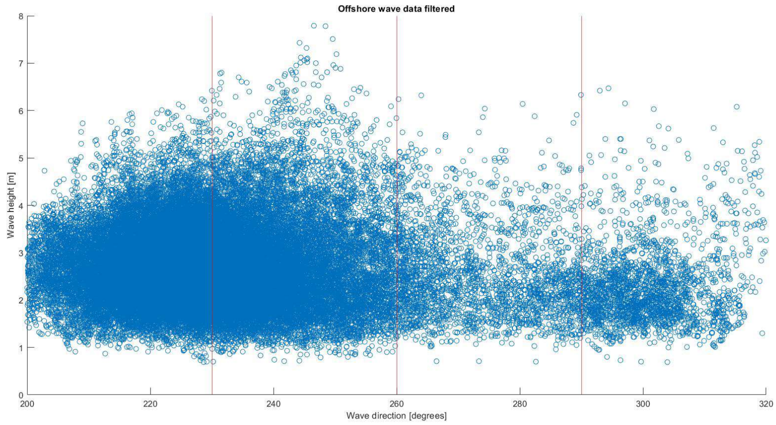


Figure 2.12: Significant height vs peak direction 200°-320°, divided into 4 bins

In order to come up with wave data scenarios that represent the wave climate as good as possible each bin from Figure 2.12 is evaluated further. The range of wave height and wave periods is divided into classes of 0.5 meters and 2 seconds respectively. Plots for the amount of wave heights and wave periods in each class are made for the four directional bins, they are depicted in Appendix G. The data which is plotted in those figures is also displayed in table form. For each combination of classes the percentage of occurrence is calculated. Table 2.2 represents wave height vs wave direction and is depicted below. Tables G.1 and G.2 represent wave period vs wave direction and wave height vs wave period respectively. Both are stated in Appendix G. For the wave direction of each bin the direction in the middle of the bin is chosen, so 205°, 245°, 275° and 305°.

	Significant Wave height [m]																			
Wave direction [°]	0.0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5	4.5-5.0	5.0-5.5	5.5-6.0	6.0-6.5	6.5-7.0	7.0-7.5	7.5-8.0	8.0-8.5	**Total**	**% of total**	**Cumulative** [%]
205	0	25	799	4244	8788	9194	5869	2874	1029	347	136	52	6	0	0	0	0	33363	55%	100%
245	0	55	1007	3850	5798	5099	3407	1760	946	551	199	106	54	26	10	3	0	22871	37%	45%
275	0	4	214	586	661	440	268	179	112	61	23	7	5	0	0	0	0	2560	4%	8%
305	0	7	238	770	651	322	134	80	64	31	19	3	5	0	0	0	0	2324	4%	4%
Total	0	91	2258	9450	15898	15055	9678	4893	2151	990	377	168	70	26	10	3	0	61118	100%	0%
	0%	0%	4%	15%	26%	25%	16%	8%	4%	2%	1%	0%	0%	0%	0%	0%	0%			
Cumulative	100%	100%	96%	81%	55%	30%	14%	6%	3%	1%	0%	0%	0%	0%	0%	0%	0%			

Table 2.2: Significant height vs peak direction

From Table 2.2 the most occurring significant wave height for each directional bin is chosen. The corresponding values for bin 1 till bin 4 are **2.5**, **2.5**, **2** and **2** meters respectively. In order to determine the corresponding peak wave period plots for significant height against peak period are made for each bin. In the same plots, which are stated below, also so-called box plots are made for the different wave heights mentioned above. The horizontal red line represents the median value of the peak wave periods for the corresponding significant wave height. The red cross displays the mean of the peak wave periods.

As can been seen in Figure 2.16 waves coming from directional bin 4 can be divided into two groups depending on their peak wave period. Waves with the larger period are swell waves and the ones with the smaller period are wind waves. In Figures 2.17a, 2.17b and 2.17b the data is separated and box plots are made for a significant wave height of 2 meters for the swell waves and for a significant wave height of 3.5 meters for wind waves.

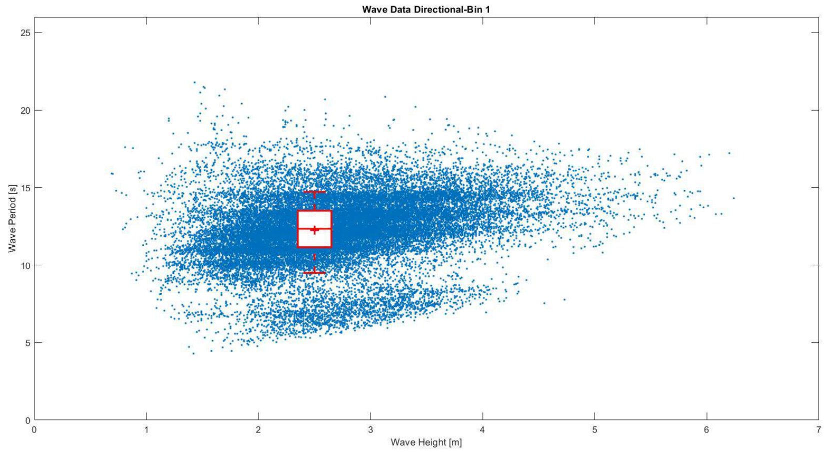


Figure 2.13: Significant height vs peak period bin 1

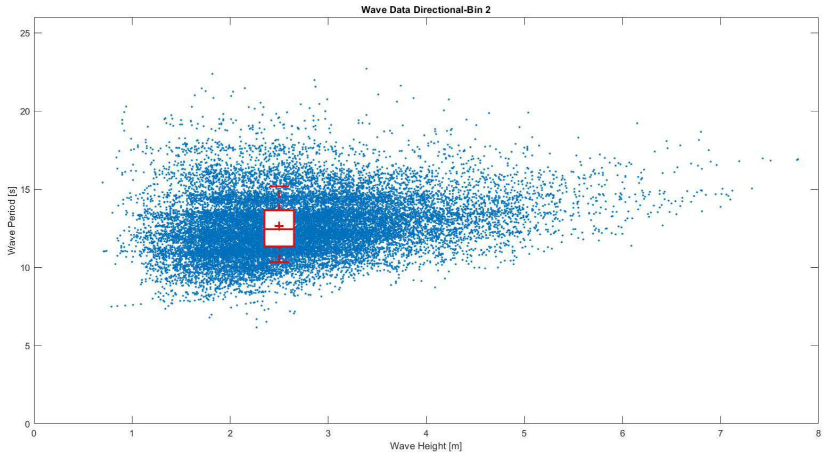


Figure 2.14: Significant height vs peak period bin 2

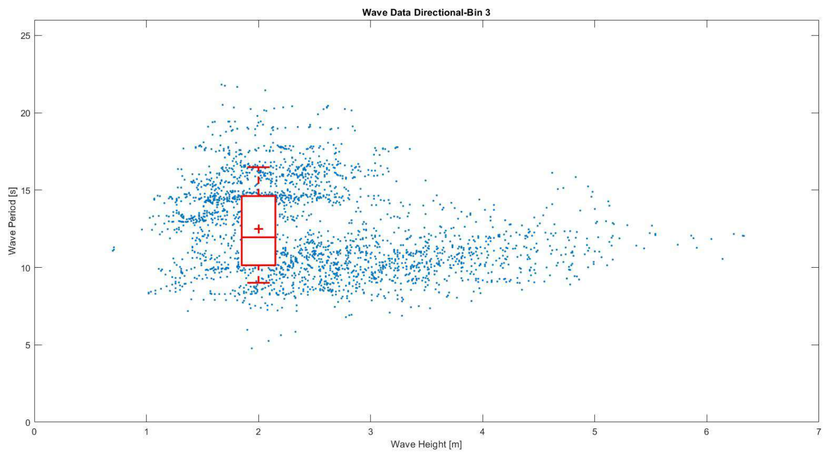


Figure 2.15: Significant height vs peak period bin 3

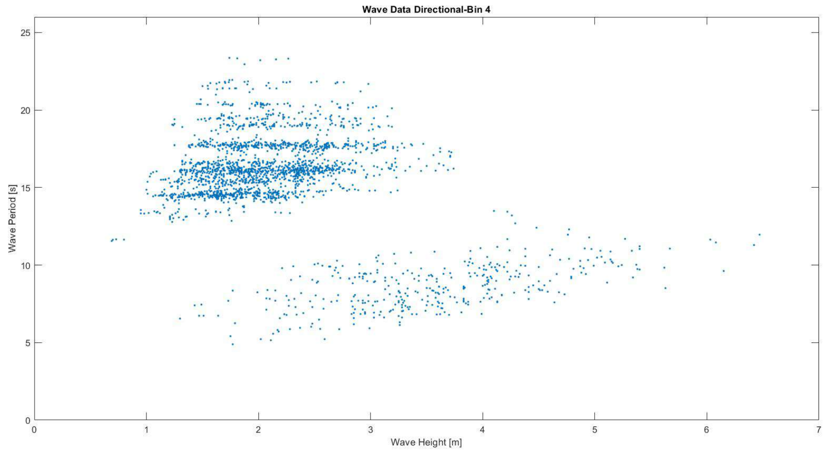
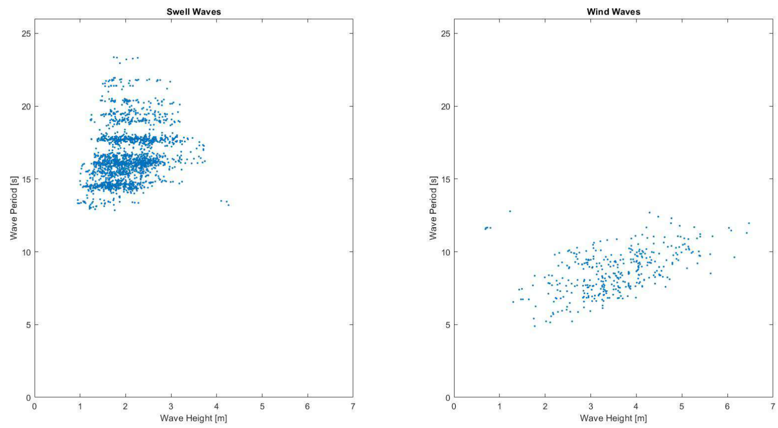
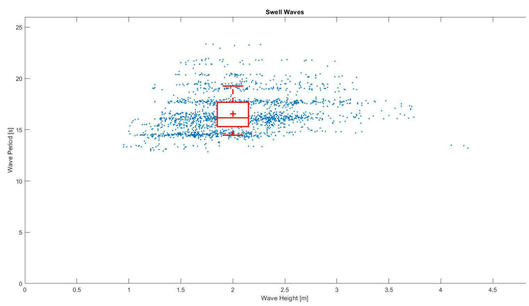


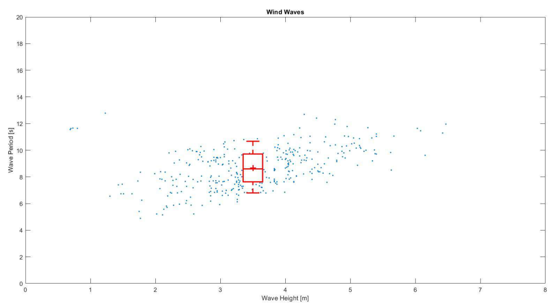
Figure 2.16: Significant height vs peak period bin 4



(a) Significant height vs peak period Swell & Wind



(b) Significant height vs peak period Swell



(c) Significant height vs peak period Wind

Figure 2.17: Analysis Bin 4

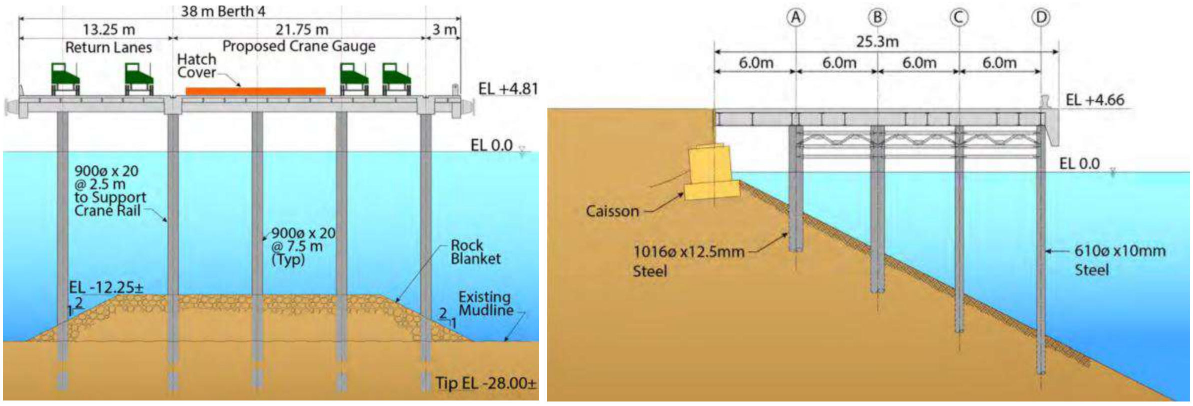
In Table 2.3 an overview is given of the offshore wave parameters that are representing the governing wave climate. Those values are later on used for the different model scenarios. The values of the different periods correspond to the red crosses in the above significant wave height vs peak wave period figures.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Peak Direction [°]	205	245	275	305	305
Significant Wave Height [m]	2.5	2.5	2	2	3.5
Peak Wave Period [s]	12.3	12.6	12.5	16.7	8.7

Table 2.3: Offshore wave scenarios

2.2.4. Hydraulic structures

The two main hydraulic structures inside the port are a breakwater and a quay wall. The latter of the two structures clearly visible in Figure 2.18. The breakwater provides shelter against incoming waves from the west and northwest. It has a length of 680 meters and rises 5 meters above MSL. From a site visit it became clear that the outer slope of the breakwater consists of tetrapod armour units and an inner slope of riprap elements. The quay provides 5 different mooring locations. In practise however only 4 of them are used frequently. The seaward end of the quay consists of a jetty structure with water on both sides. The remaining part of the quay also consists of a jetty structure but here the sea is only present at one side. The two different cross sections are displayed in the figures below. Both figures are retrieved from Bardi (2013)



(a) Seaward end jetty structure

(b) Jetty structure

Figure 2.18: Cross sections jetty structure

2.2.5. Subsoil

The soil in the bay area of the port, at berth 5, has been investigated by Geovenor (Geovenor (2007). Multiple surveys have been carried out, using Standard Penetration Tests (SPT) and compression tests on specimens. From the tested locations, SM1 is chosen from Figure I.1 as it can be seen as a representative survey for the area of interest to the land reclamation. The soil is generally classified as SM in the USCS classification and consists of relatively fine sand with grain diameters ranging between 0.06mm to 2mm. As is shown in Figure 2.19, the sediment is relatively well-graded.

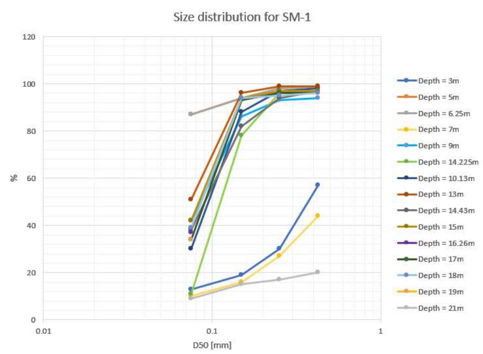
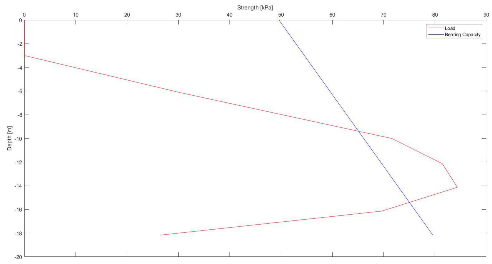


Figure 2.19: Grading of the soil at sampling location SM1 Geovenor (2007)

For the land reclamation, bearing capacity is of importance. A calculation in order to determine this capacity is performed in Section I.4, from which follows that the first 6 meters of the subsoil has to be removed as it bears no load carrying capacity. This is shown in 2.20b, layers 2-5 are strong enough form the foundation of the reclamation.

(a) Grading of the soil at sample location SM1



(b) Bearing capacity versus loading

Figure 2.20: Soil characteristics at location SM1

2.2.6. Tsunami's

As mentioned in Section 2.2.1, the San Vicente port in Concepción is located in a seismic active region. With earthquakes occurring on a regular basis, the chances of a tsunami striking the port is present. It is therefore worth mentioning. In Section 6.2 this is further elaborated and analysed with help of some simulations.

3

Problem definition

This Chapter elaborates on the upcoming problem in the port of San Vicente. Future throughput is expected to rise, therefore the storage yard area needs to increase as well. The two main aspects considering this problem, supply and demand, will be highlighted. Eventually, a conclusion will be drawn to whether a port expansion is a suitable solution.

3.1. Illustration

A port expansion might be a solution for the upcoming problem in the port of San Vicente. Figure 3.1 which is depicted below gives a schematic overview of how a port expansion might solve the problem. Section 3.2 elaborates on the supply side. Problems occurring at the demand side will be discussed in Section 3.3.

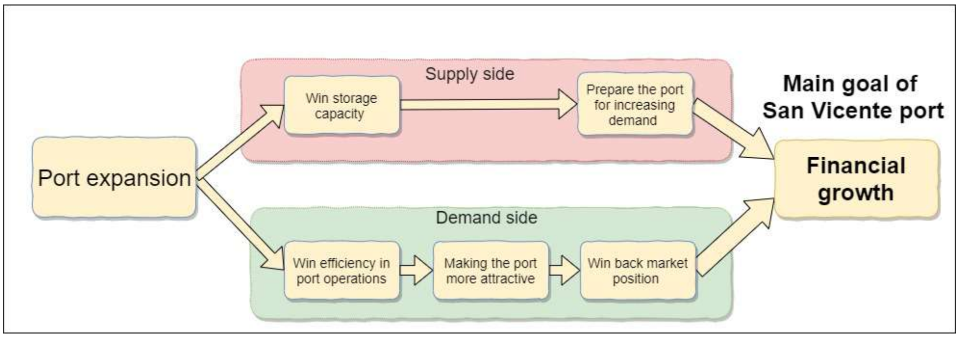


Figure 3.1: Reason for port expansion San Vicente

3.2. Supply

The supply side of the San Vicente port refers to the total amount of a specific service that is available to the clients. The service that is available is the amount of land to store the containers. The clients are the shipping lines. The shipping lines expect the port to supply a certain area to store their containers.

The port of San Vicente expects a significant rise in container throughput for the coming years. A demand forecast for the Biobío region was provided (Empresa Portuaria Talcahuano San Vicente, 2017). This forecast is used to predict the required storage yard area in the future. An extensive elaboration on the theory behind the calculation on the storage yard area can be found in Appendix A.1. An analysis on the provided demand forecast is given in Appendix A.2.

The port of San Vicente currently has a market share of 40%. The port has the ambition to regain market share. The theory and the market forecast were used to predict the required amount of storage yard area for the future. Appendix A.3 elaborates on this matter. Four different scenarios were investigated. The first scenario assumes a steady market share of 40%. The second scenario assumes a market share of 45%, the third scenario a market share of 35% and the fourth scenario a market scenario of 50%. Figure 3.2 below shows the result.

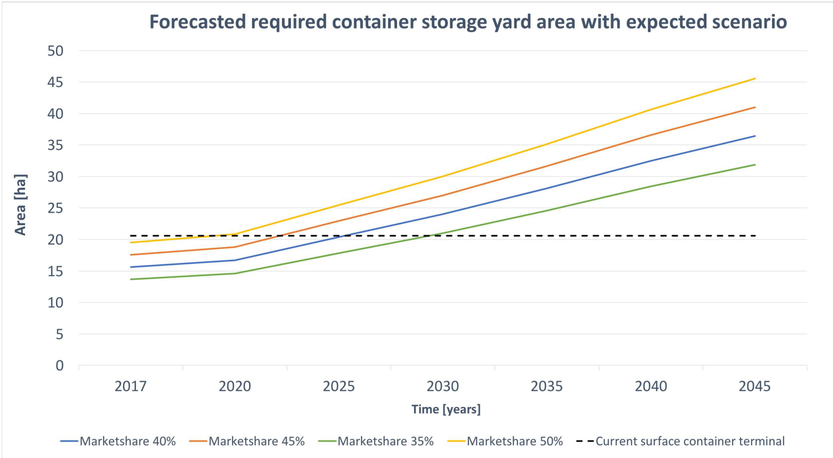


Figure 3.2: Projected area for the San Vicente port based on VIII region 2017-2045 projections and varying in market share of the San Vicente port

Documents that were provided by SVTI show that the port currently has a storage yard for containers that is equal to 20.7ha. Figure 3.2 shows that, regardless of what scenario is selected, the port will need extra storage yard area. Therefore from a supply perspective a port expansion is a good solution.

3.3. Demand

The demand side of the problem in the San Vicente port refers to the services that the clients request. The clients in the San Vicente port are the shipping lines. The services they request are the loading and unloading of the vessels. The shipping lines expect a certain handling capacity from the port, as they desire that the ships are served rapidly to minimise the turnaround time.

In the past the San Vicente port has lost big clients because of their insufficient handling capacity. Consequently, the San Vicente port has set a goal of achieving 100 container movements per hour per ship.
The handling capacity is affected by all port operations. As mentioned in Chapter 2, the port operations consist of several sub-processes. The sub-processes are the vessel operations at the quay, the internal transport, the stacking system and the continental transport. Each of the sub-processes can affect the handling capacity. Therefore each sub-process should operate efficient.

Unfortunately, in the port operations of San Vicente port quite some problems are present as described in Subsection 2.1.2. These problems are the reason that the port operations do not function as efficient as they could. The expectation is that in the future these efficiency problems will increase, when the port does not undertake action. With the predicted increase of container throughput in mind, the problems are expected to enlarge and new issues are expected to arise.

In Appendix D.5 the expected problems in the future are elaborated. These problems are identified with the assumption that the current port operations and land surface are preserved. In the list below the expected future problems are briefly mentioned.

- **Quay**:
  - when the container throughput increases, it is expected that more frequently multiple vessels need to be served at the quay at once. As the San Vicente port only has two gantry cranes combined with mobile harbour cranes, it is not possible to achieve 100 container moves per hour per ship.
- **Internal transport**:
  - the inefficient shape of the port (Figure 2.4) causes an unsatisfactory container flow. With an increased container throughput this problem will grow as more containers need to be handled in the same amount of time.
  - the predicted increase in container throughput will accordingly cause more internal transport movements. This is expected to lead to congestion inside the port as a result of too little road capacity.

- **Stacking system**:
  - when the container throughput increases, it is expected that there will be less time between calls. This results in less time to separate the containers in the yard leading to a rather unorganised storage yard. A less organised storage yard ensures that more time is needed for stacking operations.
  - when the container throughput increases, the port area will become too small to accommodate for the storage of all containers. The port is nowadays already struggling with storage space, hence this problem will enlarge.
  - it is expected that the stacking equipment can not keep up with the predicted increase of container throughput.
- **Continental transport**:
  - as the container throughput is expected to increase, the number of truck movements from and towards the hinterland is accordingly expected to increase. The port gates are expected to have too less capacity to accommodate for the predicted container throughput in peak moments causing hindrance for the port operations.

To prevent these problems from occurring in the future, the port operations must become more efficient. Extra surface area for the port will help to achieve more efficient operations. Therefore from a demand perspective a port expansion is a good solution.

3.4. Conclusion

A land reclamation is needed. It will be beneficial for the supply side as well as for the demand side. A land reclamation will result in a higher storage capacity and it will result in a higher handling efficiency. As a result the port will be prepared for the increasing throughput and become more attractive for shipping lines. If the port has more clients, the market share increases as well. This will automatically lead to the ports main goal which is financial growth.

4

PRELIMINARY DESIGNS

In this chapter multiple preliminary designs are defined and assessed for a possible expansion of the port through land reclamation. Firstly the method for obtaining the alternatives will be elaborated. These alternatives will be tested on weighted criteria, which are validated by the port authority for relevance. When this is all is assessed, a Multi-Criteria Analysis (MCA) is performed to evaluate and compare all the design alternatives. This will provide enough information to determine which alternative will be most suitable for the port. In the next chapter, the Final Design, one of the alternatives has been worked out in more detail.

4.1. METHOD

Before designing the alternatives for a possible land reclamation, it is required to know what the alternatives should abide by. As can be seen in Figure 4.1, the following things aspects should be known first in order the correctly assess the alternatives.

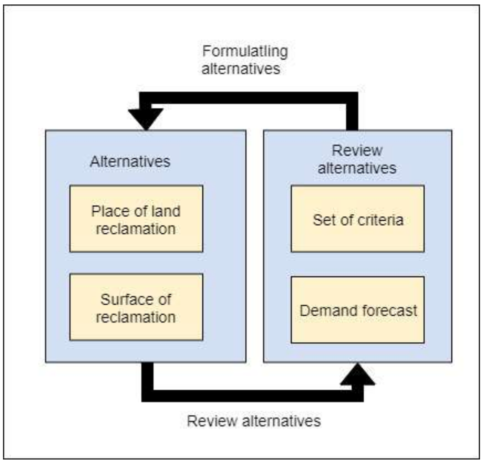


Figure 4.1: Method to create reclamation alternatives

- **Set of criteria**
  By setting the criteria, the **placement of the land reclamation** can be determined

- **Demand forecast**
  On basis of the demand forecast, the **amount of surface for the land reclamation** can be determined

4.2. CRITERIA

The criteria that have been set for this project are created all based on the main objective to maximise the financial growth of San Vicente. In order to formulate the criteria, the general objective is processed in a Goal Tree. This Goal Tree is based on a research about the objective of seaport terminal and can be found in Appendix F.2 (Kemme, 2013).

The criteria obtained from this Goal Tree in Figure F.1 for the land reclamation of the port of San Vicente are listed and briefly elaborated below.

- Storage Capacity
- Handling Capacity
- Costs
- Flexibility
- Hindrance to port operations (landside)

The storage capacity is a very important criterion for the port, as it is strongly correlated with the throughput that the port can handle. By increasing its capacity, it will immediately impact the increase of stakeholder value and thus the financial growth.

The handling capacity is another very important criterion for the port, as it affects the efficiency of the port. With an increased handling capacity it also impacts the increase the stakeholder value and thus the financial growth of the port.

The cost criterion is related to three aspects; the CapEx, initial CapEx and the OpEx. These aspects are briefly elaborated below, but is should not be forgotten that all these aspects coincide in the criterion costs.

The CapEx, also known as Capital Expenditures, are all the investments made for a whole project. This is an extremely important cost aspect to the port as it gives a clear view for the investors, in this case the port, if the investment is realistic within their budget constraints.

The next aspect is Initial CapEx, clarifies the difference between the total investments and the first investments. For investors the first investment is always a difficult decision to make, since it remains uncertain if the investments made will out to be profitable. The optimal scenario would have a maximum return rate and minimal initial investment, however this is very unrealistic. Therefore the right balance needs to be found between the two.

The OpEx, also known as the Operational Expenditures, are the annually returning costs for running a project, in this case the port operations. These costs include the rent of equipment, power, personnel and so on. In order to simplify these costs, it is will be correlated with the amount of land, as more land will mean more maintenance. This aspect should be taken into account as these costs can have a great effect on the amount of land reclaimed.

The criterion flexibility should be closely looked at for the objective set for this project. With the main objective being to maximise the financial growth, it could possibly be profitable to increase the expansion of the port after the first expansion to increase the financial growth even more, if the economic conditions allow so. However, this is not always the case. It strongly depends on the efficiency, performance and economic developments during the first phase. Therefore it is extremely beneficial for the port to maintain its freedom in flexibility.

The landside hindrance to the port operations is an aspect that should be taken into account when creating alternatives. It is desirable to keep the hindrance as low as possible for the port during the construction of the land reclamation in order to continue the operations. However, when hindrance to operations appears inevitable, minimisation of this parameter should be prioritised.

Minimum requirements

The effect on the hydrodynamics is not listed in the criteria list, however it is depicted in the Goal-Tree in Figure F.1. The reason for this is because it is seen as a requirement for this project. If the proposed land reclamation option will negatively effect the hydrodynamics, resulting a disturbance to the port operations, it will not be beneficial at all to reclaim. Therefore the effects on the hydrodynamics is seen as a condition instead of a criterion.

With all the criteria for the alternatives known, the next step is to assign each criterion a weight to specify its importance. Before addressing this subject, it should be noted that the weighting factors of the criteria have been validated by the port authority. By validating the weights of all the criteria, it ensures that the result obtained from the MCA will be relevant for this report as well as the port. For the weight factor determination each criterion is compared with another. When criterion A is assigned to be more of importance than criterion B, criterion A will get a score of one and criterion B a score of zero. If both criteria have the same importance, both will receive a score of 0.5. In Appendix F.4 the complete reasoning and comparison behind the scores for each criterion can be found. In Figure 4.2 an overview is given of the weight factor determination for all the aforementioned criteria.

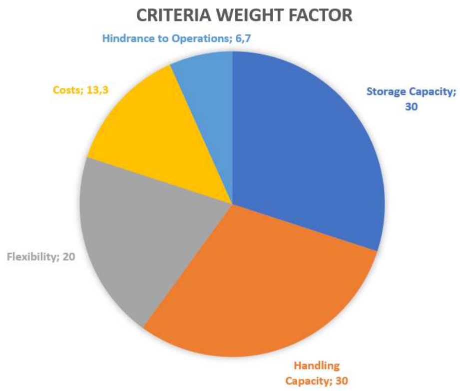


Figure 4.2: Pie chart of the weight factor for each criterion

4.3. Determine needed surface of extra land

The amount of land reclamation needed for the project is strongly related to the demand forecast. This forecast has been explained in Section 3.2 and Appendix A and is used in Section F.5 to determine the needed surface of land. To avoid many uncertainties the future brings, it is chosen to select 2025 as a reference year. With the reference year and an expected market share of 45% (reasoning can be found in Section F.5, a minimal surface of land is estimated at roughly 23 hectares, as can be seen in Figure F.10. With the port having a current area of 20.7 hectares, this it would mean that a total of 2.3 hectares still remains to be reclaimed. However, given the uncertainties about parameters pointed out in A.4 a high safety margin is advised. Moreover, there will be high startup costs when performing the reclamation. For this reason it is not attractive to reclaim small areas of land. Therefore a total of 4 hectares is suggested for reclamation.

The port could also decide that they want to be future proof until at least 2030. In this case a different reclamation plan is needed. Looking even further into the future the uncertainties will increase. Therefore having set the reference year at 2030, multiple scenarios (negative and positive) are imagined. The negative scenario will be following a 45% market share and the positive one a 50%. According to Figure F.10 the amount of land needed will be 27 hectares following the negative scenario and 30 hectares following the positive scenario. Again including a safety margin, seven hectares would be recommended in the negative scenario and ten hectares for the positive. However, having 13 hectares of total possible surface to reclaim, the positive scenario is increased to 13 hectares. For a more detailed elaboration, see Section F.5 and Appendix A.

4.3.1. General considerations

Apart from knowing the amount of surface for the land reclamation, the (engineering) challenges for this project should be analysed. The main (engineering) challenges that need to be taken into account for an alternative are listed an briefly elaborated below.

- **Amount of sand for land reclamation**
  The amount of sand needed is strongly dependent on the location for land reclamation, since the water depth in the bay varies as can be seen in Figure F.11.

- **Amount of revetment at reclaimed land**
  The revetment at reclaimed land is dependent on the shape of the reclaimed land. The type of revetment is based on the hydrodynamic conditions in the bay.

- **Length of connection at the jetty construction**
  The length of the connection to the jetty construction is important to consider as this is a difficult part to construct.

4.4. Alternatives

In this section the proposed alternatives for the land reclamation are introduced. Using the determination of the surface of land Section (F.5) and adding a null alternative as reference point, alternatives can be categorized in 4 different groups;

- 0 Hectare land reclamation - *Alternative A* - (*null option*)
- 4 Hectare land reclamation - *Alternative B to D*
- 7 Hectare land reclamation - *Alternative E to G*
- 13 Hectare land reclamation - *Alternative H* - (*maxed option*)

In Figure 4.3 all alternatives are presented. For every criterion a ultimate alternative is created. However, since some criteria will create similar alternatives, not every criterion has its own ultimate alternative. In the following section each alternative is briefly elaborated. For more elaboration on the alternatives individually see Section F.6 in the appendix.

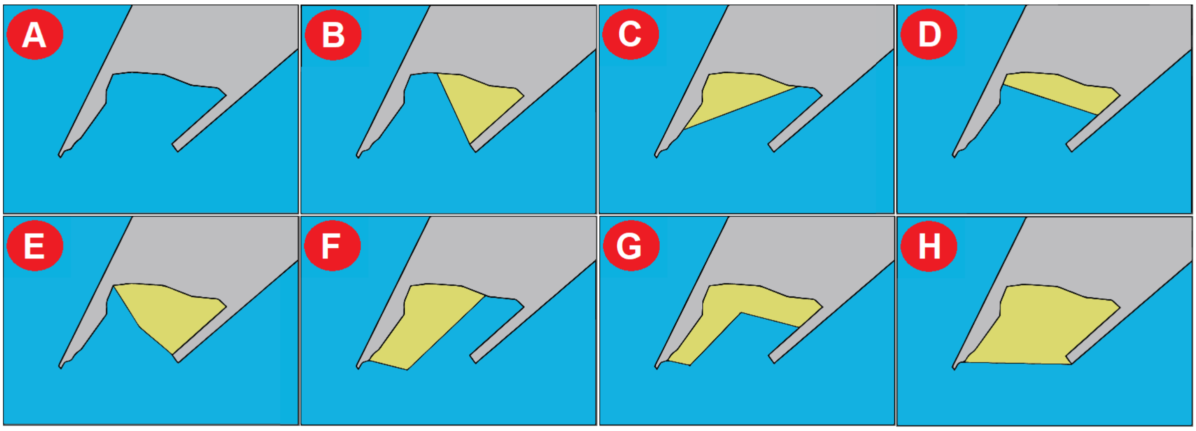


Figure 4.3: Overview of all proposed alternatives

Alternative A - (0 hectares, null option)
In alternative A , the situation when no land is reclaimed is analysed. Although this option is not a realistic one, since according to the forecast the amount of area should be increased to fulfill the future demand in 2025. But for the sake of a complete research and as a reference point, this alternative is also analysed and taken into the MCA.

Alternative B - (4 hectares with full jetty connection)
Alternative B is an alternative of reclaiming 4 hectares near the STS cranes at berth 4. Looking at the engineering challenges as mentioned before, the construction of the complete connection at the jetty construction will be the most difficult part. The amount of sand required for this area will be relatively large, as the water depth is relative large (see Figure F.11). The length of the revetment is relatively short. This alternative is formulated from a high handling capacity point of view, because it reclaims land directly behind the STS cranes.

Alternative C - (4 hectares with no jetty connection)
Alternative C is an alternative of reclaiming 4 hectares at the most shallow part of the bay. The engineering challenges of the construction of a connection at the jetty construction is avoided. The amount of sand required for this area

will be the fewest of the alternatives. The length of the revetment will be a bit larger for this alternative. This alternative is formulated from a cost (initial CapEx) point of view.

Alternative D - (4 hectares with small jetty connection)
Alternative D is an alternative of reclaiming 4 hectares and is a mixture of Alternative B and C. The engineering challenges of the construction of a connection at the jetty construction remain, but it is bounded to a small part. The amount of sand required for this area is relatively little, since the depth near the shore is smaller. The length of the revetment is comparable to Alternative B.

Alternative E - (7 hectares with full jetty connection)
Alternative E is an alternative of reclaiming 7 hectares near the STS cranes at berth 4. The shape of this alternative is similar to that of alternative B. Looking at the engineering challenges as mentioned before, the construction of the complete connection at the jetty construction will be the most difficult part. The amount of sand required for this area will be relatively large, as it is in an area with a large depth. The length of the revetment is relatively small. This alternative is formulated as a 7 hectares option from the point of view of a high handling capacity and as an expansion option from alternative B and D.

Alternative F - (7 hectares with no jetty connection)
Alternative F is an alternative of reclaiming 7 hectares at the most shallow part of the bay. The shape of this alternative is similar to that of alternative C. The engineering challenges of the construction of a connection at the jetty construction is avoided. The amount of sand required for this area will be the fewest of the alternatives. The length of the revetment will be bigger for this alternative then for alternative E. This alternative is formulated from the cost (initial CapEx) point of view for the 7 hectares alternatives and as an expansion option for alternative C.

Alternative G - (7 hectares with small jetty connection)
Alternative G is an alternative of reclaiming 7 hectares and is a mixture of Alternative E and F. The shape of this alternative is similar to that of alternative D. The engineering challenges of the connection at the jetty construction remains, but is bounded to just a small part. The amount of sand required for this area is relatively low. The length of the revetment for this alternative is the biggest compared to the rest of the alternatives. This alternative is mainly formulated as expansion variant for alternative D.

Alternative H - 13 hectares
Alternative H analyses the situation where all the area between the breakwater and the jetty construction is reclaimed. The engineering challenges of the construction of a connection at the jetty construction remains. The amount of sand required for this area is the biggest compared to the rest of the alternatives. The length of the revetment for this alternative is the comparable to the length of alternative E. This alternative is formulated from a storage area point of view and as expansion possibility of all other alternatives.

4.5. Multi-Criteria Analysis

Having investigated all possible land reclamation alternatives and the criteria in Section 4.2, a MCA analysis can be performed. The MCA method is described in further detail in Appendix F.1. With the scores of the alternative for each criteria and its corresponding weight factor the scores for the MCA can be determined. In Section F.6 all criteria for each alternative is elaborated and the point distribution is reasoned. In Table 4.1 an overview is given of the criteria scores for each scores as well as the total score for the MCA. For an overview of the exact calculation for each criterion and its weight factor see Table F.3 and Table F.4 in Appendix F.7.

Criteria	Weight Factor	Alternatives							
		4 Hectare				7 Hectare			
	WF [%]	A	B	C	D	E	F	G	H
Storage Capacity	30	1	4	4	4	5	5	5	7
Handling Capacity	30	1	7	1	4	7	2	4	7
Flexibility	20	7	5	6	6	3	3	4	1
Costs	13.3	7	4	6	4	3	5	2	1
Hindrance to Port Operations	6.7	7	2	6	4	2	6	4	1
Scores MCA	-	3.4	**4.97**	3.9	4.4	**4.73**	3.77	4.6	4.6

Table 4.1: Scores of the alternatives for each criterion

From Table 4.1 it can be concluded that alternative B (4 hectares with full jetty connection) is the best alternative according to the MCA with the weighted criteria set. For a possible second phase reclamation alternative E (7 hectares with full jetty connection) and H (13 hectares) could be recommended, as these alternatives score the best of the larger area alternatives. Also, as can be seen in Table F.5 in Appendix F.7.1, these alternatives are the only expansion possibilities feasible for Alternative B. A further expansion after alternative B is strongly dependent on the ports financial growth and its future stakeholders value. This project however will be restricted to the first land reclamation analysis and will not include a further in-depth research into a possible second land reclamation. Only the recommendation of alternative E or H is made as a possible next stage.

4.6. Conclusion

The MCA showed that alternative B was the best land reclamation possible for the port of San Vicente. Before analysing alternative B in more detail, the proposed alternative was presented to the port authority and SVTI to concur the findings retrieved from the MCA. After the meeting with the port authority and SVTI on Friday the 27^{th} of September, a view a modifications were made to the chosen alternative. These modifications are explained in more detail in Appendix F.7.2 and are briefly listed in the list below.

- **Avoid land reclamation at the tip of the jetty**
  To avoid hindrance in the manoeuvring area of the seaside port operations

- **Allow small movement at the connection to the jetty construction**
  Facilitate movement, as when mooring ships to the jetty connection a small displacement is present.

- **No further land reclamation expansion further than the indicated line**
  Would have a critical effect on hydrodynamics if breakwater is not extended, see Figure F.23

With all the above stated adaptations, the modified alternative B is illustrated in Figure 4.4.

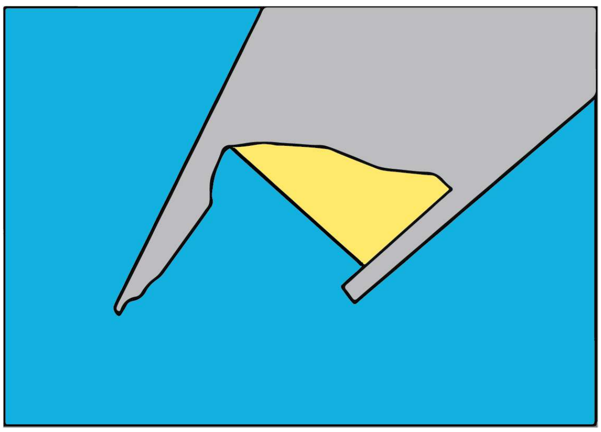


Figure 4.4: Alternative B with some adaptations made in accordance with the client

5

Final Design

This chapter discusses the various designs that contribute to the formation of the land reclamation

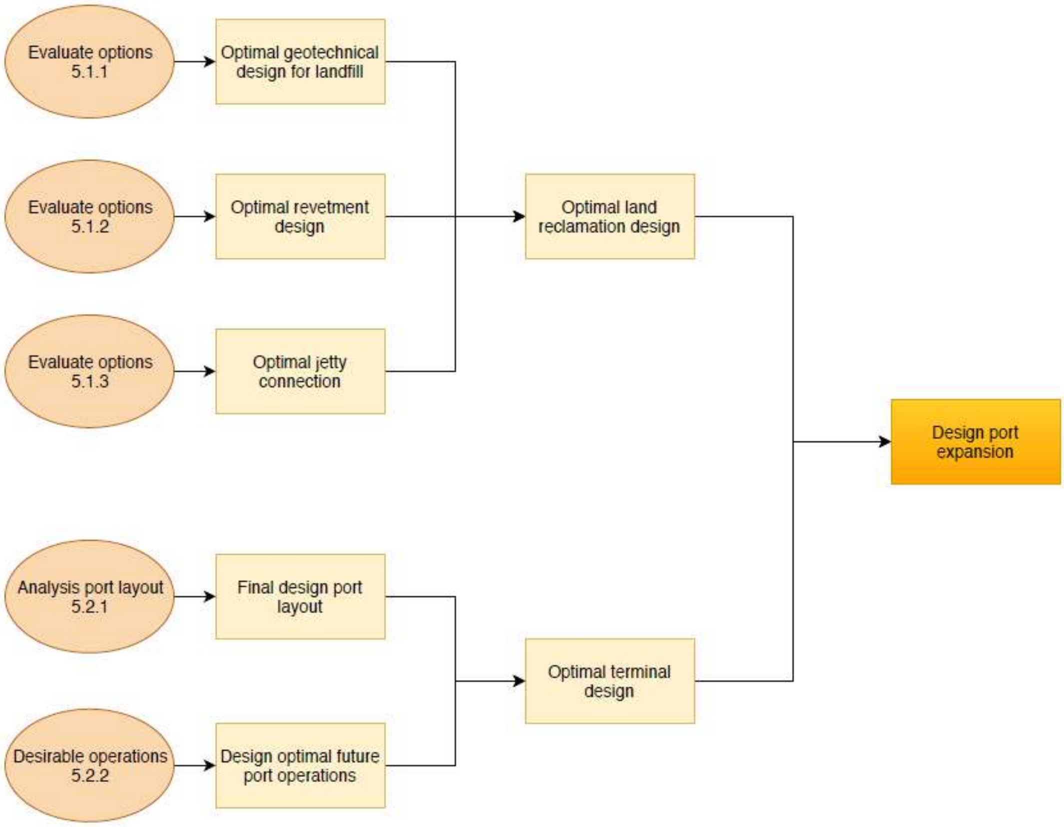


Figure 5.1: Steps to come to an expansion design

After analysing the current situation of the port and having defined the problem, this chapter will cover designs for the land reclamation and the terminal situated on top of the land reclamation.

5.1. Reclamation design

5.1.1. Land reclamation

The land reclamation is designed with the purpose to support the new container terminal. This section shortly covers the geotechnical aspects of the land reclamation. For a full elaboration on the design, one is referred to Appendix I.

As was discussed in Chapter 2, a significant amount of soil has to be removed from the site. The surrounding existing port infrastructure has to be connected to the land reclamation in order to increase the handling capacity. This means the height of the land reclamation will be level with the jetty structure, at 4.81m above MSL (Bardi, 2013). The land reclamation itself will be constructed using sand from the Biobío river nearby, which has a D_{n50} between 0.85 - 1.0mm Weller et al. (2012).

As the body of sand of which the land fill is comprised is quite large, it is important to consider settlements in the soil during lifetime operations. In Section I, the calculation is carried out using the method of Koppejan. The calculation was carried out for a period of 30 years, resulting in a settlement of 0.022m, which is acceptable.

Chile's coast experiences a lot of seismic activity, hence the land fill must satisfy local building codes such as Instituto Nacional de Normalizacion - INN. To prevent the failure method liquefaction due to seismic activity from occurring, a method is used with a safety factor. This factor is determined by the cyclic resistance ratio over the cyclic stress ratio. By means of reverse engineering, the minimum effective stress can be determined. Using this method and a factor of safety against liquefaction of 1.25 from EC-8, through the cyclic stress ratio, a desirable effective stress can be found. The desired effective stress using this factor of safety is 292.3 kPa. In the analysis of the land reclamation, the effective stress present is 305 kPa, which means the soil is sufficiently strong to handle seismic loads. An elaboration can be found in Appendix I.

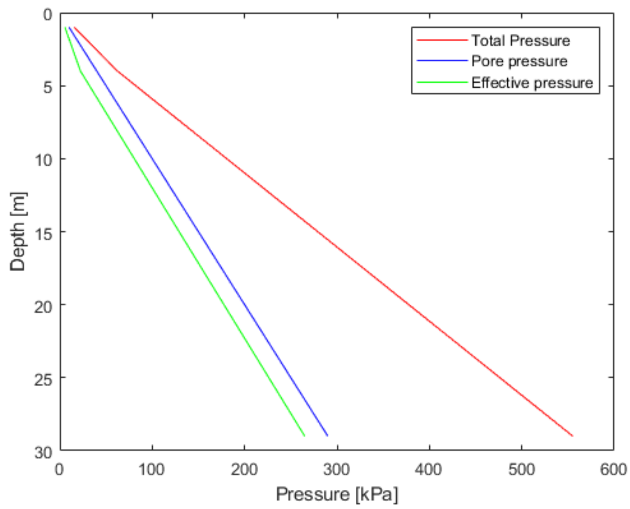


Figure 5.2: Development of pore pressure, effective pressure and the total pressure in the soil of the land reclamation

5.1.2. Revetment on seaside

The revetment is designed with the purpose to protect the reclaimed land. This section shortly elaborates on the way the revetment was designed followed by the final design. For a full elaboration on the design, one is referred to Appendix J.

Wave analysis

In order to design the revetment a significant wave height is required. A peak-over-threshold method was performed in order to cancel out most of the offshore waves and only stay left with waves that correspond to single storm events. A peak wave height of 5.5m was chosen, this corresponds with 8 storms per year. An extreme value distribution was fit to the data set. A root mean square analysis showed that a Weibull distribution fits the extreme value distribution best. A wave analysis was performed in order to determine a storm event with a return period of 1 in 100 years. This storm event was translated to wave data inside the port with a Delft3D model. For information on the Delft3D model one is referred to Appendix H. The translated wave data was used to design the revetment. For a full elaboration on the wave analysis one is referred to Section G.1. The significant wave height and period correspond to swell waves and they are shown below:

- $H_s = 0.8$m
- $T_m = 17.2$s

Design

It was decided to design a riprap revetment with natural rock armour. The *Van der Meer* formula for surging waves was used. The calculation showed that a D_{n50} bigger than 0.21m would be sufficient. The old revetment was also constructed with riprap revetment, only with a bigger D_{n50}. Since large part of the old revetment would be removed it was decided to reuse the rocks for the new revetment. Autocad files that were supplied by SVTI showed that the old revetment had a D_{n50} of 1.0m. An armour layer with a D_{n50} of 1.0m was therefore used for the final design.

Based on scouring and bed level conditions a suitable toe design was picked (The Rock Manual, 2007). The toe design can be found in Figure 5.3.

Design conditions for the under layer prescribe a D_{n50} ratio of 2 or 3 between the armour and the under layer in order to prevent the loss of material. Autocad files that were supplied by SVTI showed that the old under layer had a D_{n50} of 0.5m. This meets the design conditions stated earlier. Since large part of the old under layer needs to be removed it is decided to reuse it for the new under layer.

Design conditions for the core also prescribe a D_{n50} ratio of 2 or 3 between the under layer and the core. However consultation with Villagrán (2019) showed that sediment from the Biobío river is likely to be used as material for the land reclamation. This sediment does not meet the design criteria with respect to winnowing through the revetment layers. It is therefore decided to apply a geotextile between the under layer and the core to prevent this from happening. Based on design conditions it was decided to apply a non-woven geotextile type.

Cross section

A cross section of the Revetment is given below in Figure 5.3.

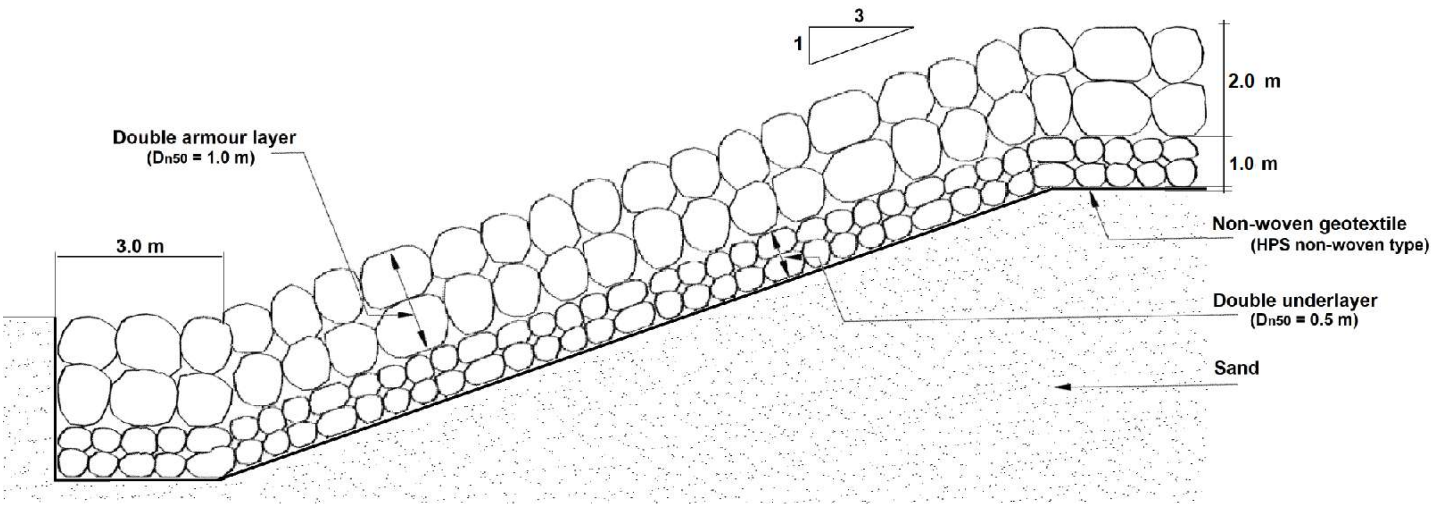


Figure 5.3: Overview of the designed revetment at the land reclamation

5.1.3. Jetty connection design

The jetty connection is designed with the purpose to connect the reclaimed land to the jetty. This section shortly elaborates on the way the jetty connection was designed followed by the final design. For a full elaboration on the design, one is referred to Appendix K.

The jetty connection is designed with the purpose to connect the reclaimed land to the jetty. All calculations and elaboration on design can be found in Appendix K The connection between the land reclamation and the port infrastructure at berth 4, the jetty, is crucial for the effectiveness of the land reclamation. Without a proper connection, direct transport to the terminal designed on the land reclamation is not possible and the handling capacity will not grow as anticipated. However, the jetty has an open structure which can allow sediment to flow to berth 4, hampering the water depth and reducing the maximum draught. This must be prevented at all costs. This subsection discusses the jetty connection design.

Design approach and scope

Two main elements are important for the jetty connection; a retaining structure or method to prevent the sediment flowing into the berth and a connection piece to link the land reclamation to the existing port infrastructure at berth 5. The design starts by evaluating different solution strategies, taking environmental conditions from 2 into account in making a decision through a qualitative multi-criteria analysis. The design is then assessed for the following stability criteria:

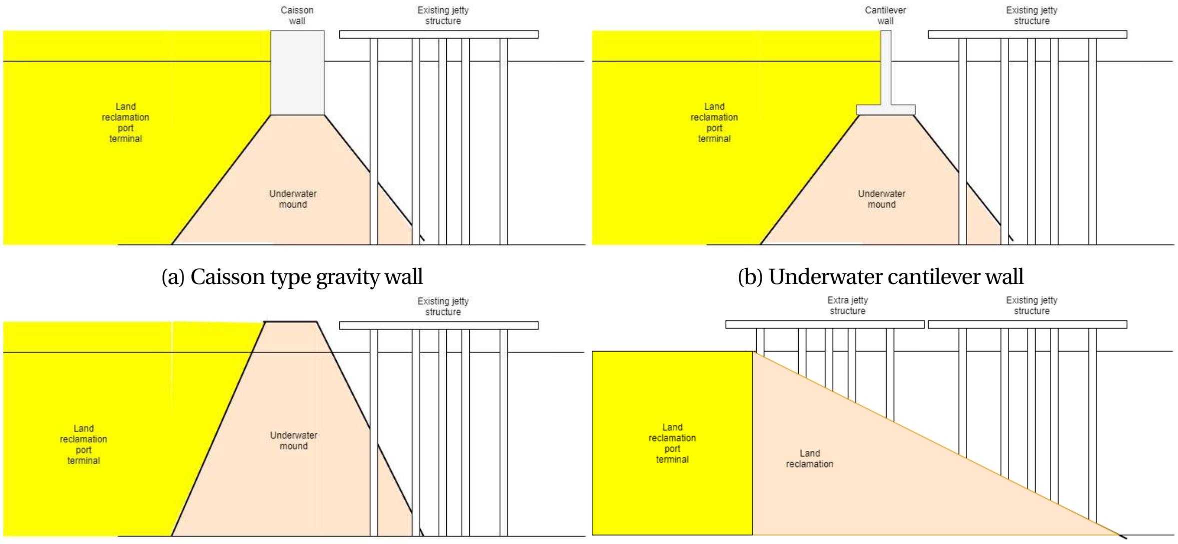
- Vertical stability
- Horizontal stability
- Rotational stability

Using MatrixFrame structural analysis software, the designed components can be evaluated for internal forces and deflections. If the deflections prove to be small enough to guarantee safety of the construction, the design is successful.

Solution strategies

The solution strategies found for retaining the sediment are shown in Figure 5.4.

- Caisson wall
- Cantilever wall
- Underwater mound
- Jetty extension



(a) Caisson type gravity wall

(b) Underwater cantilever wall

(c) Underwater mound

(d) Jetty extension

Figure 5.4: Different alternatives for the connection of the land reclamation to the jetty structure

An evaluation of alternative on the following criteria is conducted:

- Cost
- Hydrodynamics
- Availability of material
- Construction convenience

A comparison between options, described in detail in Appendix K, has proven that a cantilever wall would be the best solution for retaining sediment, as it uses the weight of the landfill to increase resistance against the lateral pressure from the landfill, reducing costs for providing this resistance. The underwater mound that support the cantilever wall will also have a slope that will help reduce wave reflection which could impair mooring conditions at berth 4. Also, it is easy to construct separate elements near the site and put them in place.

Design cantilever wall

The design of the cantilever wall is a preliminary design study, with the aim of providing the port of San Vicente with an idea of how such a structure would be dimensioned to be able to carry loads of the landfill and the terminal. In Figure 5.5 a cross-section of the jetty connection is shown, with the cantilever retaining wall and the connecting slab labelled.

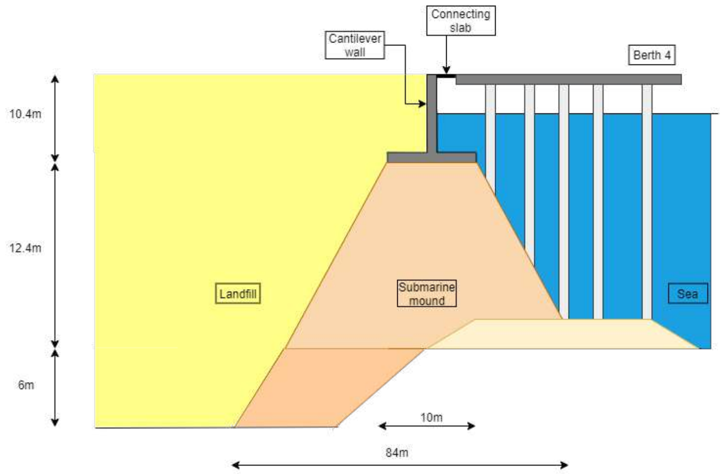


Figure 5.5: Overview of the designed connecting structure at the jetty

A first design iteration is carried out with the following dimensions for a cantilever wall as shown in Figure 5.6. For this design, a concrete type C20/25 is used.

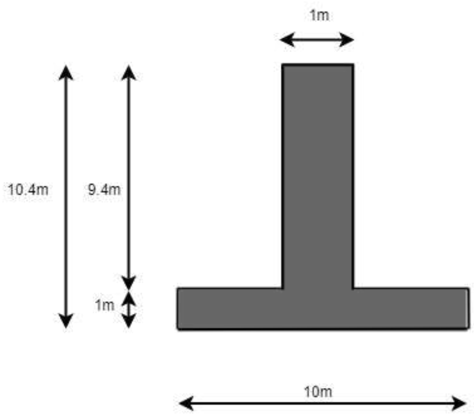


Figure 5.6: Design dimensions for a first design

Using these dimensions, calculations can be made for stability. The loads can be seen in Figure 5.7, and were calculated in Appendix K.

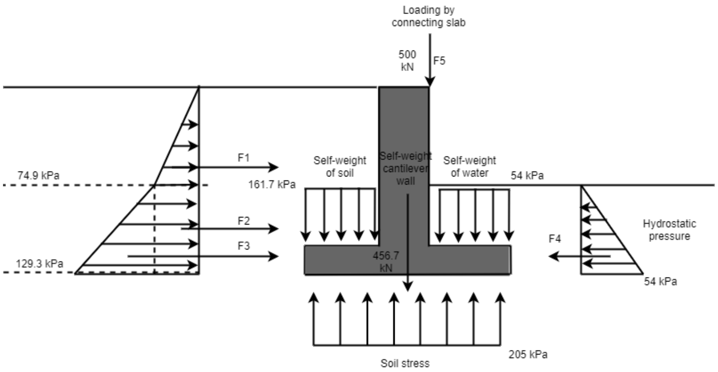


Figure 5.7: Forces on the proposed cantilever wall design

Testing on vertical, horizontal and rotational stability, as is elaborated on in Appendix K, the cantilever wall is stable enough to resist the loads imposed on it.

Stability check	Required strength	Resistance
Vertical stability test	14 kPa	54 kPa
Horizontal stability test	633 kN	671 kN
Rotational stability test	0.38m	1.66m

Table 5.1: Stability checks

Design connection slab

The preliminary design for the connection slab is focused on carrying the loads imposed by a heavy vehicle that is used in port operations, like trucks for carrying containers and reach stackers for lifting containers. Just like for the cantilever wall, a preliminary study into the dimensions is carried out with the dimensions for the slab portrayed in Figure 5.8:

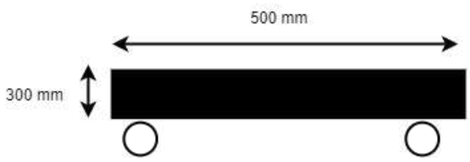


Figure 5.8: Forces on the proposed cantilever wall design

Design evaluation

In order to evaluate the designed components of the jetty connection, the designed elements are put into structural analysis program MatrixFrame, that can calculate the deflection of the members through which failure can be tested, following Eurocode 2. In Appendix K, simulation results can be observed, most notably in Figures K.13 - K.15, and K.16 - K.17.

From running these simulations, deflections for the slab are 0.0002m and the deflections for the cantilever wall is 0.02m. Following the Eurocode 2, the maximum deflection on both members are calculated by dividing the span by 250, following the Eurocode.

Member	Maximum deflection EC2	Deflection under loading
Connecting slab	0.002m	0.0002m
Cantilever wall	0.0376m	0.0228m

Table 5.2: Deflections in jetty connection members

The deflections are small enough to ensure the concrete will remain intact. It is however important to note that these deflection have been calculated for standard loading and extreme loading situations, for example incidents like one of the cranes moving over the slabs, are not considered.

5.2. TERMINAL DESIGN

In the previous design sections the hydraulic structures for the reclaimed land are designed. The following sections will elaborate on the design of the terminal considering the reclaimed land. The design of the terminal exists of the new port layout after the land reclamation and the additional port operations. Furthermore, the port layout is designed for the situation in 2025.

5.2.1. PORT LAYOUT

From an operational point of view, three reasons can be appointed for reclaiming land (Garcia, 2019). Firstly, the reclamation of land will create more space in order to separate the containers in the stacking area. This can make the stacking system process more efficient, since the yard is better organised. Secondly, the land reclamation will contribute to achieving the KPI of 100 container movements per hour. Achieving 100 container moves per hour indicates the efficiency of the port operations. Third and lastly, the land reclamation will accommodate for the predicted container throughput in the San Vicente port. These reasons are taken into consideration when designing the new port layout.

The port layout is designed in several successive steps, in Appendix C every step is discussed extensively. Firstly, the components in the port are determined. Secondly, the basic structure of the port is identified. Thirdly, the demand forecast from Appendix A is used to calculated the required storage area in the future. After that the components are one by one added to the design. The first component implemented in the basic structure is the area for export containers, then an area for (break)bulk and reefers, followed by an area for the empty containers. Finally it is examined how the containers are organised in the storage yard. For the final design of the new port layout the traffic lanes inside the port are also added.

BASIC STRUCTURE

The port consists of several components. In Figure 5.9 all the components are represented in the current layout of the San Vicente port. It is important to note that the San Vicente port also handles import containers, yet those are stored on an external area. Furthermore not all empty containers are stored inside the port. A surplus of empty containers for which there is no place inside the port, is also stored in the external area.

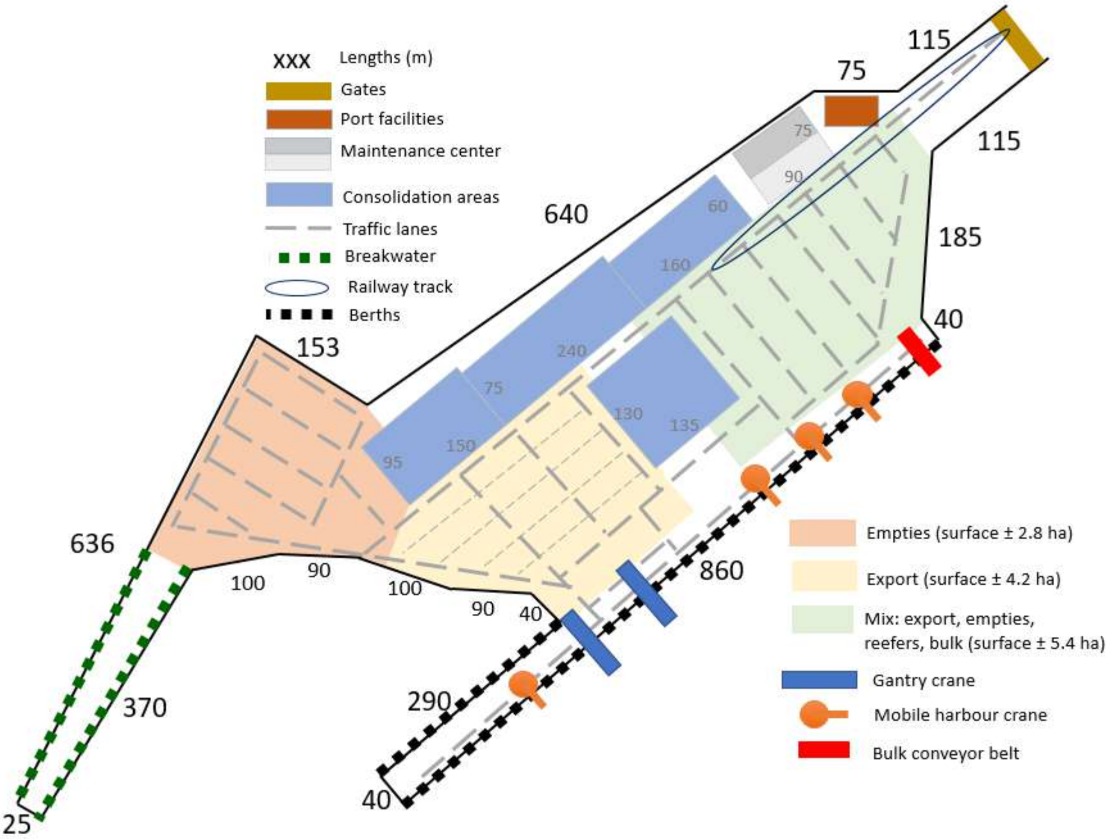


Figure 5.9: Current layout of the San Vicente port

In the current layout the port infrastructure can be divided into hardware and software. The hardware are all components that are not easy to relocate in the port. On the contrary, the software is flexible and can be relocated. In Figure 5.10 the basic structure of the port including the reclaimed land is represented. With the grey dotted lines the original quay of the port is indicated. The red dotted lines mark the reclaimed land.

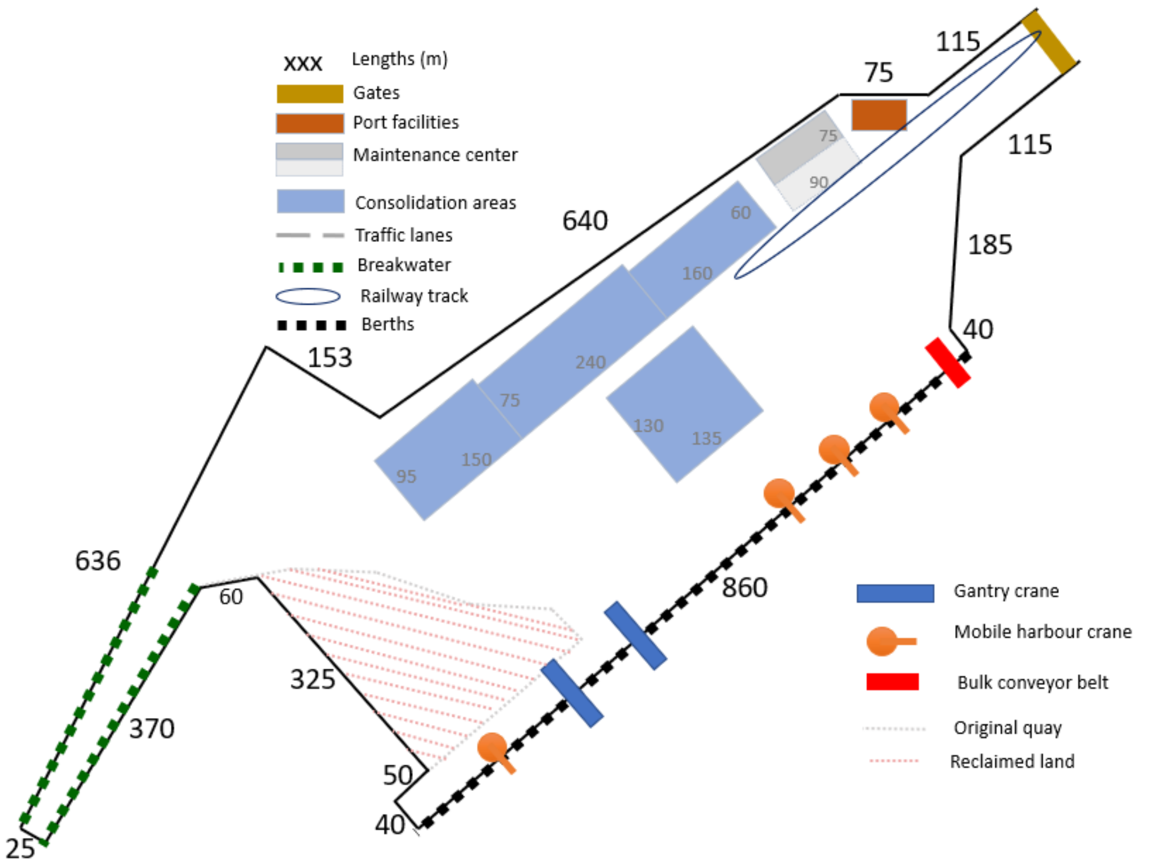


Figure 5.10: Basic structure of the new layout of the San Vicente port

Final design

Successively, the container categories (export, empty and import) are implemented in the new layout. The area needed per category is calculated with the demand forecast model, see Appendix C.1.3. The import containers and a surplus of the empty containers remains to be stored in the external area. It is desirable that all export containers are stored inside the port. This is preferred over storing empty containers inside the port when storage capacity is limited. The reason for this preference is based on the service efficiency of vessels. Arrangement of the export containers is more important when one looks at the efficiency of serving the vessels. Empty containers must first be consolidated before they can be exported, it is therefore more suitable to store those outside the port when space is limited. There is enough time to transport the empty containers to an area outside the port and back again for consolidation, without affecting the efficiency of serving the vessels too much.

The last component that needs to be added to the port layout design are the traffic lanes. In Appendix C.2.4 the details about the container organising is discussed. In the new layout the containers are organised in smaller subareas to increase container accessibility. In the smaller subareas the containers can be organised based on criteria, such as weight, length, function and destinations. Between these smaller subareas the traffic lanes are designed.

In Figure 5.11 the final port layout is proposed. Note that the design is made with the aim to improve port operations and make them more efficient. Therefore the container yard is located directly behind the cranes and the traffic lanes are straight. Moreover, there are quite some paths between the containers inside the storage yard. This will improve container separation and container accessibility, increasing the efficiency of the operations. However the roads might increase the A_{TEU} factor which may decrease the storage capacity slightly. Yet this is uncertain and will need further research.

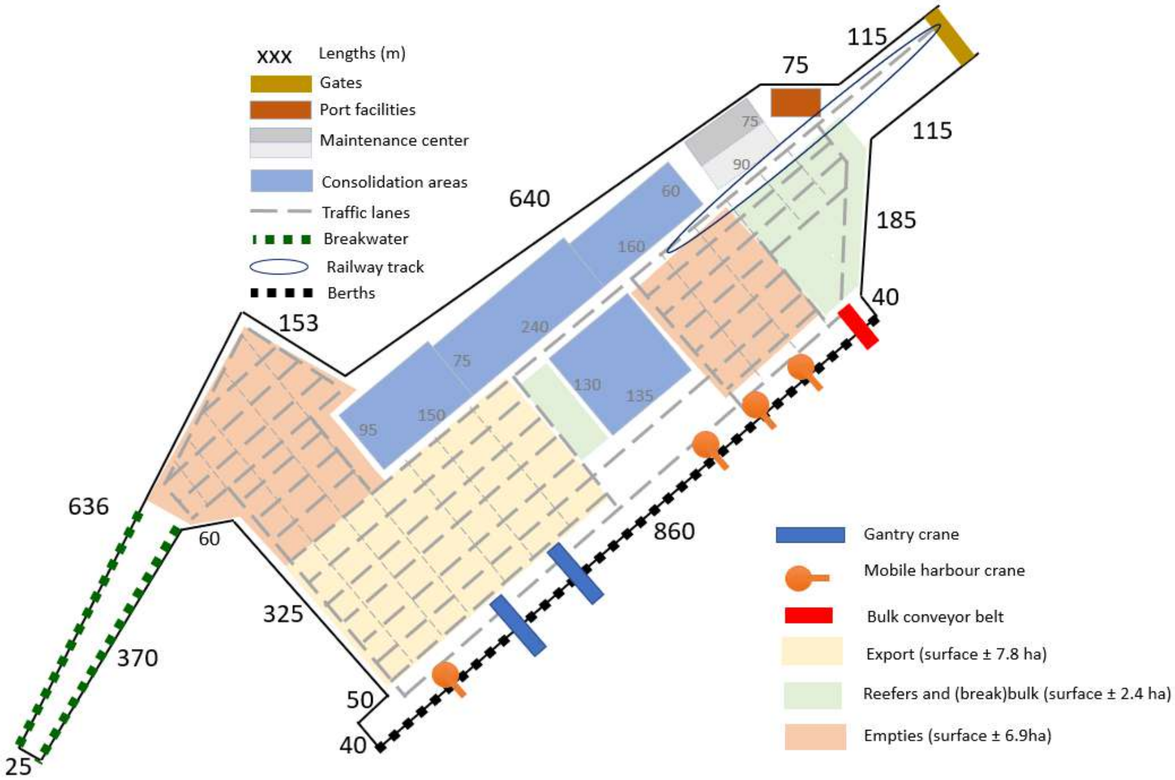


Figure 5.11: Final design of the new port layout

Alternative port layout

The new layout design is based on the most common situation in the San Vicente port where only one container vessel is mooring at the same time. In the future it is expected that occasionally two container ships moor at once. When this happens it improves the port operations if the export container storage is extended behind the other cranes at berth 1 and 2. Since the storage area for containers is not considered as hardware, the port could change the exact location of the export containers if necessary. The space required for storage space is not very large since only small container ships can moor at berth 1 and 2 because of the small depth. An alternative port layout in the event that two container vessels need to be served at once, is represented in Figure 5.12.

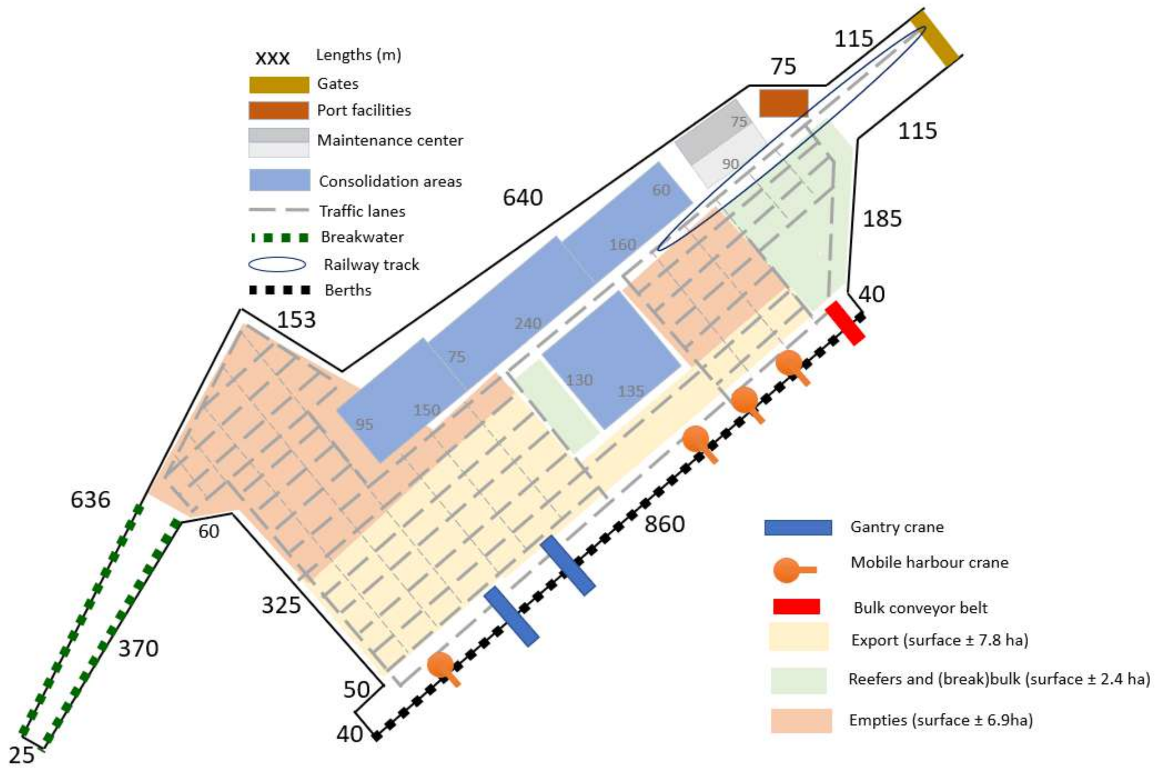


Figure 5.12: Alternative port layout in the event that two container vessels must be served at once

5.2.2. Port operations

The operations in the San Vicente port after the land reclamation will be very similar to the current operations (Appendix D). The only difference in the port operations with the land reclamation and without, is the container handling between the cranes and the storage area. With the land reclamation the containers are stored directly behind the cranes along the entire length of the quay. This improves the handling of containers as the shape is more efficient (Ligteringen, 2017; Garcia, 2019). Furthermore, future plans concerning investments in new equipment or other changes in port operations are not known.

Optimising port operations

As mentioned above, there are no plans for changing the port operations. Even though, the port expansion would be a perfect opportunity for the port to change somethings in the port operations to further improve efficiency. In this section a plan concerning the optimisation of the port operations is briefly described (also see Appendix C.4). The reason for this is to give the port of San Vicente an idea about how they could improve the port operations accordingly within the new layout. The optimisation of the port operations will be mentioned for each sub process separately.

Quay

During the event that multiple vessels require service, the mobile harbour cranes and two gantry cranes are not efficient enough to reach the desired handling capacity. Therefore additional gantry cranes should be purchased to optimise port operations in the future.

Internal transport

Internal transport should also be upgraded in order to deal with the event of multiple vessels mooring at once in combination with the establishment of extra gantry cranes. This could be done by investing in a multi trailer system or automated guided vehicles. As a result the internal transport would be optimised making the port more future proof.

Stacking system
An optimal stacking system is achieved using stacking equipment such as straddle carriers, rubber tired/rail mounted gantry cranes or overhead traveling cranes. Such stacking equipment speed up the stacking activities, making the stacking system very efficient (Ligteringen, 2017).

Continental transport
In order to minimise the queues, the gate operations should be optimised. Continental transport operations in the San Vicente port could become more efficient if the truck appointment system is improved. In the optimal situation the cargo flows are smoothed over the entire day, lowering the pressure on the port gates.

6

Design evaluation

This chapter describes the effect of the land reclamation on the hydrodynamics inside the port. Subsequently the effect on different stakeholders and hinterland are elaborated.

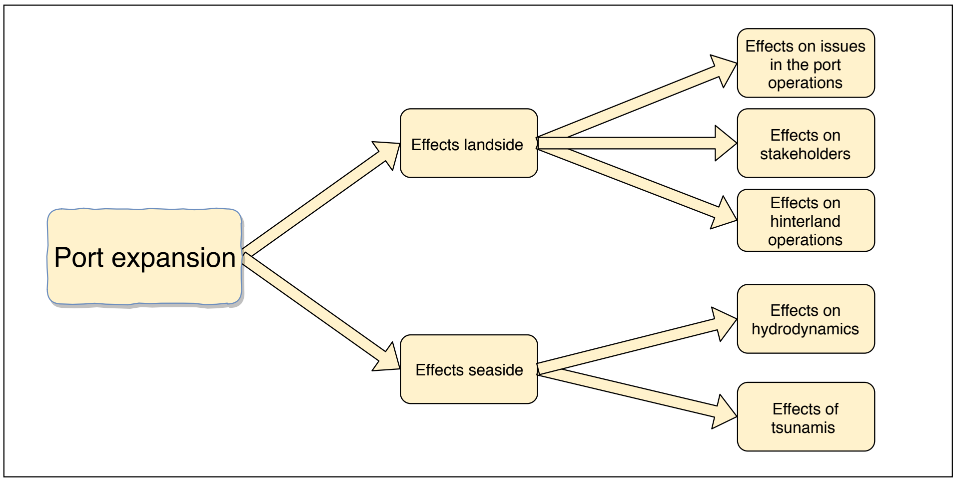


Figure 6.1: Evaluation of the design of the Expansion

6.1. Hydrodynamics

The hydrodynamics inside the port should not be influenced by the land reclamation in such a way that the manoeuvring and mooring conditions for vessels will not be negatively affected. This is set as a strict requirement for the land reclamation. Only then the downtime of the port will not be affected in a negative way. The two main aspects that determine manoeuvring and mooring conditions inside the port are the wave climate and the currents. Section 2.2.2 describes that currents do not play a significant role in the San Vicente bay area. Therefore only the impact on the wave climate is investigated.

6.1.1. Delft3D model

In order to investigate the wave climate inside the port area after land reclamation the software Delft3D-Flow is used. This computer software is useful for the simulation of multi-dimensional hydrodynamic flows and sediment transport phenomena. A computer model is built that uses online coupling of the wave and flow module. This is the most accurate coupling method of Delft3D-Flow. The Delft3D-Flow module accounts for the following hydrodynamic processes inside the bay area: shoaling, refraction, diffraction, reflection, dissipation and nonlinear wave-wave interactions (both quadruplet and triads). The Delft3D model is used to translate offshore wave data to the area of interest, the port of San Vicente. A more in depth analysis on the computational grids, the bathymetry grids, the boundary conditions, the implementation of structures and the model setup can be found in Appendix H.

6.1.2. Offshore wave climate analysis

The Delft3D model requires offshore wave input parameters at the boundaries of the computational grid. A wave analysis is performed on the wave data that was retrieved by a wave buoy. This analysis is stated in 2.2.3 and the result is depicted in Table 2.3. The different scenarios are implemented in the Delft3D model.

6.1.3. Model results

In order to evaluate the wave climate inside the port area after land reclamation, several monitoring points are added to the model. These model points enable a visualisation of the wave heights at different locations inside the port. Figure 6.2 displays the monitoring points. Also the implemented breakwater, quay and land reclamation are visible.

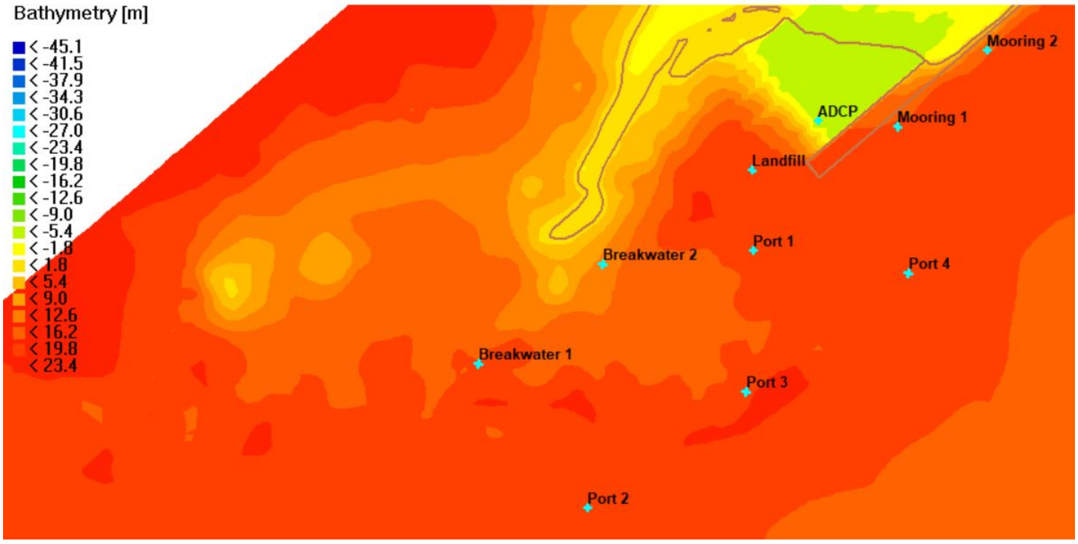


Figure 6.2: Monitoring points inside the port area

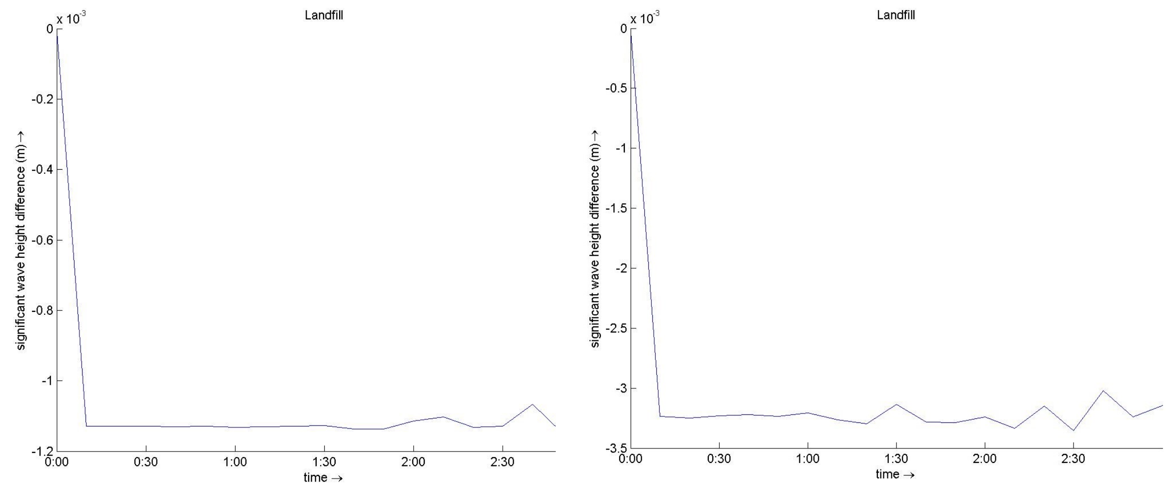
Each scenario from Table 2.3 is modelled two times, one run does include the land reclamation and the other one does not. Subsequently a comparison is made between wave heights at each monitoring location for the run including the land reclamation and the one without. At first sight the outcome was quite surprising, the wave heights did hardly show any difference when the land reclamation was included in the model. The largest difference has a value of 9.5 millimeters. Table 6.1 gives an overview of the calculated wave heights at each monitoring location for the different scenarios. Since the above mentioned difference between wave heights is so small only the wave heights for the model runs including the land reclamation are given.

ADCP is the location of the wave buoy inside the harbour. This buoy retrieved a data set that was used for validating the model, which is described in Section H.5. At this location the calculated wave height is equal to zero for each scenario because of the presence of the land reclamation. The location *Landfill* is closest to the land reclamation.

	Mooring 1	Mooring 2	Port 1	Port 2	Port 3	Port 4	Breakwater 1	Breakwater 2	Landfill
Scenario 1	0.19	0.10	0.36	0.31	0.30	0.32	0.45	0.35	0.15
Scenario 2	0.38	0.20	0.68	1.06	1.24	0.72	1.57	1.02	0.40
Scenario 3	0.48	0.25	0.86	1.09	1.12	0.64	1.48	1.40	0.54
Scenario 4	0.50	0.26	0.88	1.52	0.88	0.73	1.45	1.59	0.55
Scenario 5	0.57	0.32	1.08	1.65	1.47	0.82	2.17	1.77	0.61

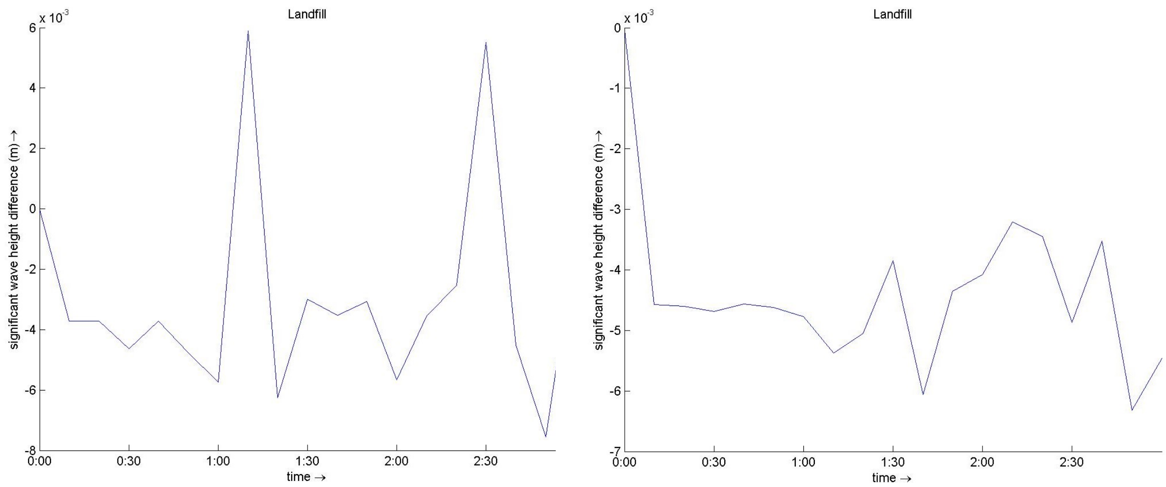
Table 6.1: Calculated wave heights [m]

Since it is expected that the wave heights at the monitoring point *Landfill* will be affected the most because of the small distance to the land reclamation, plots are made which show the difference between the wave heights after and before the land reclamation. This difference is calculated by abstracting the wave heights before the land reclamation from the wave heights after land reclamation. The plots are depicted below and start with wave input scenario 1, followed by scenario 2, scenario 3, scenario 4 and scenario 5.



(a) Wave scenario 1 (b) Wave scenario 2

Figure 6.3: Wave height difference, calculated by abstracting the
wave heights before the land reclamation from the wave heights after land reclamation at *Landfill* monitoring point for wave scenario 1 and 2



(a) Wave scenario 3 (b) Wave scenario 4

Figure 6.4: Wave height difference, calculated by abstracting the
wave heights before the land reclamation from the wave heights after land reclamation at *Landfill* monitoring point for wave scenario 3 and 4

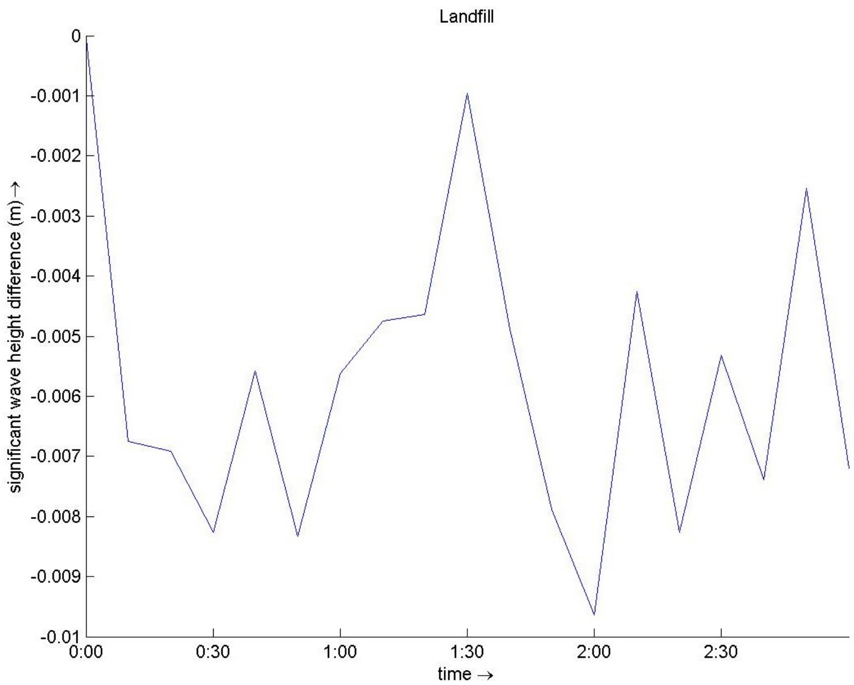


Figure 6.5: Wave height difference, calculated by abstracting
the wave heights before the land reclamation from the wave heights after land reclamation at *Landfill* monitoring point for wave scenario 5

From Figures 6.3, 6.4 and 6.5 it becomes clear that the largest difference between wave heights after and before the land reclamation is about 9.5 millimeters. Even tough the monitoring point is very close to the land reclamation, wave heights are only affected in the order of millimeters. Since the wave heights it selves are in the order of meters, this difference is very small. It is concluded that the mooring and manoeuvring conditions are not negatively influenced by the land reclamation. The downtime of the port will therefore not decrease.

6.2. TSUNAMIS

As the hydrodynamics are simulated for a relatively normal state, it is interesting to analyse if the reclaimed land will be heavily damaged in case of a tsunami. Using the simulations from the NEOWAVE model provided by Civil Engineering student V. Valdivia, it was possible to generate 50 scenarios in the seismic region of Central Chile. The 50 stochastic earthquake scenarios all have a magnitude M_w 9.0 on the scale of Richter. For further elaboration on the simulations see Appendix L.

With the results of the earthquake simulations, an analysis can be made on what kind of tsunami will be generated that could damage the port. For this analysis 4 location near the port have been selected. Figure 6.6 is a satellite map overview of the chosen locations and in Table 6.2 the latitudinal and longitudinal coordinates are given for each location.

	Latitude coordinates	Longitude coordinates
Location 1	-36.734476	-73.143848
Location 2	-36.731667	-73.148056
Location 3	-36.732008	-73.135651
Location 4	-36.736253	-73.160340

Table 6.2: Coordinates of the four chosen locations

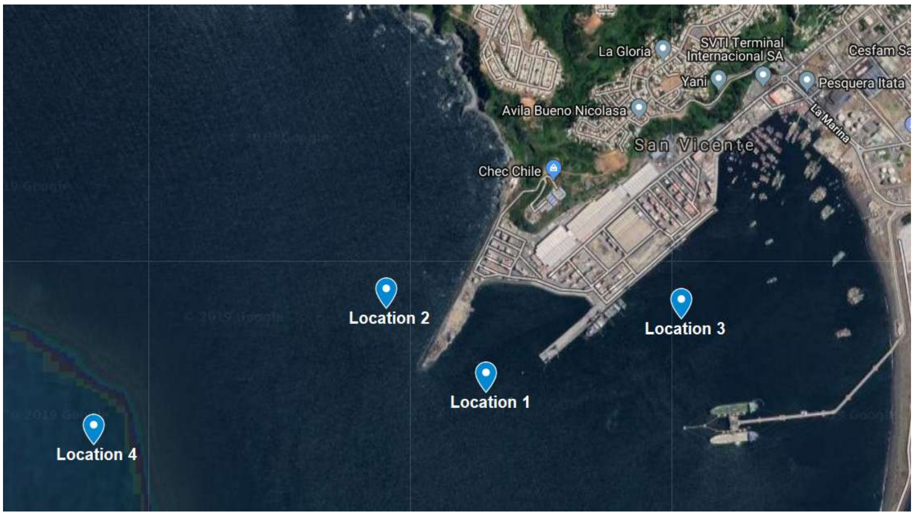


Figure 6.6: Satellite map overview with the four locations

Through the data retrieved from the simulation it was possible to plot the following diagrams for each of the four locations. In Section L.2 all the diagrams can be found for the locations.

- **Water level vs. Time** (see Figure L.3 - L.6)
  The time series from the diagrams Water level vs Time is used to determine the exceedance curves.
- **Exceedance probability vs. Water level** (see Figure L.7 - L.10)
  The probability of exceedance is calculated using empirical CDF.
- **Water level vs. Return period** (see Figure L.11 - L.14)
  For the return period Equation 6.1 is used, where the recurrence rate is set at 500 years (Dura et al., 2014).

$$T_r = \frac{1}{\frac{1}{\lambda} \cdot P_{exc}} = \frac{1}{\frac{1}{500} \cdot P_{exc}} = \frac{500}{P_{exc}} \tag{6.1}$$

All the diagrams related with location 1 are depicted below in Figure 6.7 to 6.9.

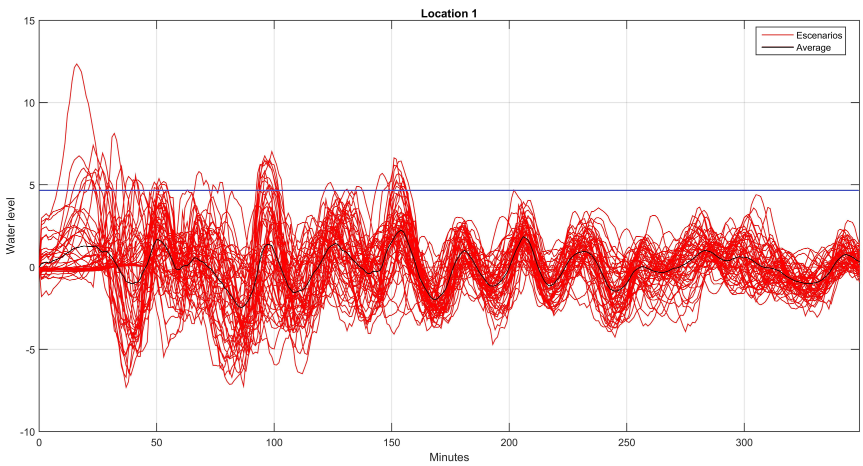


Figure 6.7: Time vs Water level for location 1

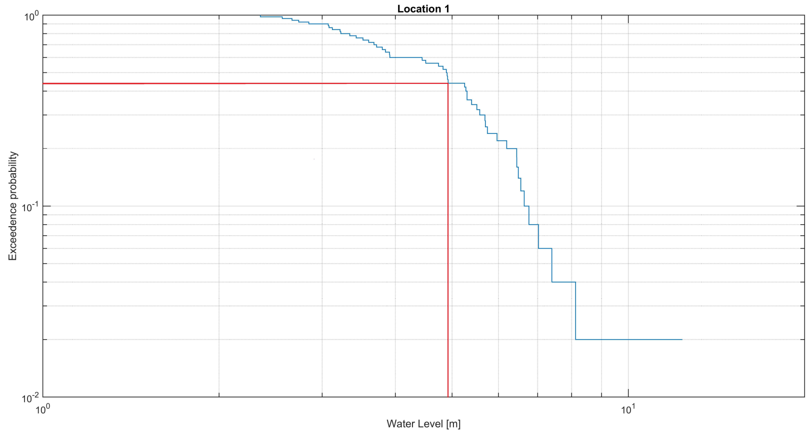


Figure 6.8: Water level vs Exceedance probability for location 1

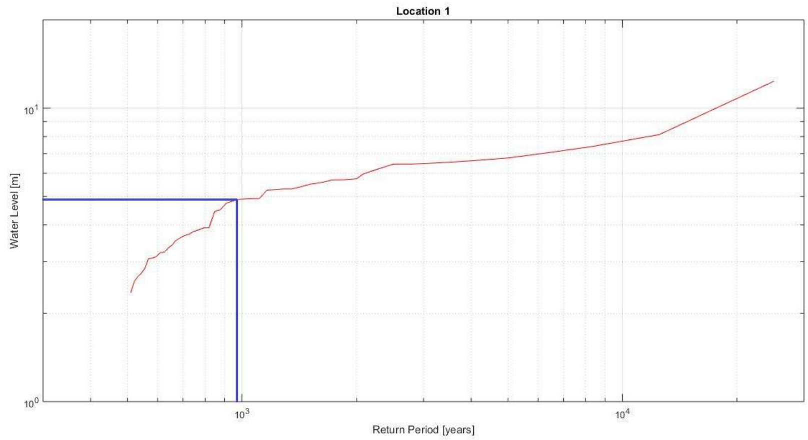


Figure 6.9: Return period vs Water level for locations 1

In Table 6.3 an overview is given of the exceedance probability and return period for each of the location. The exceedance probability and return period is determined based on the maximum allowable water level (inundation height) in the port, which is equal to 4.8 meters as stated in Section 5.1.1 (Bardi, 2013). This maximum allowable water level is marked with a line in the figures in Section L.2, which help to read the relevant parameters value from the diagrams.

As can be seen from the table, location 2 and 4 have a low probability of exceeding the inundation height (respectively ~ 30% and ~ 28%) with a very large return period (both ~ 1750 years). These locations are less relevant to the port compared to the other two, as those will have a direct impact on the port and its operations. For locations 1 and 3, the locations closest to the quay, the exceedance probability are respectively ~ 45% and ~ 65% and a corresponding return period of ~ 975 years and ~ 780 years. From this can be concluded that the risk of the port being flooded at such an event is still low, because it has a return period of roughly 800 years.

Location	Exceedance probability	Return period
Location 1	~ 45%	~ 975 years
Location 2	~ 30%	~ 1750 years
Location 3	~ 65%	~ 780 years
Location 4	~ 28%	~ 1750 years

Table 6.3: Overview of data set for the known maximum allowable water level of 4.8 meter

In the event of an earthquake that generates tsunami waves the port should be able to react accordingly. If it is possible (within the time frame of the tsunami arriving at the port) vessels should be navigated to open water out of the vicinity of the port. This in order to prevent or minimise collisions. From the water level vs. time diagrams, see Figures L.3 to L.6, can be stated that the after roughly 25 minutes the first big tsunami waves generated by the earthquake will arrive at the port. For the port this time frame is extremely valuable. Given the fact that there is a vessel inside the harbour they need to decide whether it is achievable to navigate the vessel away or not. A vessel that is being unloaded will not be able to be moved in time. A vessel just arriving might still be navigated back to open water just in time.

Another aspect that should be considered is that after the first large wave a large drop will follow, as can be seen in Figures L.3 to L.6. This means the location for evacuation of the vessels should not be in too shallow water, to prevent the vessel from hitting the seabed. Although the water depths near the port of San Vicente increase rapidly, as can be seen in Figure F.11.

Besides the emergency protocols for vessels, the protocol in the port should be familiar. All port employees should know what to do and where to evacuate to. Standard procedure states to evacuate to high grounds. Also the backup power and communication system should be available and tested. All these measures are meant to mitigate the risk and reduce the damage to the port and the number of casualties.

6.3. Problems in the port operations

With the reclaimed land and the new port layout the purpose is to make port operations more efficient and to be able to accommodate for the predicted container throughput increase. Based on the problems that are expected in the future without the land reclamation (described in Section 3.3 about the port operations), the new layout design is evaluated. Table 6.4 provides an overview of the expected problems in the future that may or may not be prevented by reclaiming the land. In Appendix C.3 an extensive explanation is given per expected issue.

Expected problems in the future, no land reclamation	Prevented by reclaiming land?
Crane capacity	NO
Inefficient shape of the port	YES
Road capacity inside the port	YES
Organising containers	YES
Storage space inside the port	YES
Stacking equipment	NO
Gate capacity	NO

Table 6.4: Overview of problems and effect of land reclamation

All in all the land reclamation is a success as it solves issues the port is currently facing or will face in the future. According to the evaluation, the land reclamation can prevent most of the expected problems. Yet not all expected problems can be prevented by reclaiming land. This implies that the cranes, the stacking equipment and the gates will cause issues in the future, even though the port has been expanded. To solve the remaining issues, the port operations optimising plan should be considered, see also Section 5.2.2.

6.4. Hinterland operations

The port wants to prepare itself in order to accommodate for future expansion. In that way it will be able to deal with the expected demand. This section provides an analysis on whether the connecting, urban and hinterland roads (as specified in Chapter 2.1.3) are also able to withstand the increasing demand. This will be examined according to the following questions:

- What is the amount of extra truck movements?
- In what way will these movements be divided across the different roads?

- Do the extra truck movements have a significant influence on the traffic flows?

The current container flows (Figure 6.10) are compared with the expected container flows in 2025 (Figure 6.11) in the case of a 45% market share. Based on this comparison an estimation on the number of extra truck movement is made. The port expansion is mainly executed in order to increase the container throughput. The extra truck movements solely depend on the increased demand for containers. In total 20% of the tonnage for consolidation enters the port by train (Empresa Portuaria Talcahuano San Vicente, 2017). All goods for export that reach the port are either transported by truck or train. It can therefore be assumed that 80% of the consolidation goods are transported to the port by truck. The total amount of TEU entering the port is the sum of the export containers coming from the road and 80% of the consolidated TEU. A calculation was performed in order to express this amount of transport in truck movements per day (Appendix E.4.1). It was determined that for the current situation there is a total of 300 trucks moving into the port each day. For 2025 it is expected that a total of 450 trucks will move into the port every day. Hence 150 trucks are moving into the port extra each day. In order to obtain the amount of vehicles per hour the amount of trucks is multiplied by a factor of 2.5 (Empresa Portuaria Talcahuano San Vicente, 2017). The result, 375 vehicles, is the extra amount of vehicles that will move into the port each day. The extra traffic flow is therefore equal to 375 vehicles per day. If the same calculation is performed for 2045 (in case of a 50% market share) this would give an extra traffic flow of 1250 vehicles per day.

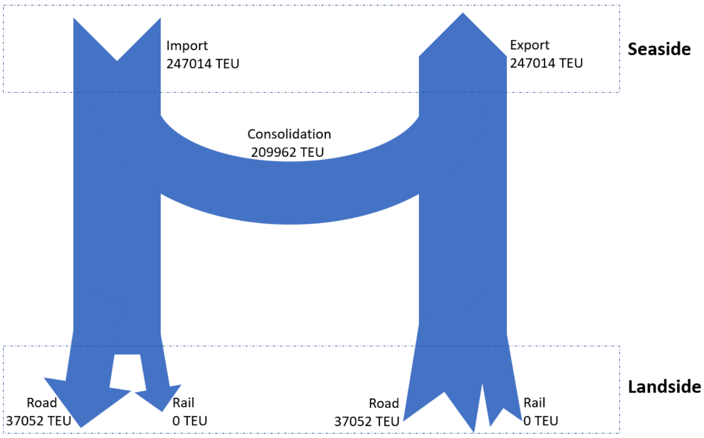


Figure 6.10: Container flow in San Vicente port current situation

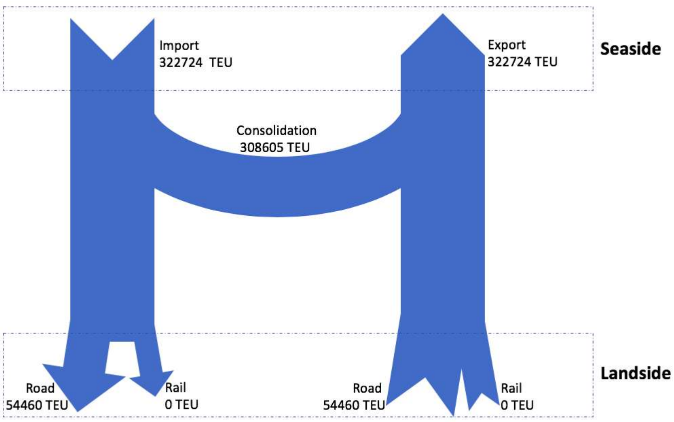


Figure 6.11: Container flow in San Vicente port based on forecast 2025, 45 percent market share

The MAPA project is one of the major projects that will increase future growth in the Biobío region, see Appendix A. As a result of the MAPA project the traffic on route 160 will increase significantly. The other two ports in the Biobío region, the ports of Coronel and Lirquén, are also expected to benefit from the MAPA project. Both of these ports are restricted to use route 160 for the transport of goods since there are no alternatives. This means that route 160 will have to accommodate for all the extra traffic that will be generated by the MAPA project. The expectation is that the MAPA project will have a major influence on the demand of the port of San Vicente. The effect on the other three main routes is therefore assumed to be limited. The other three routes have more possibilities to spread out when they approach the urban area. This results in dispersion of the traffic. All traffic will eventually come together at the main access road of the port, which is called La Marina. This means that La Marina needs to be able to accommodate for all extra traffic that is induced by the port expansion.

Considering the traffic flows in the future, the analysis provided in Appendix E.4.3 shows that route 160 and the access routes are the only critical routes. The effect on the other hinterland and urban routes will be negligible. Route 160 is already subject to congestion issues. Still it will have to accommodate for extra traffic towards the other two ports because of the MAPA project. Many factors are unclear in order to give accurate formulations about congestion issues in the future. The analysis provided in Appendix E.4.3 shows that more research into this matter is required. A proposal is given in Appendix E.4.4. The conclusion is that the extra research should give more clarity into the capacity of the road and the current traffic flows. The next step is to investigate how much extra traffic flow is generated by the MAPA project towards all the ports in the Biobío region. With this information it will be possible to give an estimate on future traffic states. Also, a bottleneck analysis with information about current speeds and traffic flows can be executed. If it is clear where the congestion issues originate, expectations can be formulated on whether the construction of a new bridge might solve these issues. Since there are new plans to construct a bridge such investigations might be interesting (Villagrán, 2019).

The situation for the connecting routes is different than the situation for route 160. The traffic flows on these roads are not critical. Almost all extra traffic comes together on these roads which have a relatively low capacity. The expectation is that the access roads should be able to accommodate the extra 375 expected vehicles for 2025, see Appendix E.4.3. The situation for 2045 is different. It heavily depends on the ability of the port authority to spread the incoming traffic across the day. An elaboration on this appointment system is given in Chapter 2.1.2.

6.5. Stakeholders

The port has a lot of stakeholders. This section will analyse on how the critical stakeholders, which were identified in Section 2.1.1, will react to a possible port expansion. Furthermore it will give advice on how the port authority should manage these stakeholders.

The first group of stakeholders is identified as a group that has the same interest as the port authority. It is therefore expected that they will not stand in the way of a possible land expansion. The first stakeholder, SVTI, is expected to have exactly the same interest as the port authority. Both parties want the port to become more efficient and to create more capacity to accommodate for future growth. The second stakeholder, Arauco Mill, will benefit from the expansion as it will promote the possibility of exporting their forestry goods from the MAPA project. The other stakeholders, the shipping lines, will benefit due to lower service times at the port of San Vicente.

Another stakeholder, CRUBC, is responsible for managing initiatives along the Chilean shoreline. This will be an important stakeholder to manage closely. The CRUBC has an independent role. They are therefore not in favour nor against the project on forehand. Nevertheless, the port expansion is expected to have undesirable effects on fishery and the community of Talcahuano. CRUBC also represents their opinions. They include those opinions before they give an advice to the National Committee about giving a permission for the expansion. The port authority must therefore convince CRUBC that there are no major consequences for the other stakeholders. On the other hand they can also show that the benefits outweigh the negative consequences. A possible benefit that the port might highlight is local economical growth. CRUBC will also give their advice to the navy on whether the expansion could possibly cause a threat on seaside. The current expansion plans are within the current territory of the port of San Vicente. It will therefore not be hard to convince CRUBC on this part.

The second group of stakeholders consists of stakeholders that are regarded as opponents to the port expansion.

The SAE Chile is one of the most important stakeholders that is regarded as an opponent. The port expansion will have a bad influence on the environment. SAE Chile tests the port expansion on different environmental norms and criteria. They have procedures to test whether the expansion can be performed. The port authority can evaluate and change the design of the land expansion based on this set of norms and criteria. Consequently the port can propose an expansion plan which directly fulfills this requirements.

The second stakeholder is the municipality and community of Talcahuano. The port expansion will be beneficial for the whole Biobío region, however the municipality and community of Talcahuano are mainly feeling the drawbacks. This stakeholder is therefore presumably against a port expansion. The municipality should therefore be managed very closely so that agreements can be made about possible consequences of the port expansion. The port could for example think about an arrangement to minimize traffic hindrance in the city. A possibility might be that the port expansion will only induce traffic within Talcahuano outside of the rush hours. Furthermore, the port authority should emphasize the opportunities that the land expansion has for the city of Talcahuano. If the inhabitants of Talcahuano are not convinced about the benefits of the project the municipality will probably do anything within their power to stop the project.

6.5.1. Competition

The expansion of San Vicente port will be a drawback for the competitive ports Lirquén and Coronel. The layout of San Vicente port already is more efficient than the other ports. With the expansion, the storage yard can be located directly behind the STS gantry cranes, increasing the difference in container handling efficiency with the other ports. It will be interesting to see how the other ports will react. As described in Section 2.1.1 the other ports are private ports. Giving them the opportunity to solely focus on profitable cargo. Looking at the past, the private ports transported a lot of container cargo (Merk, 2016). So this is financially an interesting type of cargo. Therefore it is likely that the private ports will use their financial means to react on the port expansion. Because of the fact that they are private ports there is relatively a lot of money available for investments.

On the other hand, the port of Coronel has little expansion possibilities, as was explained in Section 2.1.1. Investing in more STS gantry cranes seems not valuable as long as the berths are located far from the container terminal. This is due to the fact that there is only a two lane road (one lane in both directions) from the container terminal to the berths. Thus it is expected that this currently forms the bottleneck with respect to container handling. It is therefore difficult for the port of Coronel to react on the port expansion of San Vicente. It will be interesting to see which port will have a lower service time for vessels once the expansion of San Vicente is ready. Coronel benefits from more STS gantry cranes and San Vicente benefits from a more efficient layout. Based on the service time, shipping lines could decide to change to the competitive port. In any case, the future prospect of San Vicente is better. Changing equipment to make the port operations more efficient is easier then reclaim land and change the port layout. Coronel also does not have a strategic location compared to the hinterland companies, except for Arauco Mill. This could make them in the future very dependent on Arauco Mill and the MAPA project.

The port of Lirquén has more opportunities to make their operations more efficient in the future. Nowadays they only use mobile harbour cranes, in the short run they may decide to invest in STS gantry cranes to improve their competitive position. Still they will have the limitation of locating their cranes a large distance from the container terminal as mentioned in Section 2.1.1. Lirquén has the advantage that they are currently not operating to their full capacity. This gives some room for growing container throughput without the need for an expansion. Because Lirquén is acquired by DP world this will give them a competitive position. The company can force their clients to import goods that are destined for the Biobío region through the port of Lirquén. Consequently Lirquén does not necessary need to be the most efficient port to win clients in the coming years. Therefore it is expected it is easier to gain advantage from Coronel compared to Lirquén.

7

Conclusion and Recommendations

In this chapter, the conclusions from the previous chapters are given. Subsequently recommendations for future research will be provided.

7.1. Conclusion

This project has focused on improving the port of San Vicente which has been losing market share in the region. Using economic forecasts from the Biobío region and the current market share, it was found that the port of San Vicente cannot cope with expected growth needed to compete with other ports in the near future. It was then found that in order to become competitive again, both the capacity of the terminal should be increased, as well as increasing the handling capacity of the port. The former to accommodate increased throughput (from 260000 boxes or 483600 TEU annually to 1613620 TEU annually in 2025), the latter to regain competitiveness in unloading vessels by achieving the KPI of 100 moves per hour, set by SVTI.

This study has focused on creating space in the port to accommodate growth of the previously mentioned parameters. As the port of San Vicente has little opportunity to expand due to its position on a headland and the neighboring fishery harbour, an expansion into the sea is needed by means of a land reclamation.

After evaluating various options in the designated area in the bay in Chapter 4 considering economic growth of the harbour and incorporating desired growth, option B was identified to be the most suitable alternative for a land reclamation, following the MCA conducted in Chapter 4.

For this land reclamation, a final design was made in Chapter 5, designing the following elements:

- Revetment
- Land fill
- Jetty connection
- Terminal layout
- Terminal operations

These elements were tested and found to be sufficiently strong. In Chapter 6, the effect on the hydrodynamics near the berthing locations was found to be negligible. The extra operations will lead to increased congestion in the region. This will be most notable on route 160, but also inside the port. As the port continues to grow the current crane capacity, stacking equipment and gates will not suffice. As route 160 is a regional matter to tackle, the port can focus its efforts on optimising operations by acquiring more crane capacity (STS cranes preferably), optimising internal transport, rearranging the container terminal's stacking areas to accommodate RTG's and improve the truck appointment system to minimize queues at the gates.

7.2. Recommendations

The limitations concerning this report will be highlighted. Furthermore, recommendations for future research will be presented.

Data

- Obtain more accurate data on terminal parameters (Teu factor A_{TEU}, average stacking height r_{st}, average occupancy rate m_c, current container terminal area A and dwell times $\overline{t_{d,import}}$, $\overline{t_{d,export}}$, $\overline{t_{d,empties}}$)
- Obtain more extensive traffic data from inside the port for an accurate bottleneck analysis
- Obtain recent soil samples for a more extensive geotechnical analysis
- Obtain more accurate information on the Biobío sand that will be used for land reclamation
- Obtain data on external locations of the port
- Obtain more data on the expected growth of other commodities inside the port

Modelling

- Use other software to model the hydrodynamics, in order to compare results
- Further investigation in how to model the jetty construction and the revetment
- Investigate how parameters like the reflection coefficient and the transmission coefficient have an influence on the resulting wave heights in the port
- Include more offshore wave scenarios to increase reliability

Design

- Conduct further research into optimisation of the jetty connecting cantilever wall
- Research on scour in the submarine mound supporting the cantilever wall due to bow thrusters from vessels
- Conduct further research in the seismic resistance of breakwaters with sheet piles
- For future port expansions, consider the nautical manoeuvrability around the berths as a design requirement
- Conduct further research on the impact of new cranes and stacking equipment
- Conduct further research on the optimisation of the terminal layout

Construction

- Develop a construction plan to highlight possible problems that might occur when translating design into reality
- Execute a study on the impact of the construction on port operations
- Execute a study on the availability and costs of the required equipment such as dredgers, excavators, piling machines, dump trucks
- Execute a study on the availability of required material such as sand and rocks

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A

CALCULATION CONTAINER YARD AREA

This Appendix elaborates on how the required storage area for the container terminal was determined. The parameters that were provided by the port authority and those that are determined together with the port authority are given in Table A.1. Subsequently, a brief description will be given on the demand forecast for the port of San Vicente. The demand forecast is the main piece of information that is used to evaluate how much land is needed for the future. Finally a small analysis is performed on two parameters that are a bit uncertain.

A.1. THEORY

The parameters that were obtained in order to determine future storage yard area are depicted in Table A.1.

	Value	**Unit**
$Throughput$	488754	[TEU]
A_{TEU}	10	[m^2/TEU]
r_{st}	0.9	-
m_c	0.7	-
$\overline{t_d}_{,import}$	4.5	days
$\overline{t_d}_{,export}$	4.5	days
$\overline{t_d}_{,empties}$	11	days

Table A.1: Container Terminal parameters, provided by SVTI for base year 2017

In addition to the given parameters, SVTI mentioned that import/export rates are equal to 50%/50% (Empresa Portuaria Talcahuano San Vicente, 2017). For export all containers are filled and for import only 15% of the containers are filled (Gribnau et al., 2018). The figures that were obtained for import, export and empties are given in Table A.2.

	Throughput [TEU]
Import	37052
Export	247014
Empties	209962

Table A.2: Import, Export and Empties, provided by SVTI

Formula A.1 was used to calculate the required storage area for import, export and empties with respect to the given throughput. The total required area follows from the sum of the three. This method was applied for both the current situation as well as for the forecasts.

$$A = \frac{N_c \cdot \overline{t_d} \cdot A_{TEU}}{r_{st} \cdot 365 \cdot m_s} \tag{A.1}$$

with	A	= Total required storage area	$[m^2]$
	N_c	= Total number of containers	[-] movements per year
	$\overline{t_d}$	= Average dwell time	$[days]$
	A_{TEU}	= Required area per TEU	$[m^2]$
	r_{st}	= Average stacking height	[-]
	m_s	= Acceptable average occupancy rate	[-]

The number of total container movements N_c is obtained from the performance review provided by the port authority (Empresa Portuaria Talcahuano San Vicente, 2017) and is equal to 488754 TEU / year. Footnote is that these figures date from 2016. Dwell times for import, export and empties were provided by the port authority and are depicted in Table A.1.

The port of San Vicente has a high stacking density. Empties, import and export stacks of containers are stacked closely together in the storage yard. Stacks reach up to 5 containers high. Even the filled export containers are stacked 5 high. Although the port is operated with reach stackers and forklift trucks, the container stacks resemble a densely packed container stack that can be found in terminals operated with for example RTG's. Theoretical reference values for reach stacker and RTG operated storage terminals are found to be around respectively 25-30 m^2/TEU and 6-20 m^2/TEU (Ligteringen, 2017). After consultation with the port authority (Salgado, 2019) a value of 10 m^2 was chosen as the required area per TEU.

The ratio average stacking height over nominal stacking height (r_{st}) is theoretically found between 0.6 and 0.9. As was discussed before, container stacks inside the port of San Vicente are usually 5 containers high. Therefore a value of 0.9 is chosen as average stacking height.

The average stacking height r_{st} and required area per TEU A_{TEU} were derived in theoretical way. Section A.4 provides an uncertainty analysis on these two parameters.

The value m_s is the occupancy rate of the storage area in the container terminal. This value typically varies between 0.6 and 0.7. After consultation with the Port Authority (Salgado, 2019) it was decided to set the acceptable average occupancy rate to 0.7.

For the current port operations a calculation was performed. The outcome shows how much storage area is required for import, export and empties. Results are depicted in Table A.3 below.

	Required area [m^2]
Import	0.73
Export	4.83
Empties	10.04
Total	15.6

Table A.3: Required area [ha] container storage yard for 2017

The current area of the port has been a point of discussion. The Port Authority has defined their current container terminal area as 20.7 ha in their performance review Empresa Portuaria Talcahuano San Vicente (2017). However, the port authority has informed us that the port currently uses 15 ha for storing the containers, of which a part is located outside the port (Salgado, 2019). After consultation 20.7 ha was set as the total area available for container storage of which 15 ha is currently used.

A.2. Demand forecast

A demand forecast for the Biobío region was provided by SVTI (Empresa Portuaria Talcahuano San Vicente, 2017). This forecast is evaluated and used to predict the future throughput of the port. The provided forecast also includes the expected future throughput with respect to the MAPA project. The MAPA project is a large project that is expected to significantly increase future export (ARAUCO, 2018). Since the container throughput is closely linked to macro-economic trends in the hinterland region, such developments should be taken into account. The port authority expects to have a significant rise in container throughput. The container storage area is therefore expected to form an obstacle when one concerns the future planning of the port of San Vicente. The available information in the demand forecast that is related to future container throughput is therefore used for computations.

The current situation in the port of San Vicente is such that import equals export. However, future predictions suggest that import increases slightly more than export. The demand forecast provided by the port of San Vicente highlights two methods of forecasting. The first method focuses on the old situation in which import equalizes export. This method is highlighted as method I in Table A.4. The total throughput simply follows from a summation between import and export. The second method, highlighted as method II, includes the slight increase in import. This method is also referred to as the aggregated total method. Results for this method are also included in Table A.4. A comparison shows a slight difference between the two forecasting methods. The port of San Vicente also expects a slight increase in import with respect to export. It is therefore chosen to work with the second method. Table A.5 shows the figures for export, import and the aggregated total. The last column are the numbers that will be used for the forecasting model.

	I: Total Import + Export [TEU's]			**II: Aggregated Total [TEU's]**		
Years	Pessimistic	Neutral	Optimistic	Pessimistic	Neutral	Optimistic
2017	1.175.095	1.175.095	1.175.095	1.235.068	1.235.068	1.235.068
2020	1.223.566	1.230.566	1.232.623	1.310.259	1.321.036	1.323.632
2025	1.437.794	1.465.114	1.471.102	1.577.272	1.613.620	1.623.806
2030	1.635.524	1.680.839	1.715.322	1.839.586	1.901.049	1.953.425
2035	1.856.047	1.922.110	2.012.709	2.136.601	2.226.629	2.360.899
2040	2.100.953	2.171.665	2.341.503	2.472.627	2.572.083	2.823.966
2045	2.308.684	2.385.734	2.642.878	2.774.196	2.885.136	3.274.277

Table A.4: Projection scenarios transfer loads VIII region 2017-2045, Empresa Portuaria Talcahuano San Vicente (2017).

	Export [TEU's]			**Import [TEU's]**			**Total [TEU's]**		
Years	Pessimistic	Neutral	Optimistic	Pessimistic	Neutral	Optimistic	Pessimistic	Neutral	Optimistic
2017	587.547	587.547	587.547	587.547	587.547	587.547	1.235.068	1.235.068	1.235.068
2020	611.783	615.283	616.312	611.783	615.283	616.312	1.310.259	1.321.036	1.323.632
2025	718.897	732.557	735.551	718.897	732.557	735.551	1.577.272	1.613.620	1.623.806
2030	817.762	840.419	857.661	817.762	840.419	857.661	1.839.586	1.901.049	1.953.425
2035	928.023	961.055	1.006.355	928.023	961.055	1.006.355	2.136.601	2.226.629	2.360.899
2040	1.050.476	1.085.833	1.170.751	1.050.476	1.085.833	1.170.751	2.472.627	2.572.083	2.823.966
2045	1.154.342	1.192.867	1.321.439	1.154.342	1.192.867	1.321.439	2.774.196	2.885.136	3.274.277

Table A.5: Expected transfer loads VIII region 2017-2045, Empresa Portuaria Talcahuano San Vicente (2017).

A.3. Required area

Figure A.1 is a graph that shows the required storage yard area plotted against the time, using the neutral scenario in the demand forecast. Four different scenarios are highlighted. The first scenario assumes a market share of 35%, the second a market share of 40%, the third a market share of 45% and the fourth scenario is very optimistic with a market share of 50%. Also the current surface of the container terminal is added to graph. This graph will be used in Appendix F to set the minimal area that should be reclaimed for different alternatives.

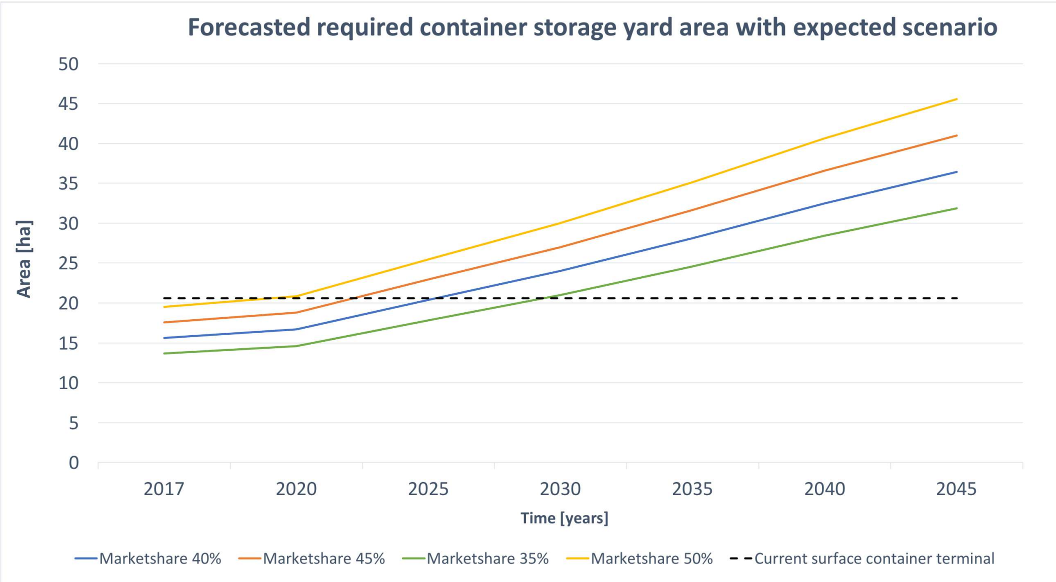


Figure A.1: Projected area for the San Vicente port based on VIII region 2017-2045 projections and varying in market share of the San Vicente port

A.4. Uncertainty Analysis

As stated in the Section A.1, the values found for A_{TEU} and r_{st} are mainly based on theory (with approval of the port authority). These parameters are therefore slightly uncertain. To visualise the possible effect of this uncertainty an uncertainty analysis is performed.

The A_{TEU} is relative low for a storage yard that uses reach stackers. For r_{st} the highest theoretical value is taken. Therefore a scenario is formulated in which A_{TEU} is higher and r_{st} is lower. The provided demand forecast already shows three scenarios: one that assumes low economic growth, one that assumes neutral economic growth and one that assumes high economic growth. To also show the effect of the different growth scenarios this is also considered in the uncertainty analyses. This gives a total of 6 scenarios for the uncertainty analyses.

- **Negative economic growth, high r_{st} and low A_{TEU}**
  This scenario assumes negative economic growth. The values of r_{st} and A_{TEU} are equal to respectively 0.9 and 10.

- **Normal economic growth, high r_{st} and low A_{TEU}**
  This scenario assumes normal economic growth. The values of r_{st} and A_{TEU} are equal to respectively 0.9 and 10.

- **High economic growth, high r_{st} and low A_{TEU}**
  This scenario assumes high economic growth. The values of r_{st} and A_{TEU} are equal to respectively 0.9 and 10.

- **Negative economic growth, low r_{st} and high A_{TEU}**
  This scenario assumes negative economic growth. The values of r_{st} and A_{TEU} are equal to respectively 0.8 and 12.

- **Normal economic growth, low r_{st} and high A_{TEU}**
  This scenario assumes normal economic growth. The values of r_{st} and A_{TEU} are equal to respectively 0.8 and 12.

- **High economic growth, low r_{st} and high A_{TEU}**
  This scenario assumes high economic growth. The values of r_{st} and A_{TEU} are equal to respectively 0.8 and 12.

The 6 scenarios described above are used to evaluate what would be the effect on the results when parameters are different compared to the parameters used in A.1. All scenarios are plotted in the situation that the market share of the port remains 40 percent, shown in Figure A.2.
The scenario used for this research with neutral economic growth and the values for r_{st} and A_{TEU} equal to respectively 0.9 and 10 is depicted in blue. The scenario that assumes negative economic growth and values for r_{st} and A_{TEU} equal to respectively 0.9 and 10 functions as a lower bound scenario and is depicted in green. The scenario that assumes positive economic growth and the values for r_{st} and A_{TEU} equal to respectively 0.8 and 12 functions as upper bound scenario and is depicted in red.

As is clearly visible the scenario with low r_{st} and high A_{TEU} shows that there is a need of 20 hectares of land for storage. This is approximately the amount of storage area that is available right now. Hence this scenario would suggest that the port is already operating at its full capacity. However, observations and consultations with the port authority have shown that this is not true. The parameters that were selected for this scenario are therefore assumed to be pessimistic. Otherwise the port is expected to have more storage yard available then they suggest in the performance review. It can be seen when following this scenario, that the needed container storage yard is increasing more rapidly. This would mean that in an earlier stadium more surface of land should be reclaimed. Although this scenario is not according to the expectations, it makes clear that it is important to get more certainty about the parameters.

The lower bound scenario shows that it the effect of the pessimistic economical scenario compared to the neutral scenario is relative limited. This would suggest that even when the region would have an economical growth according to the negative scenario, in the longer term Port San Vicente still needs to reclaim land.

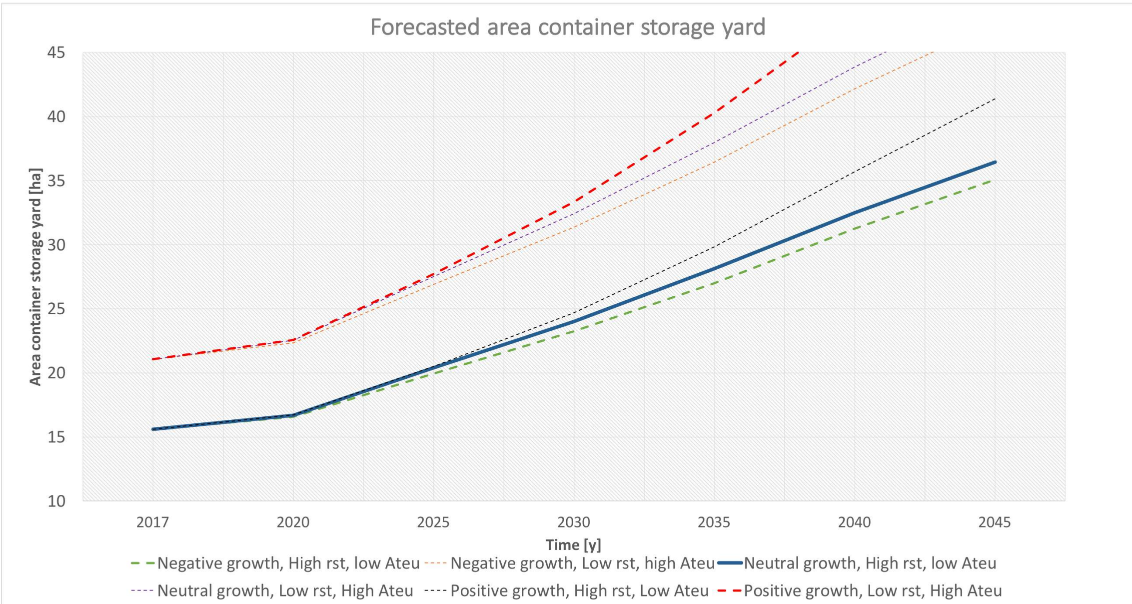


Figure A.2: Projected area for the San Vicente port based on VIII region 2017-2038 projections 40 market share

B

STAKEHOLDER ANALYSIS

This Appendix elaborates on the fact if more actors are involved in the decision making process concerning the port expansion. The aim is to find out whether these actors have different interests and whether they have the power to influence the decision making process. As a first step the problem owner is defined.

B.1. PROBLEM OWNER

The port of San Vicente is part of the Chilean public port system. It is owned by one of the ten port authorities that own public ports in Chile (Merk, 2016). Together these ten authorities own a total of twelve ports. The port of San Vicente is owned by Puertos de Talcahuano. Besides the port of San Vicente they also own the port of Talcahuano. State ports use the landlord model (Merk, 2016). This means that the port authority owns the land and that they are responsible for regulation and administration inside the port. The port authority assigns concessions to private operating companies that will operate inside the port. The private operating company operating in the port of San Vicente is called San Vicente Terminal Internacional (SVTI). The current concession runs until 2029 (Empresa Portuaria Talcahuano San Vicente, 2017). After 2029 the port authority could opt for another private party to perform the operations.
This report is written for the port authority of San Vicente and for SVTI. The port authority is the actor that will decide on whether a port expansion will happen or not. The port authority is therefore assumed to be the problem owner.

B.1.1. GAP BETWEEN DESIRED AND CURRENT SITUATION

As was described in the problem description the port faces two problems concerning the future. At first, the port wants to gain back its lost market share. They have therefore set a KPI (un)loading rate of 100 container moves per hour. The current layout of the port is not efficient when one tries to reach this target. Secondly, the market for the Biobío region is increasing. Therefore the throughput in the port is expected to increase, hence more storage capacity is required. The gap between the current and desired situation is therefore formulated as: *"The port wants more space to increase efficiency and capacity, which is not available at this point"*. In the end a port expansion will increase the value of the port, and therefore commercial parties will be more attracted.

B.2. STAKEHOLDERS

The objective of the port authority is clear. It is now interesting to take a look at the objectives of the other stakeholders. Table B.1 below gives an overview of all stakeholders that are involved. The table also includes their interest and possible gap between the desired and current situation.

Stakeholders	Interest	Objectives	Gap between desired and current/possible future situation
Puertos de Talcahuano	Reclaiming land to create more space for terminal operations. Make San Vicente interesting for commercial parties to operate.	Reach higher throughput (100 moves per hour per ship) and create more storage capacity.	At this point not enough space to be able to reach KPI and store all expected containers. Not attractive enough for private commercial parties.
SVTI	Having more land available to make terminal operations more efficient and future proof.	Reach higher throughput (100 moves per hour per ship) and create more storage capacity.	At his point not enough space to be able to reach KPI and store all expected containers.
Shipping lines	Low turnaround times at the port of San Vicente.	Unload ships as fast as possible. High number of moves per hour.	Port of San Vicente is at this point not efficient enough and therefore less attractive.
Fishery	The fishery berths should have good accessibility.	Securing future profit.	More vessel movements could make it more difficult for the fishery boats to access their berths. More vessel movements could affect fishing spot.
Navy	Controls the maritime territory.	Only grant maritime territory when it is in public interest.	Port reclaiming land at sea outside current territory could be a threat at the seaside.
Contractor companies	Want to execute reclamation in order to make profit.	Make profit because of land reclamation.	There should be a definite plan for reclamation.
Arauco Mill	Market for MAPA project.	Making profit with MAPA project.	Ports in the Biobío region should grow to be able to accommodate future growth of the MAPA project.
Hinterland companies /wood processing companies	Deliver goods to the ports in the region.	Making profit with the transport of goods.	Ports should be able to accommodate future economic growth of the region.
Community of Talcahuano	No hindrance because of port expansion.	Pleasant living area.	The expansion could mean more traffic passing through the city. More operations of vessels could lead to more air pollution.
Municipality of Talcahuano	The inhabitants should not have hindrance because of the port expansion	Create pleasing living environment for inhabitants of Talcahuano.	The expansion could mean more traffic passing through the city. More operations of vessels could mean more air pollution. This will lead to complaints by inhabitants.
Competitive ports in the region	Expansion of San Vicente could result in a loss of market share.	Protecting the environment in an efficient and effective manner.	Expansion of port means more operations and traffic, which will lead to more pollution.
Environmentalist/SEA Chile/Ministry of environment	Port expansion will have influence on the environment, therefore the expansion has several environmental criteria that must be met.	Protecting the environment in an efficient and effective manner.	Expansion of the port means more operations and traffic, which will lead to more pollution.
National Committee (Ministry of Finance/ Ministry of Public Affairs)	Decide whether an infrastructural plan like a port expansion can take place and if it should be financed.	Increasing the welfare of the community in Chile.	Pro: To stimulate local economics the port should be able tro grow. Therefore, expansion is needed. Con: The port expansion could be a threat to surroundings and environment.
CRUBC	Commission that is responsible on a local level for the the use of the shoreline.	Give good advice about shoreline projects to the national committee.	The expansion could influence stakeholders in such a way that it should not be performed.
Potential bidders for new concession	Port expansion makes the port of San Vicente more attractive for future investments.	Making as much profit as possible.	The port should be expanded of the port of San Vicente and SVTI must lose their concession.

Table B.1: Stakeholders interest and decision process

B.3. INFLUENCE OF THE STAKEHOLDERS

Some stakeholders are more powerful than others. In order to obtain an overview of the most influential stakeholders a closer look is taken to the means that all stakeholders have. The port authority then knows what stakeholders it has to consider for the decision making process. A closer look is taken to whether stakeholders are replaceable or if the port authority is dependent on a certain stakeholder. Such stakeholders will be considered critical stakeholders. The fact if stakeholders are replaceable and if the port depends on them will be reviewed. This is all done with taking the main objective of the port in mind: expanding the port. Table B.2 gives a clear overview. Table B.3 gives a small overview of the stakeholder involvement.

Stakeholders	Most important means to influence decision	Replaceable?	Dependend?	Criticial?
Puerto de Talcahuano	Not initiating the expansion	No	Yes	Yes
SVTI	Not cooperating in using extra land for operations	No (concession runs until 2029)	Yes	Yes
Shipping lines	Using other ports instead of San Vicente	No	Yes	Yes
Fishery	Making objections to the National Committee and CRUBC	Yes	No	No
Navy	No permission to reclaim land in their territory	No	Yes	Yes
Contractor companies	Not cooperate with the port of San Vicente	Yes	Yes	No
Arauco Mill	Use the other ports to accommodate their goods	No (Not likely that another company in the region will come with a comparable project)	Yes	Yes
Hinterland comapnies /wood processing companies	Use the other ports to accommodate their goods	Yes (on an individual basis, they are replaceable)	Yes	No
Community of Talcahuano	Complaining and forcing municipality to make objections	No	No	No
Municipality of Talcahuano	Making objections at the CRUBC and national committee	No	Yes	Yes
Competitiive ports in the region	Reacting, increasing own attractivity	Yes	No	No
Environmentalist/SEA Chile/Ministry of environment	Testing expansion on criteria and when the project does not suffice, not giving permission to start the project	No	Yes, SEA is a commission working for the Chilean authorities, so the port needs permission	Yes
National Committee (Ministry of Finance/ Ministry of Public Affairs)	Not giving permission to perform the project or not financing it	No	Yes	Yes
CRUBC	Giving advice to the national committee by reviewing all effects of the project	No	Yes, if the CRUBC is not positive about the project, it is not likely that it will be executed	Yes
Potential bidders for new concession	Already making bids on the next concession	Yes	No	No

Table B.2: Stakeholders evaluation

	Dedicated		Not dedicated	
	Critical	**Not critical**	**Critical**	**Not critical**
Shared interest	∘ Port authority ∘ Arauco mill ∘ CRUBC	∘ SVTI ∘ New bidders for concession ∘ Other hinterland companies ∘ Contractor companies	∘ Shipping lines ∘ National committee	
Opposite interest	∘ Municipality Talcahuano ∘ CRUBC ∘ SAE Chile	∘ Fishery ∘ Community Talcahuano ∘ Competitive ports	∘ National Committee ∘ Navy	

Table B.3: Overview stakeholder involvement

Figure B.1 below shows all the shareholders on a power interest grid.

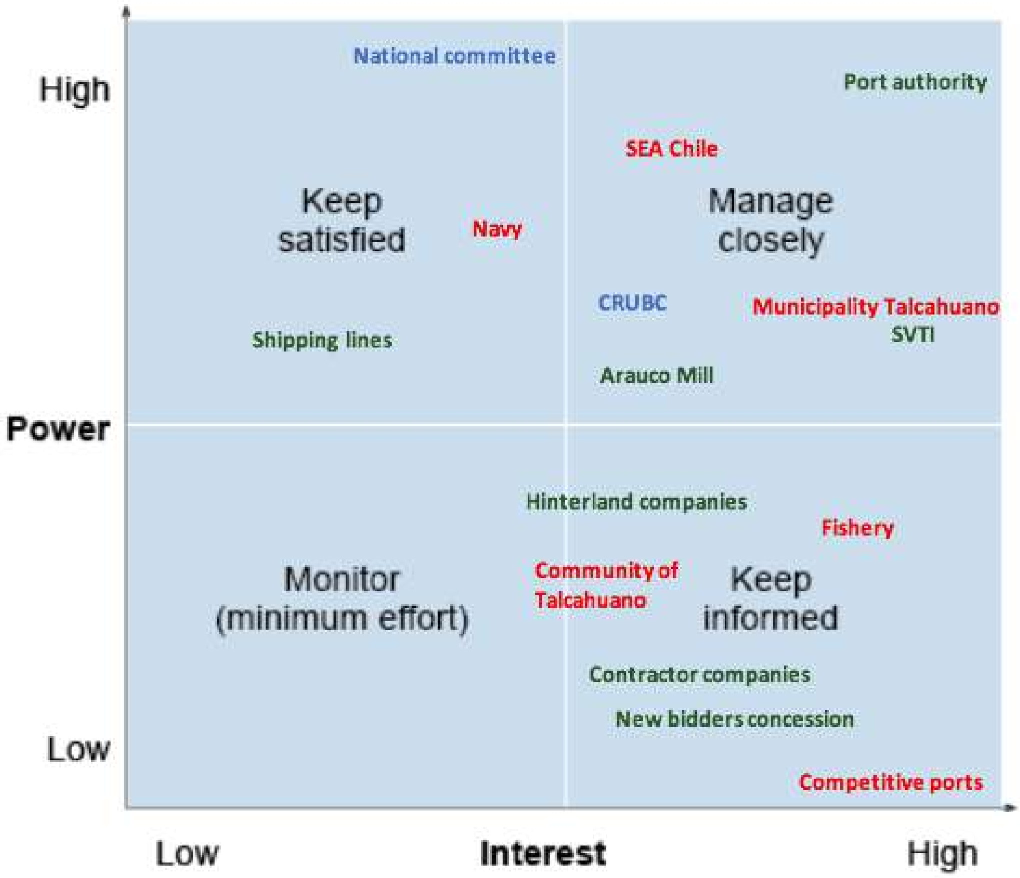


Figure B.1: Power Interest grid of Stakeholders

B.4. Conclusion

B.4.1. Stakeholders to manage closely

As was previously discussed there are different kinds of stakeholders. Every stakeholder needs to be managed in a different way. Figure B.1 in the previous Section gives a good overview of how the stakeholders for the port should be managed. There are five stakeholders that need to be managed closely.

The first stakeholder that needs to be managed closely by the port authority is SVTI. The port authority and SVTI work closely together. Because SVTI performs all operations in the port the port authority benefits from a close relationship with this stakeholder. One could argue that SVTI is replaceable by other commercial parties, which are willing to perform the operations of port San Vicente. However, since SVTI has the concession until 2029 it will not be possible not to work with them during the expansion. Because at this stage SVTI has the exact same interest as the port authority, there are no expected difficulties in managing this stakeholder.

The second stakeholder that needs close management is CRUBC. CRUBC is responsible for managing initiatives along the shoreline. This stakeholder gives advice to the national committee and the navy on whether they should give permission for the execution of projects that concern the shoreline. The advising role that CRUBC has, involves managing stakeholders that might be influenced by the project. Stakeholders that normally have no influence on the decision process can make objections at CRUBC. The CRUBC will analyse all assets, for example economic growth for the region and compare this with the drawbacks. Based on this they will form an objective opinion that they share with the national committee. The advice that CRUBC gives to the navy is more on a technical basis. This concerns giving away territory in the sea. Based on an hydraulic analysis the CRUBC will advice the navy about threats that might occur on the seaside (CRUBC, 2019).
Because CRUBC performs all analyses about projects that include the shoreline, like the the project in the port of San Vicente, they are more dedicated to the decision making process than the parties that they give advice to. This stakeholder should therefore be managed very closely. When CRUBC gives a positive advice to the national committee and to the navy a project is very likely to get approval. The CRUBC is independent and neutral. They are therefore not in favour or against the project on forehand. They are therefore highlighted in blue in Figure B.1.

The third stakeholder is the SAE Chile. SAE Chile is an independent and decentralised organ that gives environmentally based evaluation on projects. The projects are tested on the current norms, criteria, environmental procedures etc. that are all formulated by ministries and governmental authorities (SAE). The port expansion will definitely have influence on the environment. SAE Chile will therefore follow this project with great interest. The criteria that SAE Chile tests on should therefore be kept in mind by the port authority when they formulate their expansion plans. These plans must be convincingly enough to get SAE Chile on board.

The port of San Vicente is located in the city of Talcahuano. The fourth stakeholder is therefore the municipality of Talcahuano. The port expansion will be beneficial for the whole Biobío region, however the municipality of Talcahuano mainly feels the drawbacks. This stakeholder is therefore presumably against a port expansion. The municipality should therefore be managed very closely so that agreements can be made about possible consequences of the port expansion. Furthermore, the port authority should clarify the opportunities for the city of Talcahuano that the port expansion will create. If the inhabitants of Talcahuano are not convinced about the benefits of the project they will probably do anything within their power to stop the project.

The fifth stakeholder that should be managed very closely is Arauco Mill. This company is the initiator of the MAPA project. This project will significantly enlarge the market for the forest industry (ARAUCO, 2018). The MAPA project will therefore also increase the throughput through the ports in the Biobío region. It is therefore important that a positive relationship between the port of San Vicente and Arauco Mill is maintained. When the ports expands they should not lose this business partner. Arauco Mill will have a positive opinion about the expansion of the port of San Vicente. When the port expands, it will be easier for Arauco Mill to export their forestry goods.

B.4.2. Stakeholders to keep satisfied

There are a few stakeholders that will follow the developments concerning the port expansion less extensively. Nevertheless, these stakeholders should still be satisfied because the port expansion heavily depends on them. The first two are the national committee and the navy. As pointed out previously, the CRUBC has an advising role towards the national committee and the navy. The national committee and the navy on their turn have the final say concerning the execution of the project. The national committee will not be very interested in this specific project because it operates nationwide. The navy wants to protect the seaside and therefore it normally is against reclaiming land from the sea. However the port authority is not planning to expand outside of the port area, and therefore the navy is not considered to form a problem.

The third stakeholder to keep satisfied is the shipping lines. The shipping lines are of great importance to the port of San Vicente. When shipping lines decide to use other ports, the port of San Vicente loses market. The port expansion makes the port more efficient, shipping lines therefore benefit from the port expansion since it will very likely lower the service time. Nevertheless, shipping lines will not pay much attention to the expansion plans since the port is easily replaceable for other ports. It is therefore of upmost importance to keep the shipping lines satisfied.

B.4.3. Stakeholders to keep informed

There are a lot of stakeholders that have no influence but are influenced by the decisions of the port authority concerning the port expansion. It is not necessary to manage these stakeholders closely, nevertheless these stakeholders should be kept informed. Stakeholders that will feel positive about a port expansion include: the hinterland companies, contractor companies and potential new bidders for a concession. The hinterland companies will benefit from a higher capacity to transport their goods. Contractor companies can make profit by executing the expansion and for new bidders the port of San Vicente becomes more interesting once there is more land available to operate.

The fishery and the community of Talcahuano will feel negative about a port expansion. The fishery likely experiences hindrance from the expansion works and the accessibility of their berths will be limited. Moreover, the port expansion might form a threat for their fishing spots. The community of Talcahuano likely experiences hindrance from the pollution. Also traffic congestion inside the city is likely to occur. Both parties heavily depend on CRUBC and the municipality of Talcahuano to protect their interests.

The other two competitive ports in the region, Lirquén and Coronel, will also pay great attention to the port expansion. Both ports have no influence concerning the port expansion. However, they will probably react on the port expansion in order to defend their own market position. This will have influence on the future prospect of the port of San Vicente. The interaction between the port of San Vicente and its competition will highly influence the developments inside the port. Therefore an analysis is performed in which the port of San Vicente is compared with its two competitors, Lirquén and Coronel.

B.5. Competition analysis

The port of San Vicente is not the only port in the Biobío region. For example, to the north there is a port called Lirquén and to the south there is a port called Coronel. Both ports are pointed out in Figure B.2. These three ports have a highly competitive relationship concerning the market share in the Biobío region. As was previously mentioned the port of San Vicente is a public port. The ports of Coronel en Lirquén on the other hand are private ports. The difference lies in the fact that the port of San Vicente, by Chilean law, is obligated to handle all cargo types. This is in contrast with the other two ports. They can solely focus on profitable cargo. The ports of Coronel en Lirquén can therefore increase their market share more rapidly by just focusing on the most profitable products. Both private ports have invested a lot of money lately. Public infrastructure investments for the port of San Vicente reached USD 61 million from 1994 till 2016. In the same period Lirquen invested USD 104 million and Coronel USD 132 million dollar Merk (2016). These investments have led to a decrease in the market share of San Vicente. San Vicente witnessed a reduction of its market share from almost 70% in 2006 to about 55% in 2014 Merk (2016). In order to stay competitive the port of San Vicente should take action. This Section elaborates on the opportunities an threats that the two competitors port have with respect to the port of San Vicente. The insight that was used to write this Section was obtained through an interview with prof. M. Villagrán from UCSC (Villagrán, 2019), an expert when it comes to the port sector in Chile.

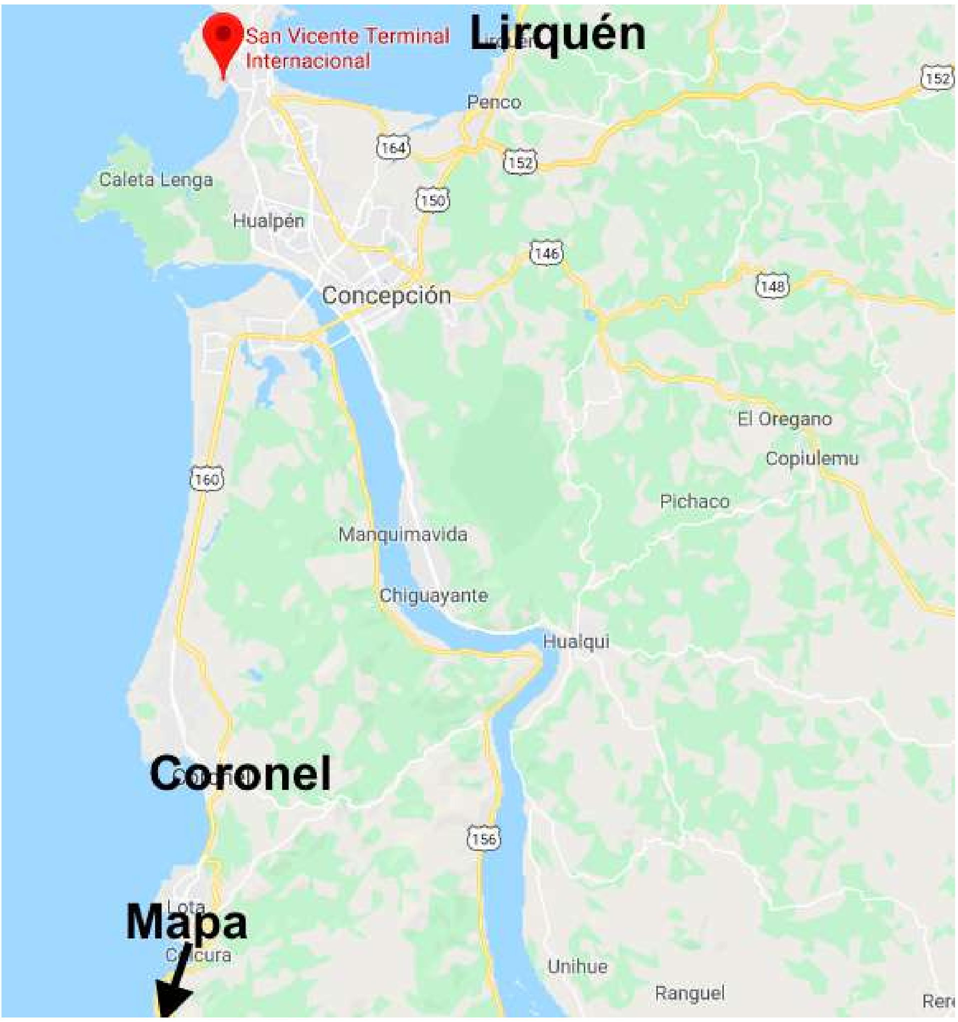


Figure B.2: Geographic location of competition

B.5.1. Competitive position Coronel

The port of Coronel has two important advantages compared to the port of San Vicente. The first advantage is that Coronel has recently invested in four new gantry cranes. The port of Coronel can therefore achieve more than 100 container moves per hour per ship. This increases the attractiveness of the port for shipping lines. The port of San Vicente has lost big clients because of these investments in Coronel. The layout of the port of Coronel (including the gantry cranes) is given in Figure B.4. The second advantage for Coronel is its strategic location with respect to the MAPA project. The port of Coronel is located very close to Arauco Mill. At this point the port of Coronel is already the biggest exporter for Arauco Mill. It is very likely that Coronel will be the preferred port for Arauco Mill concerning the growing export demand.

At the same time the location of the port of Coronel is also one of its main downsides. The port can only be accessed through one route, route 160. In Appendix E.1.2 it is pointed out that route 160 suffers from damage and lack of maintenance. The route is consequently congested. Luckily for Coronel the part of route 160 that connects Coronel with Arauco faces less congestion issues. For a lot of big exporters (highlighted in Appendix E.1.2) the port of Coronel is relatively inaccessible. Except for Arauco Mill, the port of San Vicente is more strategically located for all the other exporters. This points out that the port of Coronel is very reliable on Arauco Mill. The inaccessible road position also explains why 50% of the cargo to Coronel is transported by rail (Merk, 2016).

A second problem for the port of Coronel is that the port has few possibilities to expand. The new STS cranes in combination with the MAPA project presumably lead to a larger container throughput in the port. It is uncertain if the storage capacity of Coronel will be able to accommodate for this expected throughput. Figure B.3 shows that the port is located next to a city. Expansion to land is therefore unfeasible. Especially considering the bad relationship that the port has with the local community. Expansion to sea is also not easy. Hindrance to the city is unavoidable considering an expansion. When the port capacity cannot keep up with the market it is likely that the port of Coronel will lose market share.

Figure B.3: Port Layout Coronel with surroundings

The last issue considering the port of Coronel is clearly illustrated in Figure B.4. The STS cranes are located on a jetty. The jetty has a road that contains two lanes. Therefore there is only one lane for each direction. When the STS cranes operate at full capacity the transport of containers to and from the jetty is very likely to form a bottleneck.

Figure B.4: Port Coronel with gantry cranes

B.5.2. COMPETITIVE POSITION LIRQUÉN

The port of Lirquén invested in a port expansion a few years ago. This investment increased the container terminal area. Due to this investment the port became more attractive for shipping lines. On top of that, the port of Lirquén has recently been acquired by DP world. DP world is a global port company with a big network of investors. The company forces their clients to import goods that are destined for the Biobío region through the port of Lirquén. It is therefore assumed that the port of Lirquén will become an important container port in the future.

A main advantage for the port of Lirquén is its strategic location with respect to the main routes. Appendix E elaborates on this matter. The port of Lirquén is located very close to highway 150, see Figure B.2. The location of the port of Lirquén is also especially favorable for companies located at route 152 and route 146. This is in contrast with the port of San Vicente where the companies have to cross the city of Concepcion. Congestion issues can be avoided if the port of Lirquén is chosen. On the other hand, if one comes from route 160 (main route for the MAPA project) and route 156 towards Lirquén, trucks have to bypass the congested los Carrera through the middle of Concepcion, see Section E.3. Therefore, with respect to the MAPA project, the port of San Vicente is preferred.

The port of Lirquén has a relatively high container terminal capacity. Especially when one compares this with their current throughput. For this reason the port can easily accommodate for future growth. Especially considering the MAPA project this is an important advantage.

The port of Lirquén currently has a drawback compared to the port of San Vicente. It uses only mobile harbour cranes. The port of San Vicente has two STS gantry cranes. The theoretical (un)loading rate is therefore higher at the port of San Vicente. The berths at Lirquén are placed on a jetty. The berth lies further into the sea than the jetty at Coronel. One can easily see this in Figures B.6 and B.5. The road on the jetty towards the berths has two lanes. This can cause capacity issues. Even if the port of Lirquén would invest in STS gantry cranes, the port of San Vicente would still be able to reach a higher efficiency.

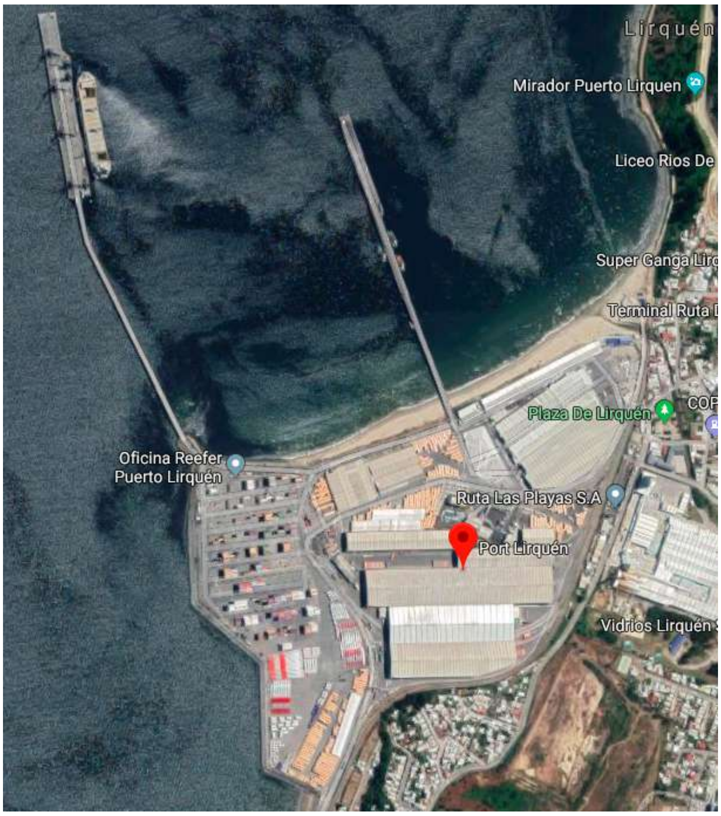


Figure B.5: Port Layout Lirquén with surroundings

Figure B.6: Port Lirquén with mobile harbour cranes

C

PORT LAYOUT DESIGN

In this Appendix a new layout design for the port is proposed. The design is based on the surface of the port including the reclaimed land. First the design specifications are discussed based on what needs to be located in the port, where components are currently located in the port and how much surface is needed per component. When this is all established the new design of the San Vicente port is represented. Subsequently, the new design is evaluated based on if it solves the expected problems in the future. Lastly, the future operations are briefly discussed as they are quite similar to the current operations

C.1. DESIGN SPECIFICATIONS

From an operational point of view, three reasons can be appointed for reclaiming land (Garcia, 2019). Firstly, the reclamation of land will create more space to separate the containers in the stacking area. This can make the stacking system process step more efficient, since the yard is even better organised. Secondly, the land reclamation will contribute to achieving the KPI of 100 container movements per hour. Achieving 100 container moves per hour indicates the efficiency of the port operations. Third and lastly, the land reclamation will accommodate for the predicted container throughput in the San Vicente port. These reasons are beard in mind when designing the new port layout.

C.1.1. COMPONENTS IN PORT LAYOUT

The port layout exists of several components. All these components need to be considered when making a new design for the port layout. In the list below the components are defined. The list concerns components that are located in the current port layout. In the future it is not expected that additional or new components are considered in the port layout.

- **Berths**: for the mooring of the the vessels.
- **Cranes**: for the unloading of the vessels and loading trucks.
- **Empty containers**: area in the port to stack empty containers.
- **Export containers**: area in the port to stack export containers.
- **Import containers**: area in the port to stack import containers (note that for the San Vicente port this is done externally of the port).
- **(Break) bulk storage area**: area in the port to store (break) bulk.
- **Consolidation areas**: areas where the containers can be consolidated, additionally it provides space to store (break)bulk.
- **Maintenance center**: maintenance center for port equipment.
- **Traffic lanes**: for trucks to travel inside the port.
- **Reach stacker manoeuvring area**: space for the reach stacker to maneuver during stacking activities.
- **Railway track**: train is used to transport bulk into the port.
- **Gates**: entrance and exit of the port.
- **Port facilities**: area for offices and meeting rooms.
- **Parking area**: place to park for cars and for trucks that need to wait for service.

C.1.2. Basic structure

The current port layout is represented in Figure C.1. Based on the current layout the new port layout will be designed.

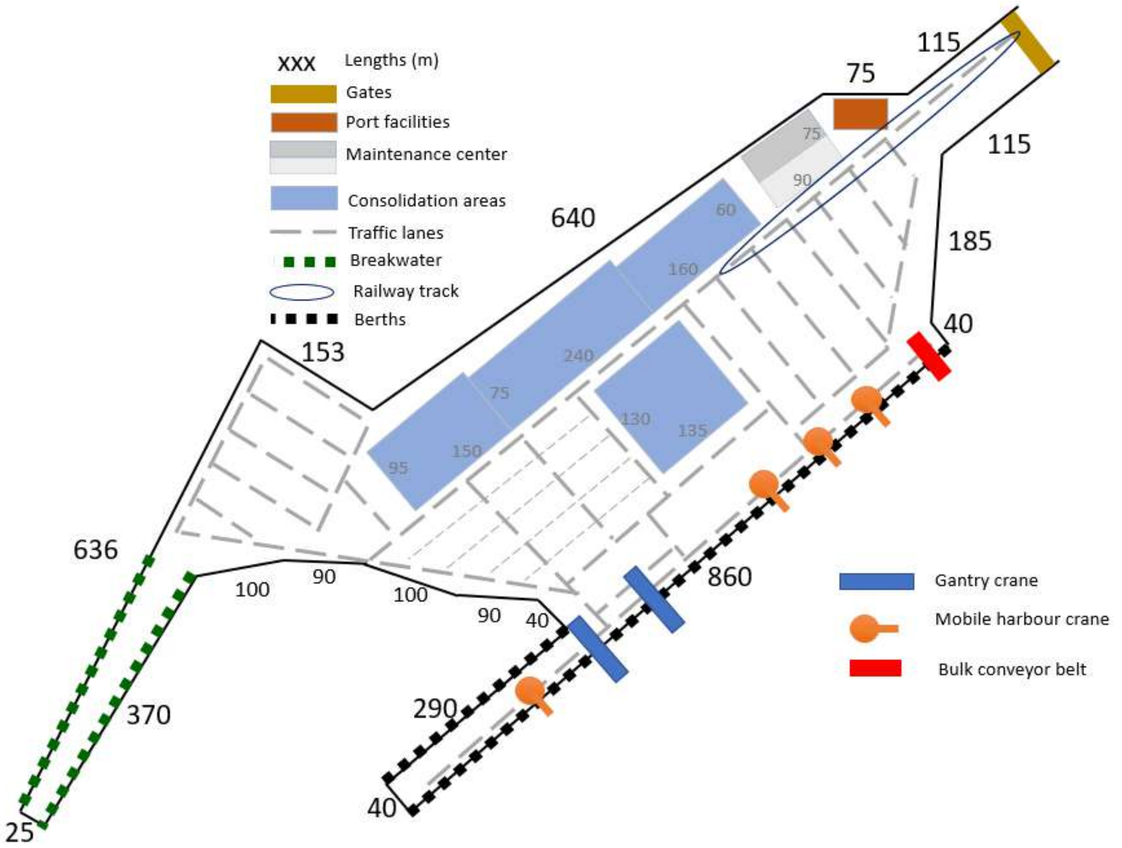


Figure C.1: Current layout of the San Vicente port

In the current port layout a distinction can be made between hardware and software. Hardware considers port segments that are not easily relocated, thus are not flexible. Software considers the more flexible segments in the port. Considering the criteria in the multi criteria analysis (Appendix F), it is decided that the hardware in the port will not be changed. Changing the ports hardware would be expensive and causes a lot of hindrance to the port operations. The hardware in the San Vicente port includes the buildings (consolidation areas, maintenance center and port facilities), the port gates, the railway track, the berths and the breakwater. The traffic lanes on the other hand are not considered hardware but software. The port entirely exists of pavement. Therefore the traffic lanes can be shifted and are more flexible.

Furthermore there are a few other factors that are not interchangeable in the port design. These factors must also be considered in the basic structure. For instance the backreach and the rail gauge of the gantry cranes cover a fixed distance. These two factors are relevant for the new design. The backreach of the cranes determines how far behind the cranes the container yard can start. Since the gantry cranes are larger than the mobile harbour cranes the port also uses, the design is made to fit the gantry cranes.

- The rail gauge of the gantry cranes is 30 m (Ligteringen, 2017).
- The backreach of the gantry cranes is 23 m (Ligteringen, 2017).

Thus the area the cranes need to operate at the quay is 53 meter in length. This implies that the storage yard can start 53 meter from the seaside.

Note that in the figures representing the layout of the San Vicente port, there are two gantry cranes represented and only four of the nine mobile harbour cranes. The reason for not displaying all MHC's is that there are never nine cranes operating at the quay simultaneously. Moreover the port handles bulk, therefore the bulk conveyor belt is also considered in the basic structure.

Two other important factors when designing the new layout of the San Vicente port are the manoeuvring areas of reach stackers and trucks around the port. Yet those two factors are taken into account by the storage area calculation (in the A_{TEU} factor) in Appendix A. Consequently, they will not be taken into account separately in the layout design.

The port layout with the hardware and cranes is shown in Figure C.2. This will be the basic structure of the new design.

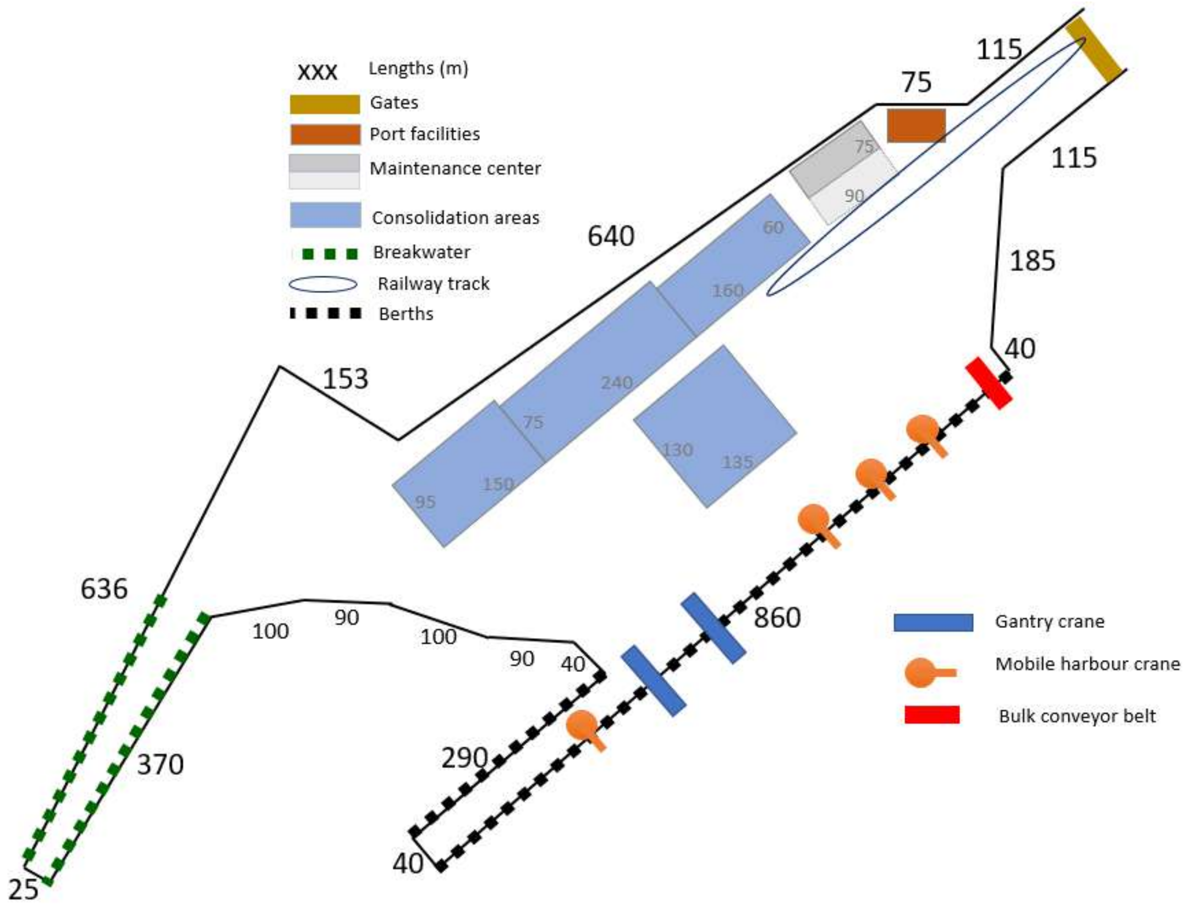


Figure C.2: Basic structure San Vicente port

C.1.3. Demand forecast

As is mentioned in the current operations in Appendix D the port organises the storage yard quite well. There are separate parts for storing the empty containers, export containers and import containers. Note that the imported containers are not stored inside the port but at the external area the port rents. Furthermore, at this external area a part of the empty containers are stored.

In Figure C.3 it is indicated where the different containers are currently stored inside the port and how much space is used. Notable is the green area where a mix of containers, reefers and (break)bulk is currently stored.

As stated in the demand forecast, given in Appendix A, the throughput in the San Vicente port is likely to increase the coming years. Using the demand forecast model from Appendix A it is decided how much space will be needed for the empties, export, and import containers in 2025.

- Empties: 14.76 ha

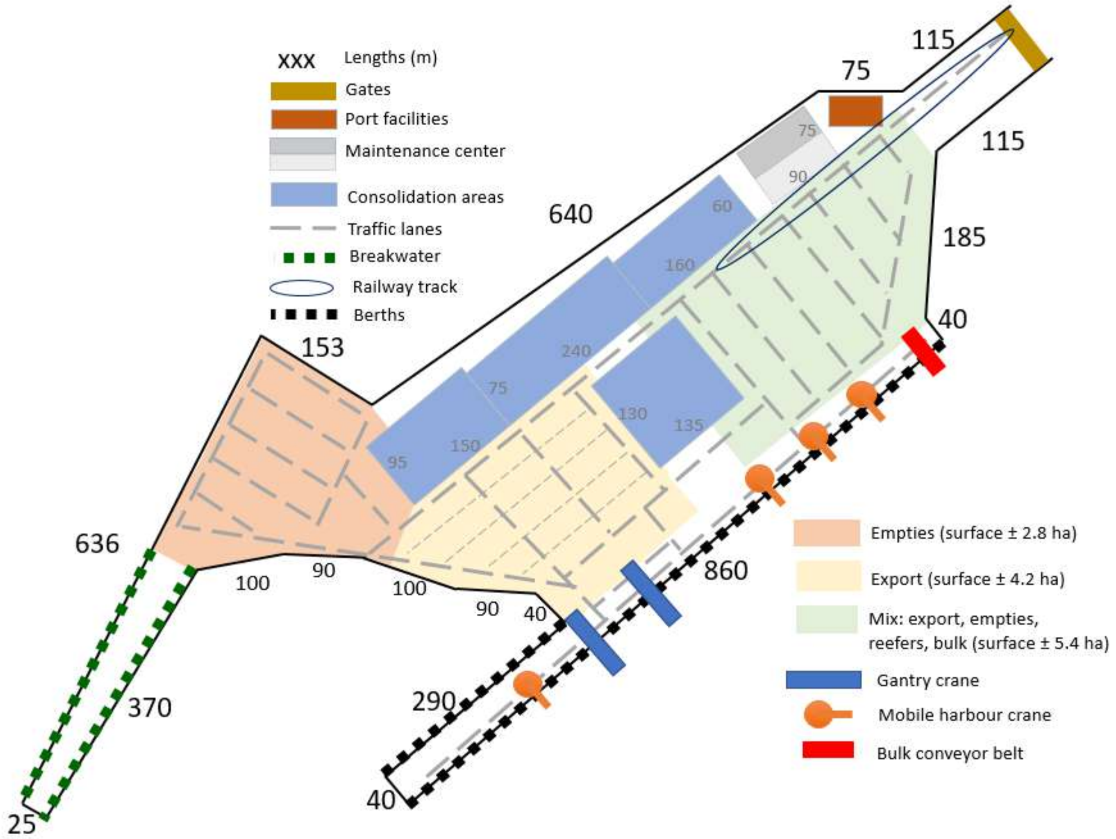


Figure C.3: Separation containers in the storage yard

- Export: 7.1 ha
- Import: 1.07 ha

Note that in the future the import containers are also expected to be stored at the external rented area. Even though the port will have more surface after the land reclamation, without the external area the port is still not able to accommodate for the increasing demand. The port indicated that it currently has 20.7 ha of storage area (Empresa Portuaria Talcahuano San Vicente, 2017), inside the port a total of 12.4 ha is measured for storage area. Hence the port has at least 8.3 ha of external storage area. From conversations it came forward that the port even has 10 to 15 ha of storage area outside the port. Therefore storing a part of the containers outside the port area will be possible. It is especially important that inside the port there is enough space to store all export containers. The export containers need to be loaded on the ship and therefore it is very inconvenient if the export containers would be stored outside the port. The port operations will increase in efficiency with the export containers located directly behind the cranes (**?**).

Hence, the new port layout design must account for at least 7.1 ha storage place for export containers. The 1.07 ha storage area for import containers is found external of the port. For the empties in total 14.76 ha storage place is needed. Preferably as much as possible storage space for empties is found inside the port, the remaining needed area is found externally. Note that the manoeuvring area for reach stackers and trucks is included in the predicted hectares for storage area.

C.2. Designing the port layout

Using the design specifications that are established, the design of the new port layout can be determined. As was indicated before the hardware of the port will not be changed in the design.

After various options for land reclamation have been considered in Appendix F, the best option has been selected in consultation with the port of San Vicente. By reclaiming the land, the port of San Vicente creates a larger storage yard for the containers. This way the port can accommodate for the predicted increase in throughput in the future. The chosen reclamation option will make the port area sufficient at least until 2025, considering an expected market share of 45%. Based on Figure C.2, Figure C.4 represents the basic structure of the new layout design with the reclaimed land (red dotted lines), including the hardware and the backreach of the gantry cranes.

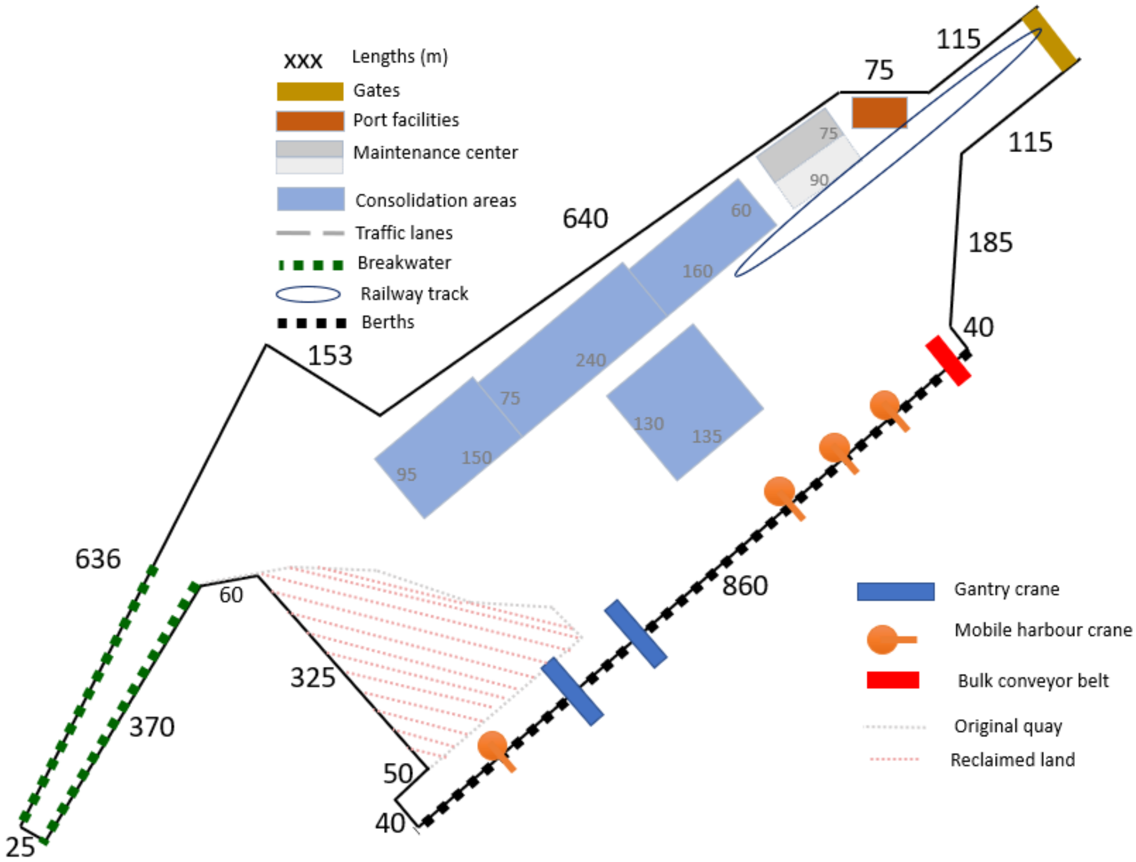


Figure C.4: Basic structure of the new layout design of the San Vicente port

What remains to be designed in the basic structure are the container storage yard, an area for (break)bulk and reefers and the traffic lanes. The sequence in which the components will be designed in the layout is as follows: first the export area, then the reefer/bulk area, than the empty container area and lastly the traffic lanes. Note that the import containers will be stored outside the port as they do not really have a function inside the port. Moreover, by storing import containers on a external location the port creates a push system, which prevents containers from unnecessarily remaining in the port (Negenborn, 2018).

It is desirable that all export containers are stored inside the port. This is preferred over storing empty containers inside the port when storage capacity is limited. The reason for this preference is based on the service efficiency of vessels. Arrangement of the export containers is more important when one looks at the efficiency of serving the vessels. Empty containers must first be consolidated before they can be exported, it is therefore more suitable to store those outside the port when space is limited. There is enough time to transport the empty containers to an area outside the port and back again for consolidation, without affecting the efficiency of serving the vessels too much.

C.2.1. Export area

As mentioned the required area for storing all export containers in 2025 is 7.1 ha. This area includes traffic lanes (Appendix A). The area for the export containers is used as a starting position for the design.

Since the required area is based on a forecast and market share estimation, a safety margin of 10 % is included for the export container area. In the event that the export throughput increases more rapidly, there will be enough space to store the export containers. Moreover, when the throughput does not increase as rapidly the containers can be stacked less high, increasing the containers accessibility and speeding up the stacking activities. Figure C.5 indicates an area of 7.8 ha for export.

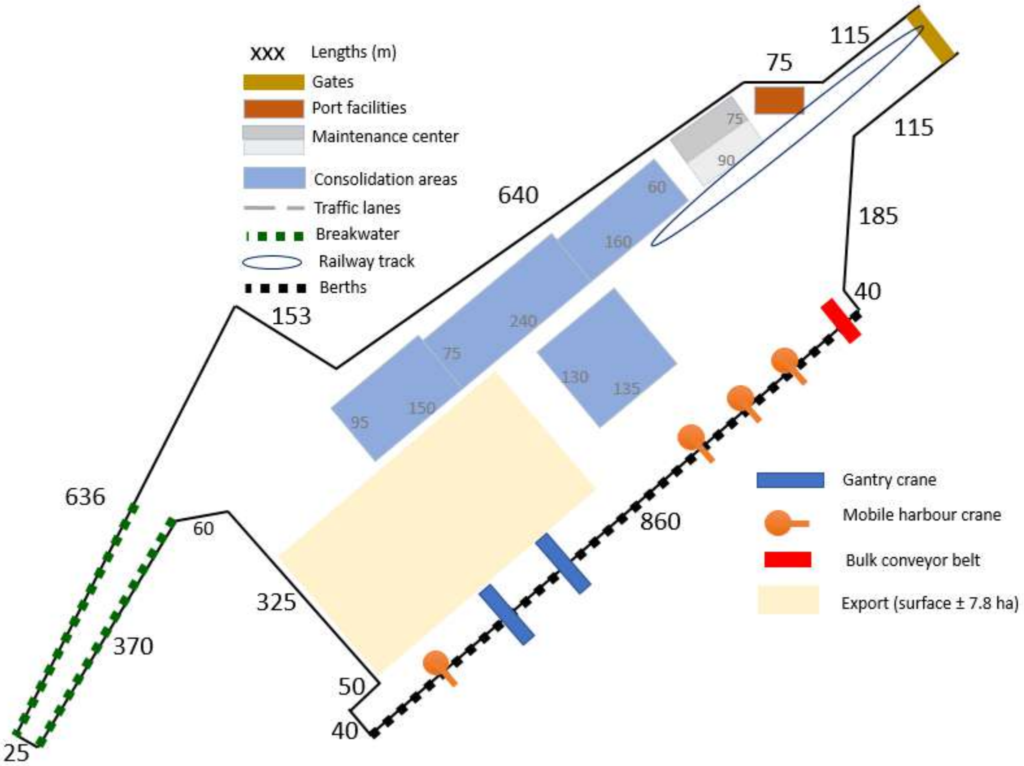


Figure C.5: Required area for export container storage in the San Vicente port

Furthermore, the location of the export container yard is located directly behind the cranes to improve handling operations. Yet this is based on the situation where only one container ship at the time is moored in the port.

C.2.2. (Break)bulk and reefer area

The next thing to consider in the layout design is the area for reefers and (break)bulk. Currently the reefers and (break)bulk are mixed with empty and export containers, see Figure C.3. In the future design the empty and export containers will not be mixed with the reefers and (break)bulk. Furthermore, the port intends to construct a (break)bulk area, located between the export container yard and the consolidation center in the middle with a surface of about 0.8 ha (determined with Google Maps). This is considered in the new port layout design.

The exact required surface area for (break)bulk and reefers is unknown. Therefore an assumption is made based on the current area occupied by reefers and the planned bulk terminal, measured in Google Maps (about 1.5 ha). The container throughput is expected to increase with 47% until 2025 (obtained from the forecast model, Appendix A). The current area covered by reefers and (break)bulk is multiplied with 47% to calculate the area required in 2025. Note that this is a very simplified approach to find the required area based on the assumption that reefers and bulk will increase with the same factor as the containers.

In Figure C.6 the (break)bulk and reefer area is shown. For the reefer and (break)bulk a safety margin of 10% is also taken into account, resulting in a required area of 2.4 ha. Note that a lot of the (break)bulk is stored inside the consolidation centers, therefore the additional required area outside the centers is not very large.

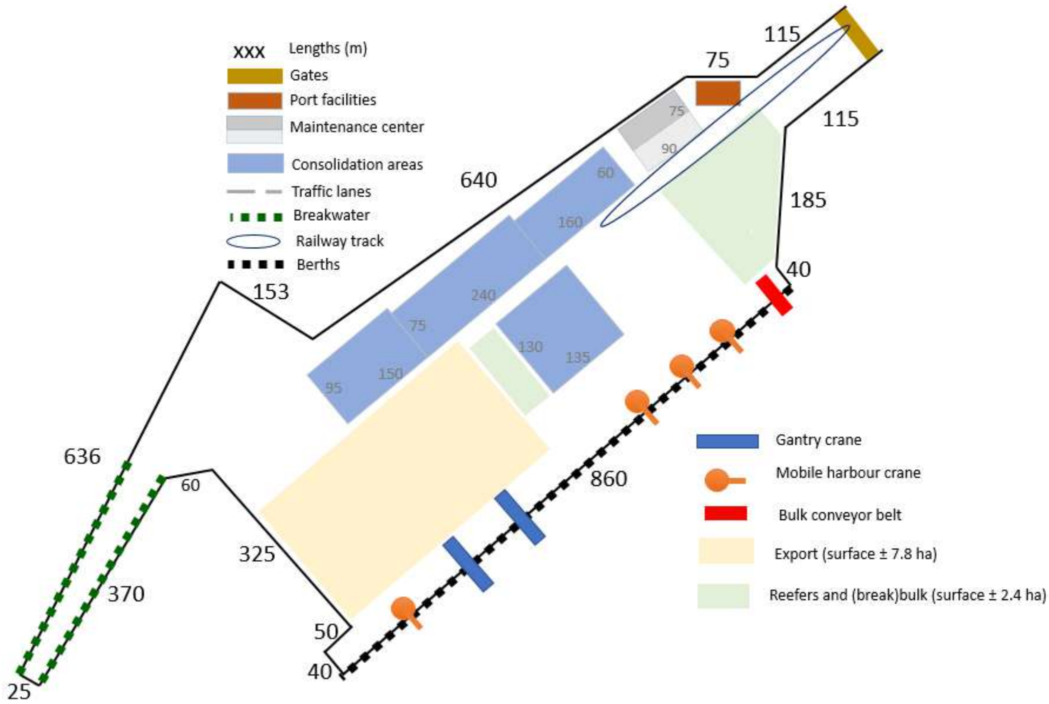


Figure C.6: Required area for (break)bulk and reefer storage in the San Vicente port

C.2.3. EMPTY AREA

All the space that is remaining in the port will be filled with empty containers. That implies that 6.9 ha of empty containers can be stored inside the port. The rest of the empty containers (7.84 ha) are stored in the external area outside the port. A safety margin is not needed for the empty containers as the surplus of empty containers, for which can not be accommodated inside the port, will be stored outside the port.

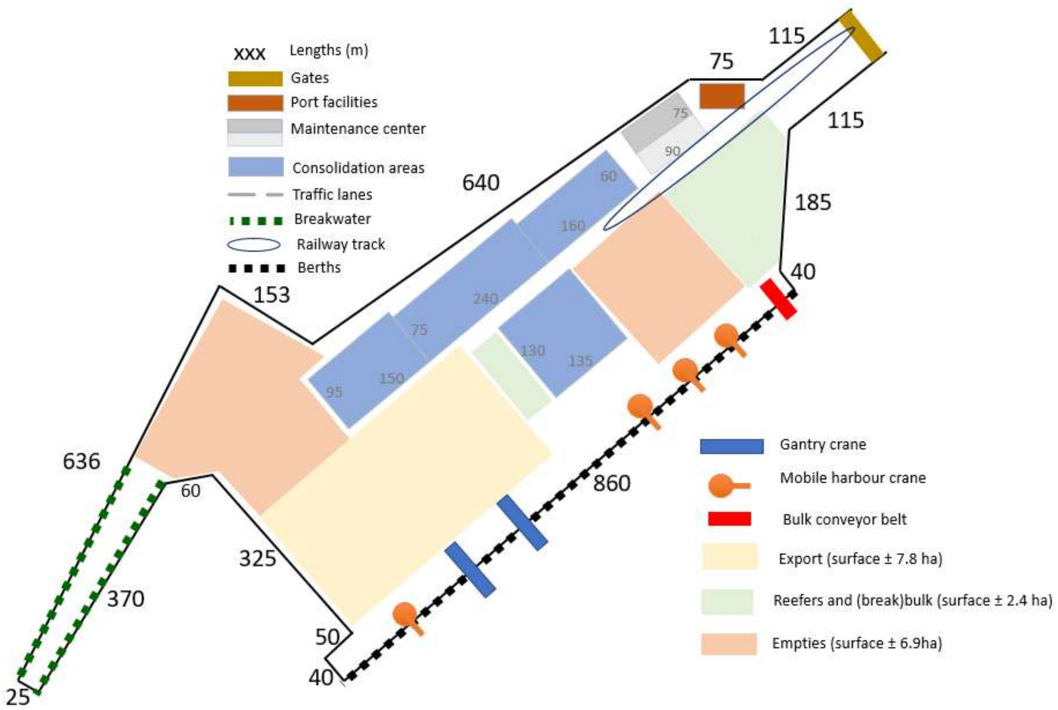


Figure C.7: Required area for empty container storage in the San Vicente port

C.2.4. Container organising

When designing a port layout, it is very important to consider the stacking handling system in the port and the means of internal transport (Ligteringen, 2017). In the port of San Vicente stacking operations are done by reach stackers (Appendix D). At least until 2025 the reach stackers will be carrying out the stacking activities as there are no known plans for investing in a new stacking system.

Usually the length axis of the containers is located to be perpendicular or parallel to the waterfront (Ligteringen, 2017). Since the internal transport in the San Vicente port is carried out by regular trucks and not by Automated Guided Vehicles or a Multi Truck System, it is most obvious that the orientation of the containers should be parallel to the quay (Ligteringen, 2017). Nevertheless the containers are not preferred to form an entire parallel row along the quay, as the reach stackers need enough manoeuvring area to lift containers in and from the storage yard and to increase container accessibility. Therefore the container storage will be organised in smaller sub areas, as is shown in Figure C.8. Moreover, organising the containers in smaller sub areas is preferred since it allows for easier separating the containers based on criteria such as weight, length, function and destination (Garcia, 2019). Between the smaller sub areas traffic lanes will be realised.

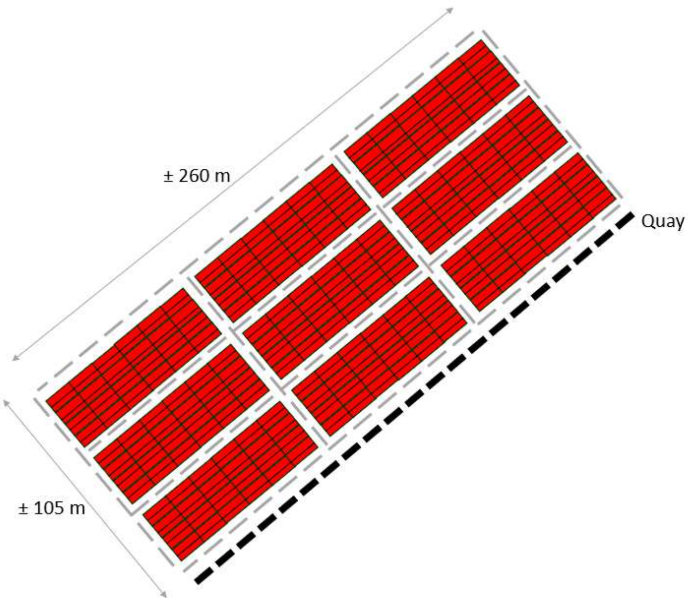


Figure C.8: Organising the container yard in the San Vicente port

The static capacity that the port will have with the new port layout after the land reclamation is calculated with Equation C.1, using the A_{TEU} factor from Appendix A. By dividing the available storage area by the A_{TEU} factor, the number of TEU's possible to fit on the ground is obtained. In theory the containers can be stacked until five high. To calculate the static capacity of the new storage yard, number of TEU's that fit on the ground is multiplied by 5.

From the new layout design it arises that there is 14.6 ha (146000 m^2) available inside the port to store containers. The area for (break)bulk and reefers is not taken into consideration to calculate the static capacity of the storage yard.

The A_{TEU} factor is equal to 10 m^2, as stated in Section C.1.3. In the new design the road capacity will slightly increase, this will affect the space that is used per TEU. Yet there is quite some uncertainty about the exact A_{TEU} factor, therefore the A_{TEU} factor from the demand forecast model is used.

Filling in the formula with these numbers leads to a static capacity of 73000 TEU. This means that 73000 TEU can be stored in the storage yard.

$$C_s = \frac{A}{A_{TEU}} \cdot 5 \tag{C.1}$$

with C_s = Static capacity [TEU]
A = Total available storage area $[m^2]$
A_{TEU} = Required area per TEU $[m^2]$

C.2.5. Traffic lanes

The last component that needs to be implemented in the new port layout design, is the traffic lanes. The traffic lanes are used in the internal transport sub process in the port operations. Trucks use the traffic lanes to transport containers from and to certain locations in the port.

As shown in Figure C.8 the container yard is organised in smaller sub areas. Between these smaller sub areas traffic lanes will be located. Figure C.9 represents the layout design including the traffic lanes. This is the final step for the port layout design of the expanded San Vicente port. Note that in the right bottom part there is a part with no crossing traffic lanes, this is because this will be a bulk storage area.

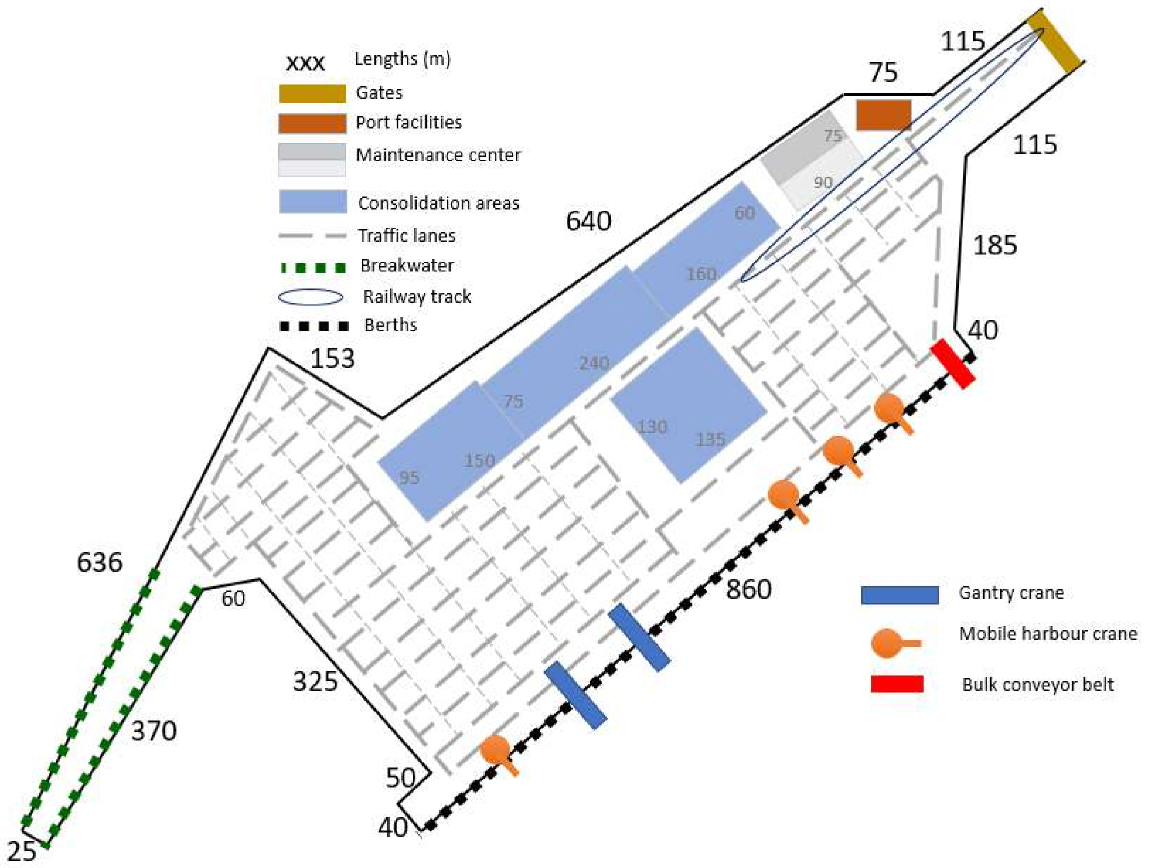


Figure C.9: Traffic lanes in the new port layout

C.2.6. Final design

Figure C.10 below shows the final port layout. Note that the design is made with the aim to improve port operations, making them more efficient. Therefore the container yard is located directly behind the cranes and the traffic lanes are straight. Moreover, there are quite some paths in between the containers and the storage yard. This will improve container separation and container accessibility, increasing the efficiency of the operations. However the roads might increase the A_{TEU} factor which may decrease the storage capacity slightly. Yet this is uncertain and would need further research.

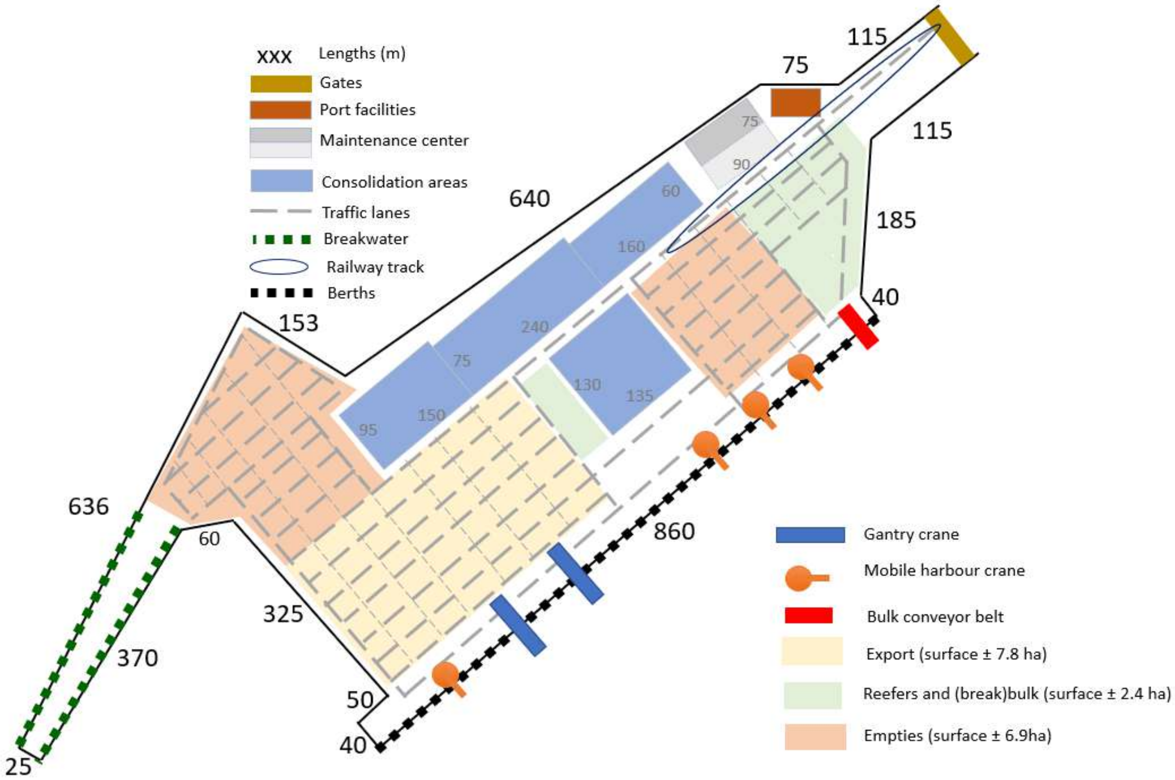


Figure C.10: Final design of the new port layout

C.2.7. ALTERNATIVE PORT LAYOUT

The new layout design is based on the most common situation in the San Vicente port where only one container vessel at a time moors. In the future it is expected that occasionally two container ships moor at once. When this happens it improves the operations if the export container storage is extended behind the other cranes on berth 1 and 2. Since the storage area for containers is not considered hardware, the port can change the exact location of the export containers if necessary. The space required for storage space is not very large since only small container ships can moor at berth 1 and 2 because of the small depth. An alternative port layout in the event that two container vessels need to be served at once, is represented in Figure C.11.

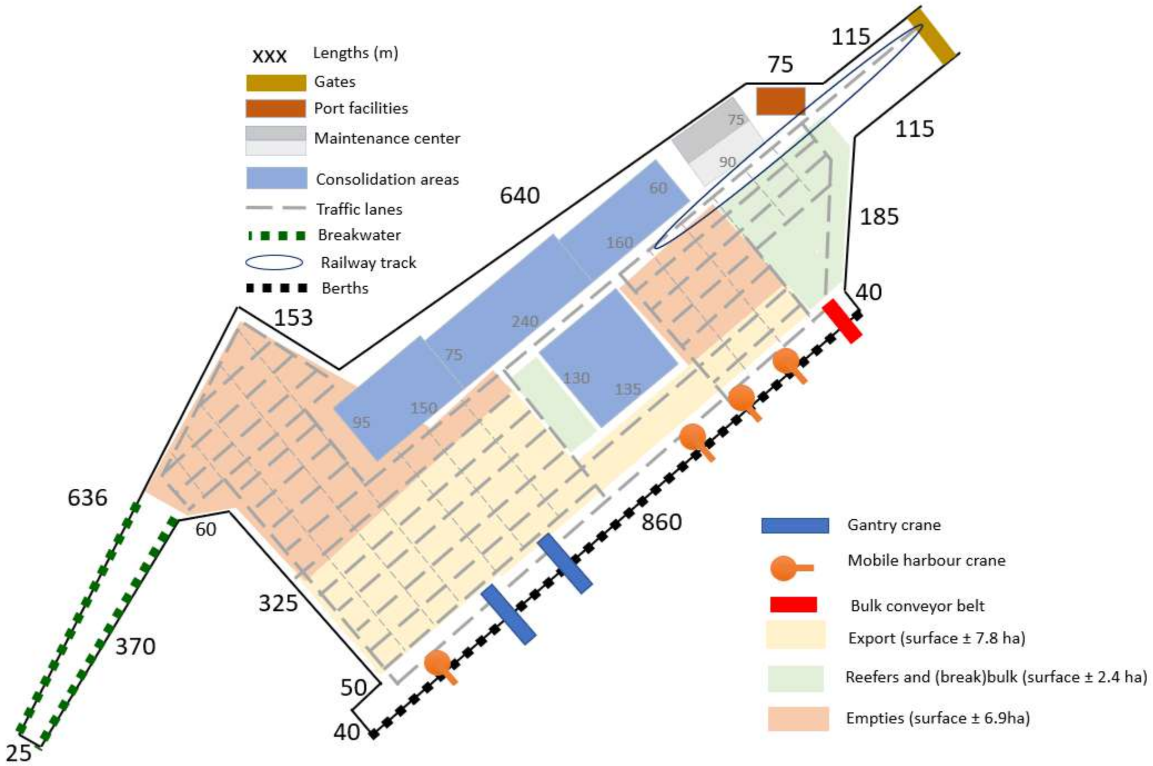


Figure C.11: Alternative port layout in the event that two container vessels must be served at once

C.3. Evaluation

With the reclaimed land and the new port layout the purpose is to make port operations more efficient and to be able to accommodate for the predicted container throughput increase. Based on the problems that are to be expected in the future without the land reclamation (described in Appendix D about the port operations), the new layout design is evaluated. The sub-processes where problems are expected with no changes in the port, are at the quay, in the internal transport process, in the stacking system and in the continental transport process. The new layout design is checked along the expected future problems, evaluating if the land reclamation will prevent the expected issues.

C.3.1. Quay

The problem that is expected to occur in the quay operations concerns the moves per hour. With an increase in container throughput, it is expected that multiple vessels will moor at once at the quay. The port does not have the crane capacity to achieve 100 container moves per hour per ship if more than one vessel needs to be unloaded at the same time. Unfortunately, with the land reclamation this can still not be achieved since the land reclamation does not as such increase crane capacity. Do note that the land reclamation does benefit to achieving the KPI of 100 moves per hour if only one ship at the time is unloaded. As a result of the land reclamation, there is more space to store the containers and the containers are stored directly behind the cranes improving the crane operations.

C.3.2. Internal transport

The inefficiency in the internal transport operations is caused by the shape of the port. Considering the land reclamation the shape of the port will change and become more efficient for internal transport operations (Figure C.12. Therefore this issue will be prevented with the land reclamation. Furthermore another problem that is expected in the internal transport operations is caused by the lack of road capacity. This issue will also decrease with the land reclamation as the new port layout has more road capacity and no inefficient route allowing the trucks to block each other.

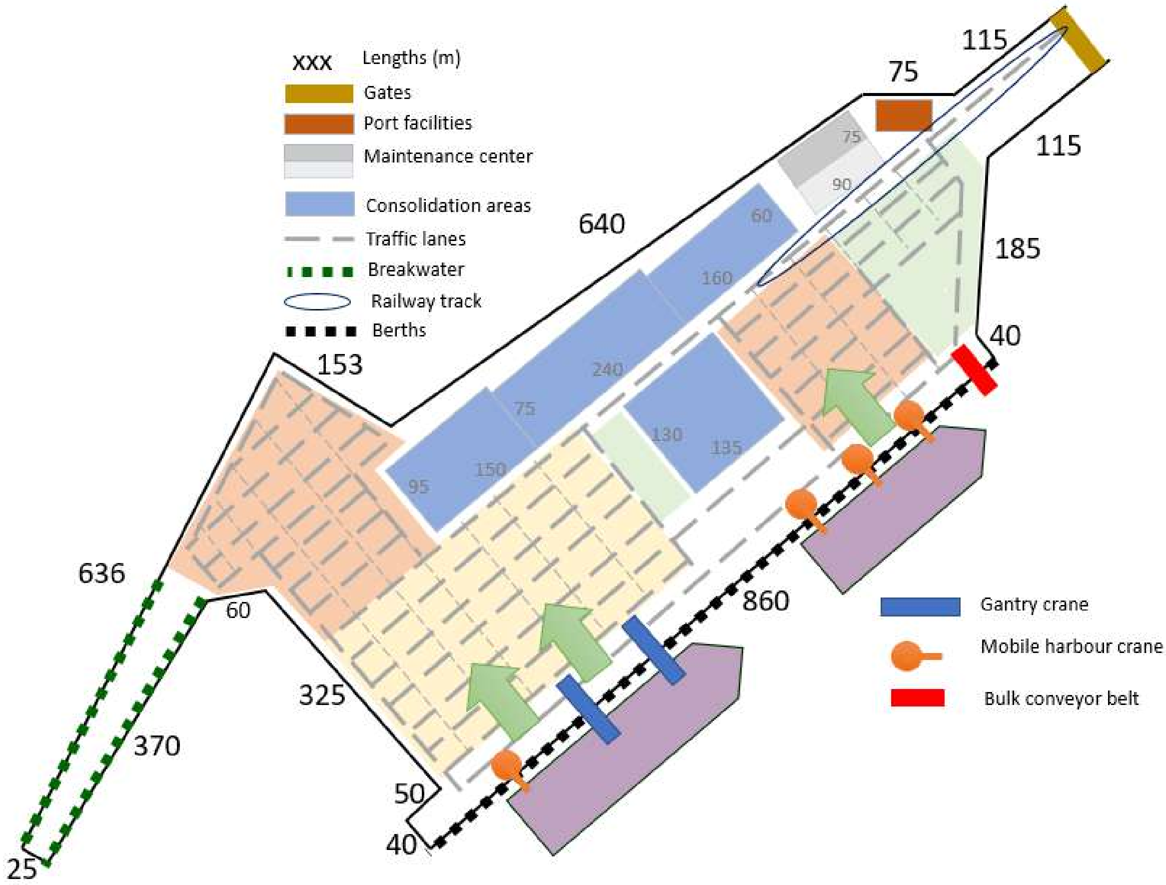


Figure C.12: Part of the container journey in the new port layout design

C.3.3. Stacking system

Another expected problem is caused by organising the containers in the port. In the new port layout the containers are stored in smaller sub areas where they are organised based on criteria such as weight and length. With the land reclamation there will be more space available to separate the containers. This increases the container accessibility resulting in less required time for organising the containers.

The most largest problem that is expected in the port without the land reclamation is the amount of storage area in the port. Without the land reclamation the port will not be able to accommodate for the predicted increase in container throughput. With the land reclamation the port will be able to accommodate the increase in containers. The port indicated to have 20.7 ha storage area currently (Empresa Portuaria Talcahuano San Vicente, 2017), inside the port 12.4 ha is measured for the storage area. Hence the port has at least 8.3 ha of external storage area. In 2025 it is predicted that almost 23 ha is needed (Section C.1.3). The new port layout with the land reclamation indicates 17.1 ha in the port. With the external area of at least 8.3 ha, the port can easily accommodate for the increase in container throughput.

The last issue within the stacking system that is expected to occur in the future is the capacity of the stacking equipment. The stacking equipment might not be able to keep up with the increasing number of container. The land reclamation unfortunately does not prevent this issue since the expansion does not as such increase the capacity of stacking equipment.

C.3.4. Continental transport

An increase in container throughput implies that more trucks will need to pass the port gates. In trough moments a queue of at least one truck might always be present. In peak moments this might result in a spill back of trucks far back into the port area, causing hindrance for the port operations. The gate capacity can therefore result in a problem in the future. The port expansion does not focus on increasing number of gates, therefore this issue can still occur in the future even though the port is expanded.

C.3.5. Conclusion

In Table C.1 an overview of the effects of the land reclamation is provided. All in all the land reclamation is a success as it solves issues the port is currently facing or will face in the future. According to the evaluation, the land reclamation can prevent most of the expected problems. Yet not all expected issues can be prevented by reclaiming land. This implies that the cranes, the stacking equipment and the gates will cause issues in the future, even though the port has been expanded.

Expected problems in the future, no land reclamation	**Prevented by reclaiming land?**
Crane capacity	NO
Inefficient shape of the port	YES
Road capacity inside the port	YES
Organising containers	YES
Storage space inside the port	YES
Stacking equipment	NO
Gate capacity	NO

Table C.1: Overview of problems and effect of land reclamation

To solve the remaining issues additional investments and research are needed. The port has recently invested in two new gantry cranes, it is advised that the port invests in additional gantry cranes in the future to improve port operations and resolve inefficiency at the quay. Furthermore, extra stacking equipment must be purchased or a new stacking system should be initiated, such as straddle carriers. The gate capacity may be increased by improving the container pick up system or construct an additional gate. These are just suggestions, to surely solve the problems more research is needed.

C.4. Future operations

The future operations in the San Vicente port are very similar to the current operations (Appendix D). There are no known plans for investing in new equipment or other expected changes in the port operations. The biggest difference in the port operations with the land reclamation and without, is the container handling between the cranes and the storage area. With the land reclamation the containers are stored directly behind the cranes over the entire length of the quay. This improves the handling of containers as the shape is more efficient (Ligteringen, 2017; Garcia, 2019). Nevertheless it is advised to the port to invest in a new stacking system as this can speed up the stacking activities. Furthermore, in the future the recently purchased gantry cranes will not be efficient to handle the throughput with the desired handling speed.

C.4.1. Optimising port operations

As mentioned, there are no plans for changing the port operations. Even though, the port expansion would be a perfect opportunity for the port to change somethings in the port operations to further improve efficiency. In this section a plan for the optimisation of the port operations will be described. The reason for this is to give the port of San Vicente an idea about how they could improve the port operations accordingly with the new layout design. The optimisation of the port operations will be discussed per sub process.

Quay

Currently at the quay there are two gantry cranes present and nine mobile harbour cranes. The expectation is that the two gantry cranes have a high enough handling capacity in the future when they serve one vessel at the time. In the event that multiple vessels require service, the mobile harbour cranes are not efficient enough to reach the desired handling capacity. Therefore additional gantry cranes should be purchased to optimise port operations in the future.

Internal transport

The internal transport is currently done by manual trucks. Nowadays they suffice the handling capacity of the cranes. Yet in the future the manual trucks may not suffice the handling capacity of the cranes. Especially when extra gantry cranes are used in the operations and when multiple vessels require service at once. By investing in a multi trailer system or automated guided vehicles the port of San Vicente optimises their internal transport. Furthermore, the port will be more future proof.

Stacking system

The port indicated that in the future, the stacking equipment might not be able to keep up with the predicted container throughput. An optimal stacking system is achieved using stacking equipment such as straddle carriers, rubber tired/rail mounted gantry cranes or overhead traveling cranes. Such stacking equipment speed up the stacking activities, making the stacking system very efficient (Ligteringen, 2017).

Continental transport

At the port gates queues are present in peak moments. In the future it is expected that these queues will enlarge, causing inefficiency for the port. To minimise the queues, the gate operations should be optimised. Continental transport operations in the San Vicente port can become more efficient if the truck appointment system is improved. In the optimal situation the cargo flows are smoothed over the entire day, lowering the pressure on the port gates.

D

Port Operations

This Appendix focuses on the current port operations. Port operations in general will be described, followed by a short introduction to the San Vicente port characteristics. Next the port operations in the port of San Vicente will be described. Once a clear picture of the current port operations in San Vicente is established, a problem analysis will be performed to map issues in the current operations. Finally, the expected problems in the future in the port using the current operations will be illustrated.

D.1. General port operations

In this report, when port operations are mentioned, all activities from container arrival until departure are meant. Port operations can be divided into several processes (Ligteringen, 2017; Rijsenbrij, 2018b), below these processes are described in general. Figure D.1 is a graphical schematisation of port operations in general. The scheme highlights operations from seaside to land and the other way around.

Port operation processes

- **Vessel operations**
  Location: at the quay
  Process: (un)loading the vessels with quay cranes
  Material: Mobile Harbour Cranes (*MHC*), Ship-To-Shore cranes (*STS cranes*), gantry cranes

- **Internal transport**
  Location: between the quay and storage yard
  Process: internal transport for containers, transport of containers from the quay to the storage yard
  Material: Trucks, Multi Trailer System *(MTS)*, Automated Guided Vehicles *(AGV)*

- **Stacking system**
  Location: at the storage yard
  Process: stacking the containers with a stacking system, stacking cranes or vehicles stack the full and empty containers in the storage yard
  Material: Top loaders, Forklift trucks, Chassis, Reach Stackers *(RS)*, Straddle Carriers *(SC)*, Rubber Tired Gantry Cranes *(RTG, RMTT)*, Rail Mounted Gantry Cranes *(RMG)*, Overhead traveling cranes

- **Continental transport**
  Location: from storage yard to hinterlands
  Process: transport the containers to the hinterland with various transport means
  Material: Train, Truck, Barge

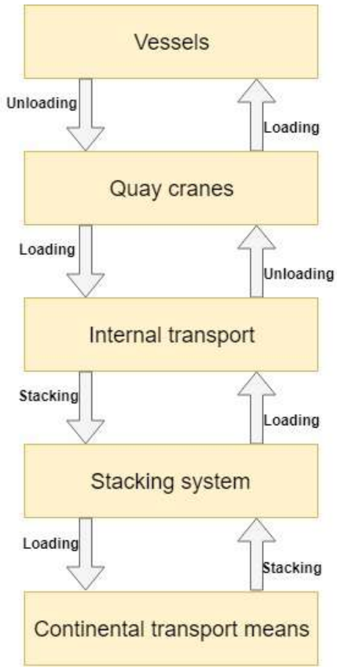


Figure D.1: Schematic overview general port operations

D.2. Port characteristics

Before the operations in the San Vicente port are explained conceptually, it is important to understand the characteristics of the port. San Vicente is mainly an export port. In the Chilean hinterland there are a lot of wood, pulp, paper and cellulose companies. These companies use, among others, the San Vicente port to export their products to the global market. The products are transported as (break)bulk to the port by train and trucks. Inside the port and at the external rented port areas the (break)bulk is consolidated in containers. From the imported containers a large percentage is empty (85%, see demand forecast Appendix A). The empty containers are used in the port for consolidation of the (break)bulk goods.

The majority of the containers handled by the port therefore enter the port by vessel and leave the port by vessel without leaving the port. Only a small part is transported to the hinterland. In Figure D.2 the container flow is represented, based on the information from the demand forecast which is elaborated in Appendix A.

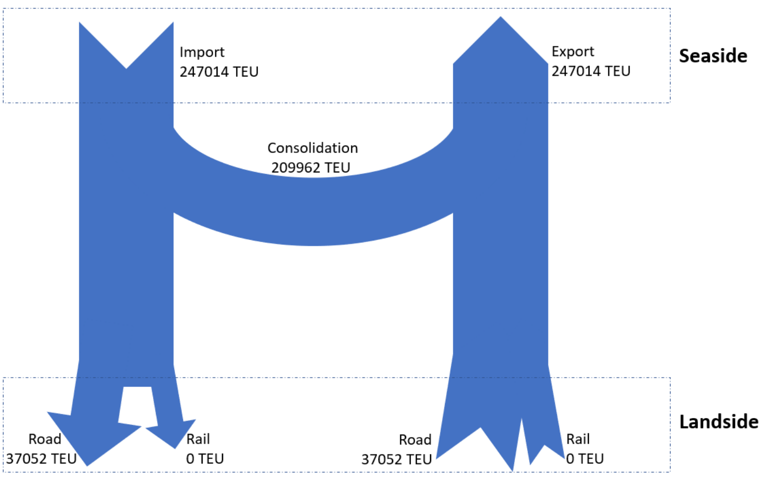


Figure D.2: Container flow in San Vicente port

As mentioned a part of the bulk arrives in the port through rail. Yet this bulk is not transported in containers by the train. Therefore in the container flow diagram 0 TEU is indicated for rail transport. It is important to realise that this does not mean that there is no transport via rail. Moreover, trucks transport (break)bulk from the hinterlands to the port. However this is transported in containers. Therefore the number of tonnage transported by trucks is higher than Figure D.2 would suggest.

Figure D.2 shows that most containers remain in the port for consolidation and do not continue to the last process step shown in Figure D.1, continental transport. These containers will return from the stacking area to the internal transport.

D.3. Port operations in San Vicente port

The port operations in the port of San Vicente are explained in this section. The processes that a container undergoes from the point of arrival until the point of departure (continental transport) are described. In the subsections the processes and materials in the San Vicente port are specified in more detail.
As the operations in the port are divided in multiple sub-processes, the container is moved around several times during its journey. Unfortunately, the average moves per container is unknown since the lack of information about the shuffling of containers in the storage yard.

Figure D.3 highlights the layout of the San Vicente port. The Roman numbers in the map are used to generate a clear overview on the port and the port operations.

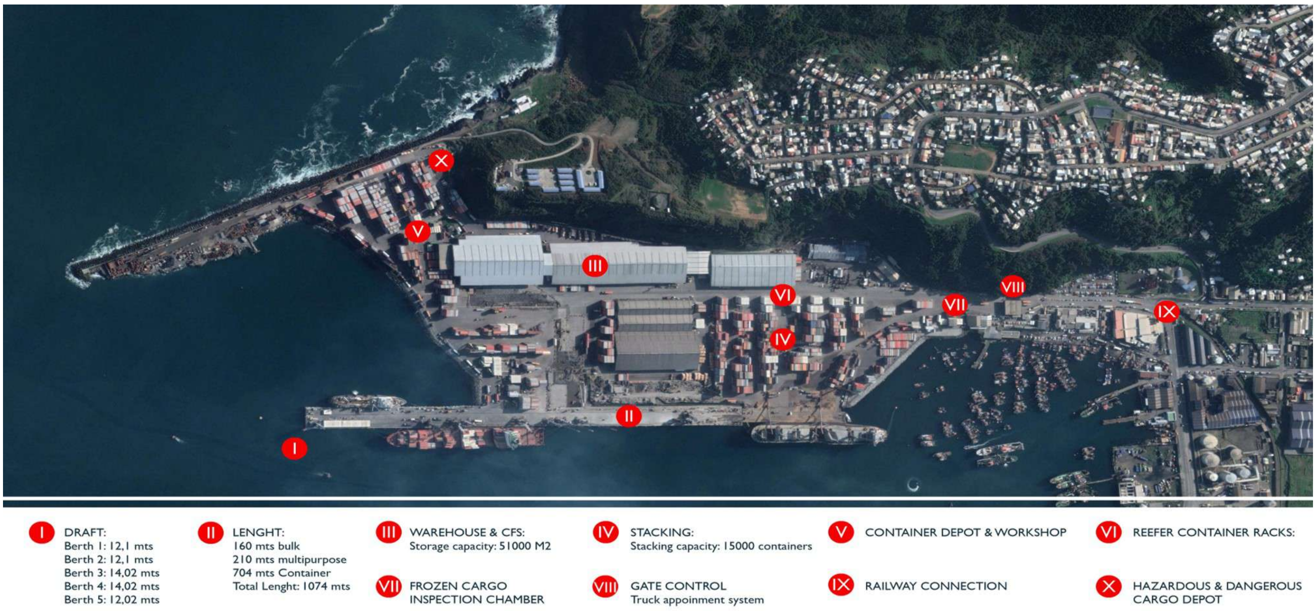


Figure D.3: Overview layout San Vicente port (San Vicente Terminal Internacional, 2019)

D.3.1. Operations

When a vessel arrives in the San Vicente bay, tugboats push the vessel to the right berth (Figure D.3 at I, II) to moor (Figure D.4a). When a vessel has successfully moored, a safety instruction is given to instruct the employees on how to safely operate during the vessel unloading activities (Figure D.4b).

(a) Vessel mooring at the San Vicente port (b) Safety instruction in the San Vicente port

Figure D.4: Vessel operations

Once the vessel has moored and the safety instruction is given, the unloading of the vessel can start. With quay cranes the containers are unloaded from the vessel (Figure D.5a). A container that is unloaded from the vessel, is directly loaded onto a truck on the berth (Figure D.5b).

(a) Vessel unloading with gantry crane at the San Vicente port (b) Truck loading with gantry crane at the San Vicente port

Figure D.5: Quay operations

After the container is loaded on the truck, the truck drives to the correct location in the port (in Figure D.3 at IV, V, VI, X). In the port of San Vicente several types of containers are handled, namely empty, export and import containers. These types are stored at different places. In the port of San Vicente the containers are stacked in separated areas based on criteria such as weight, length, function and destination (Garcia, 2019). The export containers and part of the empty containers are stored inside the port. The import containers and the remaining empty containers are stored on the external area that the port rents.

When the truck with containers arrives at the correct location in the storage yard, the container is lifted from the container by a reach stacker (Figure D.6a). The unloaded truck drives back to the berth for the next container. Next, the reach stacker stacks the container in the storage yard (Figure D.6b). The container remains in the storage yard until it is requested again.

(a) A reach stacker unloading a truck (b) A reach stacker stacking a container

Figure D.6: Stacking containers

On average the container is requested after a few days (for dwell times see the demand forecast in Appendix A). If the container is requested the reach stacker lifts the container from the storage yard and loads it onto a truck (Figures D.6b and D.6a). The truck drives the container to the next location.

A large part of the containers are transported inside the port with internal transport, as mentioned before these are empty containers that go to the consolidation area, highlighted in Figure D.3 at III. These containers do not continue to the last step of the operation process but return to the previous step and leave the port by vessel.

The full imported containers and a surplus of empty import containers are transported outside the port to the external port area or directly to the hinterland via the gate, highlighted as VIII in Figure D.3. By doing this the port creates a push system, which prevents containers from remaining in the port unnecessary (Negenborn, 2018). The containers transported outside the port are loaded on continental transport means, in the port of San Vicente these means are trucks. Before the truck leaves the port it needs to pass the gates at the beginning of the port, see Figure D.7. At the gates the truck driver is manually checked by a gate employee for legitimate documents and if the correct container is entering or leaving the port. The San Vicente port has a system of truck appointments (Merk, 2016). This system is introduced to smooth cargo flows at the port gates and reduce waiting times for trucks. On an online platform, exporters can book an arrival time to bring a container and additionally pick up a container.

Figure D.7: The San Vicente port gates

D.3.2. Equipment

The San Vicente port has various means of equipment to execute the port operations. This subsection elaborates on this.

Vessels

Multiple types of vessels are able to berth at the port, with lengths ranging from 100 to 350 meters (Empresa Portuaria Talcahuano San Vicente, 2017). Vessels larger than 350 meter currently do not moor in the San Vicente port, even though the port can accommodate for larger sizes. Yet the berth length is not sufficient to moor several large boats

at once.
The smaller vessels are able to moor at berth 1 and 2, the larger vessels can only moor at the other berths, as the depth at berth 1 and 2 is not sufficient for the large vessels.

Quay cranes

At the port of San Vicente there are two types of cranes used (San Vicente Terminal Internacional, 2019). Traditionally, the port used only Mobile Harbour Cranes (MHC). At this moment there are 9 MHC's operating in the port.
Since 2019 the port of San Vicente has installed two Ship-to-Shore gantry cranes. These cranes are currently used mainly to unload the vessels since the handling capacity of these Ship-to-Shore cranes is much higher than the handling capacity of the Mobile Harbour Cranes (Ligteringen, 2017). If necessary one or more MHC's are used in addition to the gantry cranes.

Internal transport

As mentioned in the description of the port operations in the San Vicente port, the internal transport in the port is done by trucks. The port has 44 trucks to transport the containers from the berths to the storage yard (San Vicente Terminal Internacional, 2019). One truck can transport 2 TEU at the time, this means either 2 20ft containers or one 40ft container.

Stacking system

In the San Vicente port containers are stacked in the storage yard. Empty containers are stacked five high. This is done by reach stackers as described in the San Vicente port operations. The port owns 15 reach stackers, Figures D.6a and D.6b give an example of a reach stacker in operation. In the port the stacking system is fully automated. This implies that a reach stacker automatically receives a message to pick up a container from the storage yard or from a truck if unloading is required (Garcia, 2019).

Continental transport means

Part of the containers are transported to the hinterland or to an external storage yard a few kilometers outside of the port. Similarly to the internal transport in the port, this is done by trucks. The trucks entering and leaving the port need to pass the gates at the beginning of the port (Figure D.7 and Figure D.3 point VIII). In the port of San Vicente there are 4 gates with lanes to enter the port and 2 gates with lanes to exit the port. On average it takes 1.5 minutes for a truck to pass the gates (Empresa Portuaria Talcahuano San Vicente, 2017). With the truck appointment system, the average service time of a truck in the port is 15 minutes (Maritimo, 2015), never exceeding more than 30 minutes. There is also a rail track in the port (as can be seen in Figure D.3 at point IX). As mentioned earlier trains transport bulk into the port. These bulk goods are brought to the consolidation area and there the bulk is consolidated in containers, which are later shipped of.

D.4. Current problem analysis

During several observations of the port operations in the San Vicente port and conversations with port employees (Salgado, 2019; Garcia, 2019), various problems in the operations are identified. The port operations are sequential, yet all operation steps are coherent. Therefore it is not possible to pinpoint one problem in the San Vicente port operations as the absolute bottleneck. For that reason the all problems in the port operations are analysed. For each process step in the port operations, port operations that result in issues are described.
Moreover, there is little information available to quantify the port operations in the San Vicente port. Therefore the problems are described in a more qualitative way.

Vessels

The vessels arriving in the San Vicente port do not form a problem in the current port operations.

Quay

In the past the quay cranes were the biggest problem, and therefore the bottleneck in the operations, because Mobile Harbour Cranes were used for unloading the vessels. Since two Ship-To-Shore gantry cranes were installed on the quay in 2019 the unloading of the vessels is not the bottleneck in the San Vicente port operations (Ligteringen, 2017). However, the cranes are relatively new and therefore the crane operators are not very experienced in handling the gantry cranes. The result is that the cranes do not operate at full handling capacity, leading to a limiting factor in the operations.

Internal transport

In internal transport another problem is found at San Vicente port. The cause of this problem is the current shape of the port. The containers are not stacked directly behind the cranes. Therefore the trucks loaded with a container travel an inefficient route, see Figure D.8. This implies that the internal transport is not operating as efficient as it could, hence resulting in an issue for the port operations.

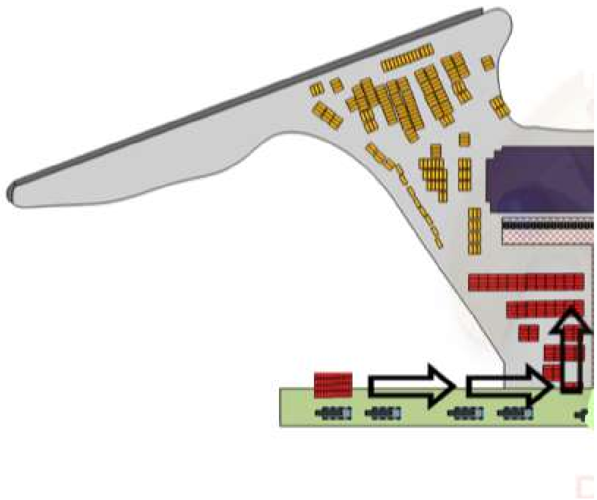


Figure D.8: Inefficient internal transport because of container travel route

Stacking system

The stacking system in the San Vicente port is organised quite well. Currently there is enough time between the arriving vessels so that the container yard can be organised. The containers handled in port are separated based on various criteria. Yet an issue remains in the stacking system. To accommodate the current throughput of the port, the containers in the storage yard are often stacked 5 containers high and very close to each other (demand forecast Appendix A). Even though the container area is very well organised, the high stacking density decreases the container accessibility (Rijsenbrij, 2018a). With a poor container accessibility the stacking operations take up more time. Therefore the stacking system does not work highly efficient, which results in a problem in the current port operations. Furthermore, at peak moments there is not enough storage area to stack all containers. Currently they solve this by cutting of traffic lanes in the yard to use this as container storage. This also indicates an issue in the stacking system.

Continental transport means

A truck entering or leaving the port needs to pass the gates at the beginning of the port. The port has four inbound gate lanes and two outbound gate lanes. Even though the port has a system for truck appointments, an issue can be identified at the port gates. In the port the truck passage has a lot of peak and trough moments. Therefore at one moment there is no queue at all, whilst at other moments there is a queue of four trucks per lane. The gates do not yet effect the port operations as such, yet it can not be denied to be an issue for the port.

D.5. Expected future problems

In the future the port of San Vicente expects a substantial growth in throughput demand, in Appendix A this is laid out in detail. Based on this demand forecast and the identified problems in the operations it can be concluded that the port can not keep up with the increasing container throughput. The following problems are expected to enlarge or arise in the operations in the future, if no action is taken by the port (Garcia, 2019).

Vessels

The vessels arriving in the port of San Vicente are still not expected to result in an issue in the future, despite the expected growth in demand and unaffected port operations.

Quay

The quay cranes will remain a crucial point in the operations, even if the crane operators become more experienced. The demand forecast insinuates that in the future more often two ships will moor at the same time in the San Vicente port. The KPI of 100 mvs/h is measured per ship. Since the port only has two gantry cranes they will theoretically not be able to reach the 100 mvs/h KPI when multiple vessels need to be unloaded at the same time. Unloading two ships at once is done by the gantry cranes and the mobile harbour cranes. The handling capacity with mobile harbour cranes can theoretically never reach 100 mvs/h/ship, causing a large problem for the operations.

Internal transport

As mentioned in the current problem analysis (Section D.4, the internal transport is not operating as efficient as it could because of the shape of the port causing a non-optimal container flow (Figure D.8). In the future, with an increased throughput this inefficient container flow will cause even more problems as more containers need to be handled in the same amount of time.
Furthermore, congestion inside the port might occur due to too little road capacity. Traffic jams might originate from the trucks blocking each other because of the inefficient route. This will cause problems for the port operations.

Stacking system

The predicted container throughput for the San Vicente port implies that in the future more vessels will be arriving at the port. This results in less time between calls. The port currently has enough time to organise the container yard. Yet when time between the calls decreases, the time for separating the containers will also decrease. In a less organised port, more time is needed for stacking operations. Thus this will result in an issue for the port.
When the throughput of containers in the port increases, eventually the storage area can not accommodate for all the containers. The port can come up with temporarily solutions for storing more containers, such as stacking higher and more dense or using more roads as storage yard. Yet, for the long run these solutions will not be enough and the storage yard will become too small and therefore a critical issue for the port operations.
Moreover, the stacking equipment might not be able to keep up with the increasing number of container.

Continental transport means

With an increasing throughput the number of containers transported from and to the hinterlands will grow simultaneously. This implies that more trucks will need to pass the port gates. In trough moments a queue of at least one truck might always be present. In peak moments this might result in a spill back of trucks far back into the port area, causing hindrance for the port operations. The gate capacity can therefore result in a problem in the future if the port and the operations remain the same.

D.5.1. Conclusion

All in all the expectation is that the port will need to undertake action to react to the predicted increasing throughput. If the port does not take action to improve operations, for example by investing in extra and/or more efficient equipment or a port expansion, the issues will develop further causing large difficulty for the port and its ability to handle containers.

E

HINTERLAND OPERATIONS

In this Appendix the hinterland transport operations are laid out. First it is specified what kind of activity can be found in the hinterland of San Vicente, followed by an illustration of the situation on the main roads. Next it is discussed if the port expansion could cause problems for the hinterland transport on the main access roads in the future. After this, the hinterland operations near the San Vicente port are discussing if problems could occur in the urban area surrounding the port.
Since San Vicente is mainly an export port, this Appendix describes and analyses the inbound hinterland operations. For the inbound system it is certain where the transport is originating from, for the outbound system the destinations are more doubtful.

E.1. HINTERLAND ACTIVITY

E.1.1. PRODUCTS

The San Vicente port transports a lot of different goods from and to the hinterlands (see Figure E.1). These goods can be divided into categories, namely food such as fresh fruits, timber products such as wood, cellulose, paper and pulp, agriculture products, and fish and other sea products (San Vicente Terminal Internacional, 2019). However, there is one category that is by far the most handled product category. Based on information received from the port, the forestry products make up almost 75% of the handled goods in the port (San Vicente Terminal Internacional, 2019).

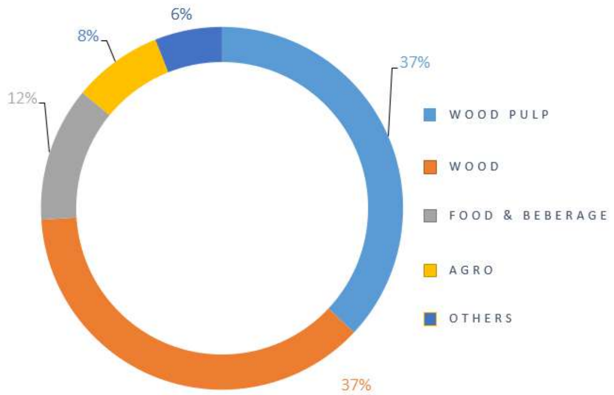


Figure E.1: Overview of port San Vicente's export in 2018 (in percentages). Information retrieved from San Vicente Terminal Internacional (2019)

In the hinterlands of central Chile there are a lot of large wood processing companies located. The pulp and paper manufacturers are big players for the Chilean ports since they export their products with vessels to the global market. San Vicente is one of the Chilean ports that those companies use to transport their goods.

The products are transported by train and trucks from the hinterland to the port. The focus for hinterland transport will be on the transport by trucks. The reason for this choice is based on that the share of truck transport (80%) is much larger than train transport (20%) and will therefore have more effect on the hinterland operations (Empresa Portuaria Talcahuano San Vicente, 2017).

E.1.2. HINTERLAND ROUTES

The San Vicente port has a strategic location as it has good connections with the main roads, see Figure E.2. What is notable, is that the San Vicente port, in contrary to other ports in the Chilean state port system, has multiple access roads (Empresa Portuaria Talcahuano San Vicente, 2017).

To be more precise, San Vicente, that is indicated by the red pin in Figure E.2, has four main access roads. This implies that the hinterland traffic on the highways is quite spread out. In Figure E.2 the four roads are visible, namely the 152, the 146, the 156 and the 160. These are the roads that are analysed with respect to the hinterland transport routes of San Vicente. The roads are all connected to route 5, the highway that travels from the Peruvian border in the north of Chile to the beginning of Patagonia in the south.

Figure E.2: Overview of road connections of San Vicente

The products that are transported to the port originate from the colored dots in the map. Northeast of Concepcion a large wood processing company is located near the city of Nueva Aldea, which is indicated by the green dot. The products transported between Nueva Aldea and San Vicente travel over route 152, also referred to as the Itata route. South of Nueva Aldea and east of Concepcion another important exporter for the port is located, near the town of Cabrero. This place is indicated by the orange dot, products are transported to the port using the 146 route, called the Cabrero route. At the bottom of Figure E.2 a black dot is shown. This dot represents all the hinterland transport from the south of Chile. For transporting products from the south the 156 route is used, named the Patagual route. This road is used to transport products between San Vicente and the south of Chile because it has a very good connection to route 5. The last road used for hinterland transport is route 160. Along this road, that is also referred to as the Coronel route, a very large manufacturer is located south of Concepcion near the city of Arauco. Between the blue dot, representing Arauco, in Figure E.2 and San Vicente a lot of hinterland activity can be found. This is according to SVTI (San Vicente Terminal Internacional, 2019) the most important player in the hinterlands of port San Vicente.

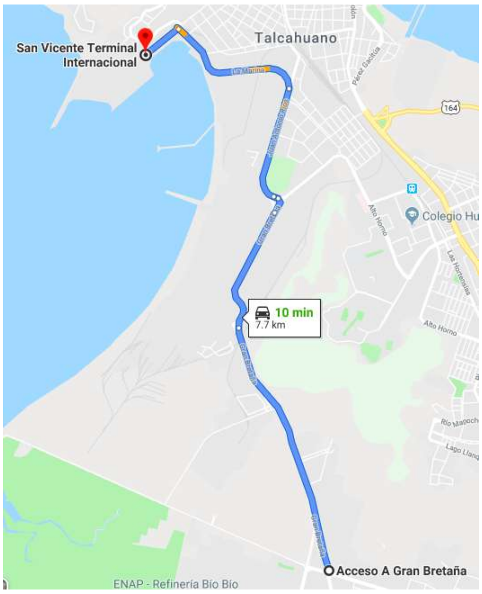
The San Vicente port is located at the west side of the agglomeration of San Vicente, Talcahuano and Concepcion. Consequently, after leaving the main roads, the trucks need to pass an urban area to travel from the hinterland to the port. This means that the trucks coming from the hinterland are merged on the urban roads. The passage of the urban area around the port is a crucial part of the hinterland operations since urban roads have less capacity than the highways, which can generate issues for the hinterland transport operations.

E.1.3. Connection of Hinterland routes to the port

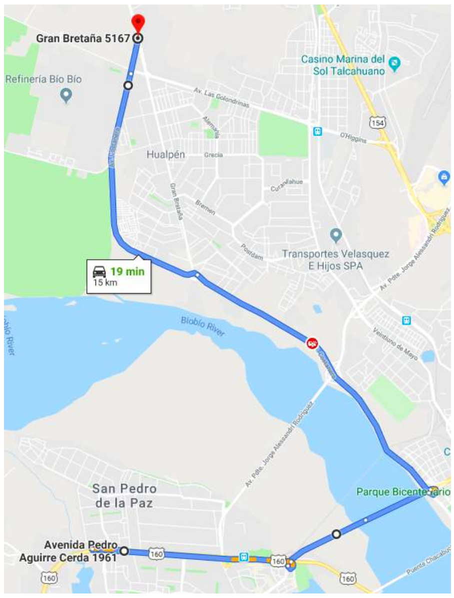
In order to investigate the influence of the port expansion on the direct surroundings, local roads are examined that connect the various main roads (depicted in Section E.1.2) to the port. The port authority wants to minimise the traffic hindrance for the inhabitants of the Concepcion agglomeration. Therefore, the port authority has restricted the hinterland traffic to use two standard routes to approach the port. The Most important one uses the Gran Bretaña, Juan Antonio Rios and the La Marina roads as shown in Figure E.3a.

La Marina is considered to be the most important access road to the port of San Vicente. According to the port authority this one lane secondary road has a theoretical capacity of 1400 veh/h Empresa Portuaria Talcahuano San Vicente (2017). In the event that this road is only used for freight transport, it would lead to a capacity of 9.124.416 TEU/year according to calculations of the port.
The Juan Antonio Rios road is an extension of the La Marina road, therefore it is assumed to have the same capacity of 1400 veh/h. Likewise, the Gran Bretaña is a secondary road. Yet, the Gran Bretaña has two lanes. Hence the capacity of this road will be higher, namely 2800 veh/h.

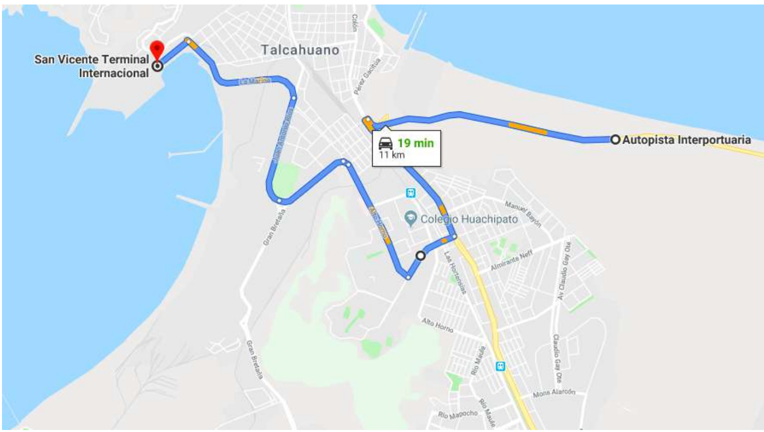
When exiting route 152 or route 146, there are several options to approach the Gran Bretaña road using the main roads of Concepcion. Depending on the chosen route, only 11 to 17 kilometer of the route to the San Vicente port uses secondary roads. According to Google Maps it takes about 15 to 20 minutes to reach the port if no congestion is present on the roads. This suggest that there is a speed limit of 50 km/h on the secondary roads.
Trucks accessing the Concepcion urban area from route 160 and 156 are not allowed to use the Jorge Allesandri Rodriquez bridge because this bridge is quite damaged (Villagrán, 2019). This forces the trucks to use the Llacolen bridge to reach the Gran Bretaña road as pointed out in Figure E.3b. Furthermore the trucks are not allowed to pass through the city of Hualpen. Therefore they take the wide curve around this city, this is also shown in Figure E.3b. In the event that the port is approached from route 160, the trucks pass 16 km of secondary roads, which takes up about 20 minutes.
Route 152 benefits from an extra opportunity to access the port, namely using road 164. In order to minimize the hindrance for inhabitants of Talcahuano, the port is approached from the 164 route as represented in Figure E.3c. After exiting the 164 route, the trucks drive only 7 kilometers over secondary roads. Yet time wise this is a longer route since the used secondary roads cross a more populated area. The roads used from the 164 route to the port are predominantly two lanes, until the Juan Antonio Rios road is reached.



(a) Approaching port San Vicente with Gran Bretana road



(b) Approaching the Gran Bretaña exiting from route 160



(c) Approaching the port exiting route 164

Figure E.3: Different ways to approach the port

E.2. Current traffic conditions

The hinterland transport analysis focuses on the access roads described in the previous section. The current situation on the highways, the urban roads and access roads are discussed. Investigation is done in order to check if there are currently congestion or capacity issues present in the hinterland operations. Exploring the current situation is done using Google Maps Traffic. In this tool the typical traffic speeds per hour of every day are shown by a color of the link (road). These estimations of speeds are based on the GPS-determined speeds of a large number of cellphone users (Matthews, 2013). It is not the most advanced tool since it does not directly indicate anything about the traffic density on the road. However using fundamental diagrams (example of a fundamental diagram can be found later in Section E.12) in traffic flow theory, the speed can be linked to the density on the road (Knoop et al., 2018). If there is no free flowing speed, it means that the traffic is more dense on the roads. In the case the density on the road gets to high, it will cause congestion and leads to low traffic speeds.

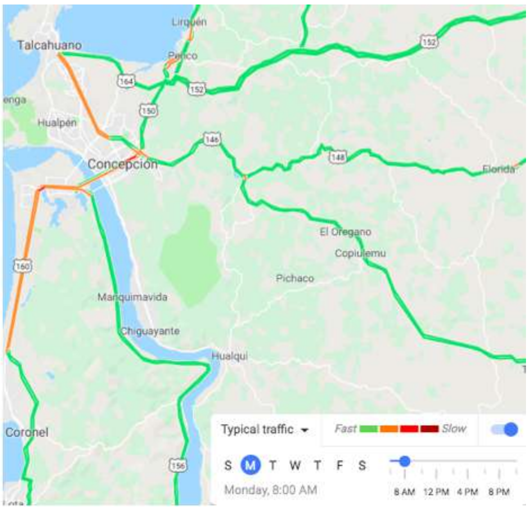
The following section is divided into three subsections. First the traffic condition on the main hinterland routes are discussed. Between the routes and the connection roads, trucks have to pass the urban area of Concepcion. The traffic conditions in the urban area has an own subsection. The last subsection will be about the traffic conditions on the access roads from Section E.1.3

E.2.1. Situation hinterland roads

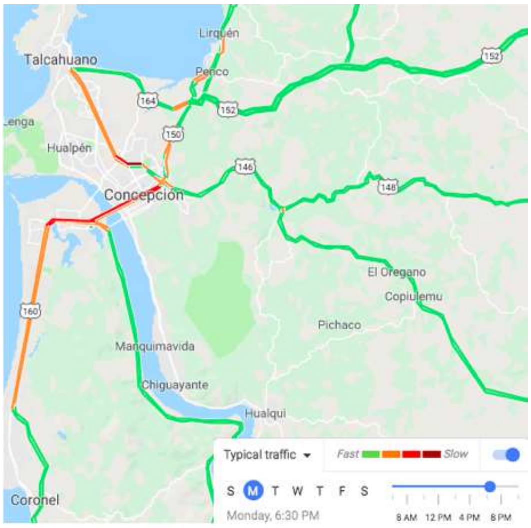
As mentioned before, the hinterland transport of the San Vicente port travels over four main routes, namely 152, 146, 156 and 160. The traffic situations on these routes are represented in Figure E.4. The situation on the highways on a Monday during the morning and evening peak and during normal conditions are shown. Since there is not a large difference between days during the week, the situation on Monday gives a satisfactory representation of the traffic during the entire week. It is visible that routes 152, 146 and 156 are not congested since a high speed is maintained on these routes, even during rush hours. Entering route 164 from route 152, located along Concepcion' north coast, the road is likewise in free flow. Route 164 functions as an alternative for passing through the urban area. Furthermore, Figure E.4 shows that on the 160 route the speed on the road is usually low, especially during the rush hours. The congestion is in particular an issue near the bridge that crosses the Biobío river south of Concepcion.

An explanation for the congestion on the Coronel route (160 route) is that the road is damaged and very badly maintained. Additionally to the damaged road, truck traffic is only allowed to use one of the bridges to cross the river since the other bridge is too weak to support heavy truck traffic (Villagrán, 2019).

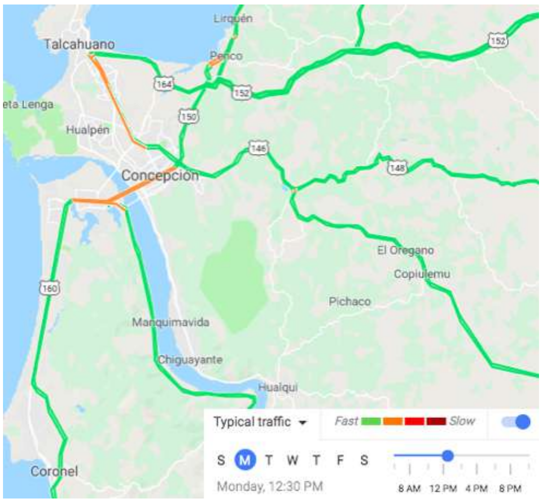
Unlike the damaged 160 route, the other three main access roads to the port are very well maintained and have enough capacity to accommodate the corresponding traffic flow. The fact that route 160 faces most congestion is a big problem for the port since the biggest share of products comes from this direction.



(a) Situation during morning peak



(b) Situation during evening peak

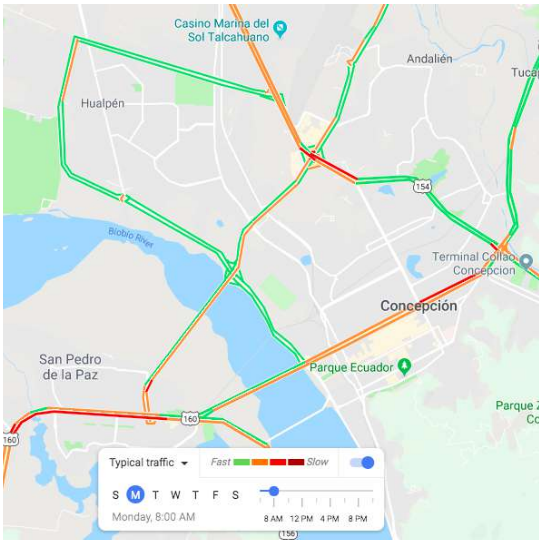


(c) Situation during normal conditions

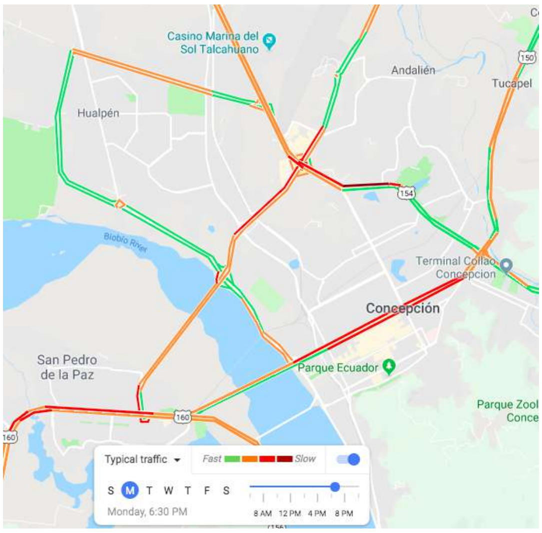
Figure E.4: Representation of traffic situations in hinterlands

E.3. Situation urban area roads

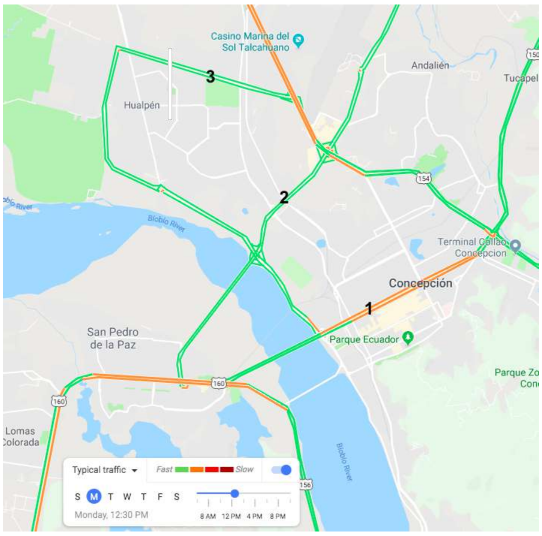
Traffic conditions over the different days of the week are very similar. Therefore a regular Monday gives a satisfactory representation of the situation on the urban roads. In Figure E.5 the situation on the roads during the morning peak, evening peak and in the middle of the day are shown together.



(a) Situation during morning peak



(b) Situation during evening peak



(c) Situation during normal conditions

Figure E.5: Representation of traffic situations in urban area

Considering the figures above it becomes clear that the road flowing out of the 160 route passing through San Pedro is congested during the rush hours. Even in the middle of the day traffic on this road is slowed down, suggesting dense conditions. The main bottleneck seems located in the city of San Pedro. The bridge itself faces only lower speeds during the morning peak. This means that traffic from road 156 faces less problems. For convenience, Figure E.5c displays two roads coming from the south. The road on the right is route 156 and the road on the left is road 160.

As mentioned before, coming from road 152 or 146 in the east of Concepcion there are multiple routes to approach the Gran Bretaña road in the north of Hualpen. It is in this case necessary to cross the urban area of Concepcion. There are three options for doing that, those options are noted with numbers in Figure E.5c.

The road los Carrera, traversing the city of Concepcion in the south east is the first option. This road has dense conditions all day. Traffic is always slowed down in the three situations considered in Figure E.5. During the evening peak the traffic on this road is even fully congested. Therefore it is more logical to travel further across road 154, to option two and three in order to reach the Gran Bretaña road. Road 154 is congested during the morning and evening peak. Because of that it is not possible to avoid congestion during peak hours when crossing the urban area.

The third option, the O. Higgins road, would in most cases be the preferred option to reach the Gran Bretaña road. Only during the evening peak traffic is not free-flowing on this road. The second option, the Jorge Allesandri Rodriquez road, is congested during peak hours and also a larger distance has to be covered.

As mentioned earlier, road 152 benefits from an extra option reaching the Port of San Vicente, avoiding the urban area of Concepcion. It can use road 164 along the coastline in the north of Concepcion which is the best way to avoid congestion during the day. At this road the ability to travel at high speeds is maintained even during peak hours, which is depicted in Figure E.4

For the urban area it could be concluded that during the day there are no significant accessibility issues for the San Vicente port. Only route 160 which passes through San Pedro faces problems beyond rush hours. During the peak hours there will always be some congestion when passing the urban area. The evening peak is worse then the morning peak, so truck movements around this time of the day are most urgent to avoid. When trying to avoid congestion completely, even during peak hours, the urban area can be avoided using route 164 when coming from down from route 152.

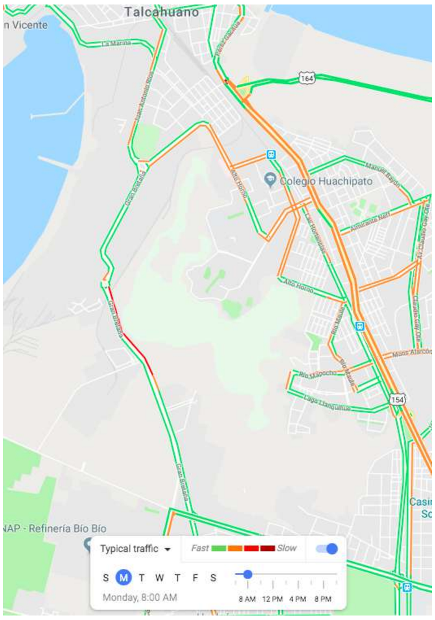
E.3.1. Situation close to the port

In Figure E.14 the roads that approach the San Vicente port are displayed in more detail. Again the traffic situation during a regular Monday is a fine representation for the traffic conditions during the whole week. The morning peak faces some congestion issues at the Gran Bretaña route. It would be better to avoid truck movements during this part of the day. During the remaining part of the day the Gran Bretaña route has free flowing conditions. The only point of attention is the first curve in the road La Marina. This curve colours orange at 12.30 even though there are no problems during peak hours. Traffic is probably slowed down due to freight traffic. This is supported by the fact that the curve is situated at the entrance of an external storage yard. Truck movements could therefore disturb traffic. Figure E.7 displays this first curve in road La Marina

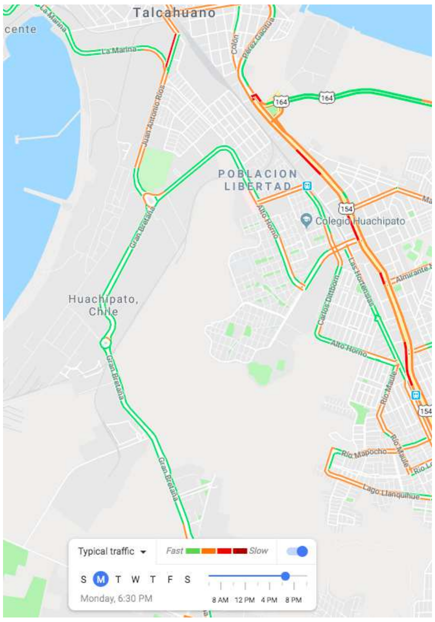
Coming from road 164 and using the route as pointed out in Figure E.3c, traffic at road 154 could be a problem. This small highway section shows slower traffic conditions during the day and morning peak. In the evening rush hour it is even fully congested. The remain part of the route after leaving road 154 (the highway section), has only slowed down speed conditions during peak hours.

Given the current traffic conditions in the area close to port San Vicente it could be concluded that the accessibility is quite good. The distance that needs to be covered across secondary roads is short. For the main access route (Gran Bretaña) there is only little congestion during the morning peak. The only point of attention is the above mentioned slowed down traffic in the curve of the La Marina road. The other way to approach the port (coming from road 164) faces more problems, as there traffic has to slow down during the whole day. Fortunately, the distance that needs to be covered across those slowed down roads is short. Moreover, only trucks coming down from road 152 could use this way in order to reach the port. Because of that this way of approaching the port is less preferable than the Gran Bretaña route.

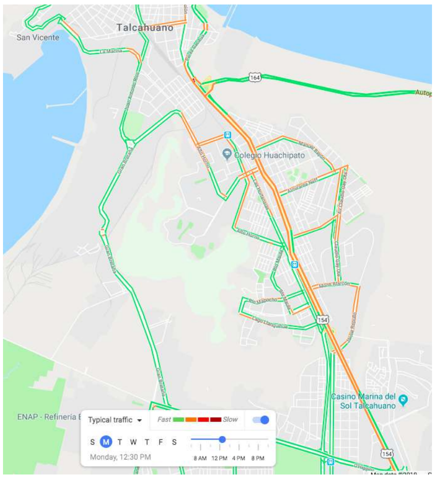
Although in the close range to the port there are only a few accessibility issues it is important to keep in mind that this area is most vulnerable to expansions of the port. These roads have smaller capacity and all traffic going to the San Vicente port is obligated to use this roads. Therefore their future prospect is investigated while the port expansion is taken into account.



(a) Situation during morning peak



(b) Situation during evening peak



(c) Situation during normal conditions

Figure E.6: Representation of traffic situations approaching port San Vicente

Figure E.7: Problems occurring at the curve in La Marina road

E.4. Future prospect

The demand forecast (Appendix A) shows a significant increase in throughput for the San Vicente port. Considering the future expansion the port authority wants to prepare the port in order to accommodate this extra demand. This section will analyse whether the connecting, urban and hinterland roads are also able to cope with the increasing demand. This is examined by giving an answer to the following questions:

- *What is the amount of extra truck movements?*
- *In which way will these movements be divided across the different roads?*
- *Do the extra truck movements have a significant influence on the traffic flows?*

E.4.1. Extra truck movements due to increasing throughput

Based on the demand forecast a rough estimation can be given about the expected truck movements in 2025. The expansion is mainly focused at obtaining extra container throughput. Therefore the extra truck movements will only be based on the increasing container throughput. This means that throughput of bulk is not considered. The current container movements are represented in Figure E.8. The challenge is to translate traffic flows to an amount of incoming truck movements. All import going towards the road will directly lead to truck movements out of the port. All export coming from the road consists of truck movements towards the port. The difficulty is to obtain the number of truck movements towards the port for the consolidation of empties. In the performance review (Empresa Portuaria Talcahuano San Vicente, 2017) the port authority stated that 20 % of the total tonnage of consolidation goods is entering the port by train. Since all goods for export reach the port by truck or train it can be assumed that 80 % of the consolidation goods comes in by trucks. Not everything is consolidated in the port itself, but also when the consolidation is external it will in the end lead to truck movements towards the port.

The total TEU moving into the port is the sum of the export containers coming from the road and 80 percent of the consolidated TEU. This comes down to roughly (209962*0.8+37052=205021.6) 200.000 TEU moving into the port by trucks. Dividing this number by the TEU factor the amount of trucks is found to be approximately 110.000 per year (205021.6/1.86=110227). Therefore on average 300 trucks (110226.7/365=302) move into the port every day. In order to give an estimation of the situation in 2025 also a chart is created for 2025. This is done while considering a 45 % market share from Appendix A. Figure E.9 visualises this expected container flow. Making the same calculations results in 300.000 TEU per year moving towards the port (308605*0.8+54460 = 301344). This comes down to around (301344/1.86= 162013) 160.000 trucks moving into the port in a year and on average almost (162013/365=444) 450 trucks a day. Meaning that ports needs to deal with approximately 150 trucks extra moving into the port every day. Since trucks take significantly more space on the road than normal traffic, the number of trucks must be multiplied by a factor of 2.5 (Merk, 2016) to calculate the amount of extra vehicles coming towards the port. Doing this leads to an extra 375 vehicles moving to the port each day.
In order to look even further into the future, also a possible situation for 2045 is calculated in the case of the 50 percent market share scenario. This is depicted in Figure E.10. This situation would lead to around 530.000 (546567*0.8 + 96453 = 533707) TEU moving into the port by truck. This comes down to around (533707/1.86=286939) 285.000 trucks moving into the port every year and on average almost (286939/364=786) 800 trucks movements each day. This is an increase of around 500 trucks each day compared to the current situation. The result is an extra of 1250 vehicles flowing into the port each day.

The information about the extra average movements per day gives hardly any information about the extra trucks per hour. However, most trucks move into the port in order to transport bulk for consolidation and therefore the movements are less restricted to calls of container vessels. Furthermore the port has an appointment system for trucks coming into the port as discussed in Appendix D. This enables the port to spread the incoming traffic as much as possible.

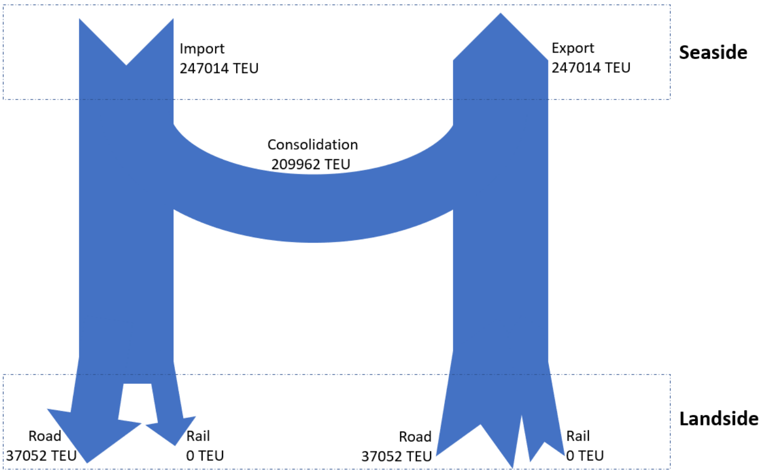


Figure E.8: Container flow in San Vicente port

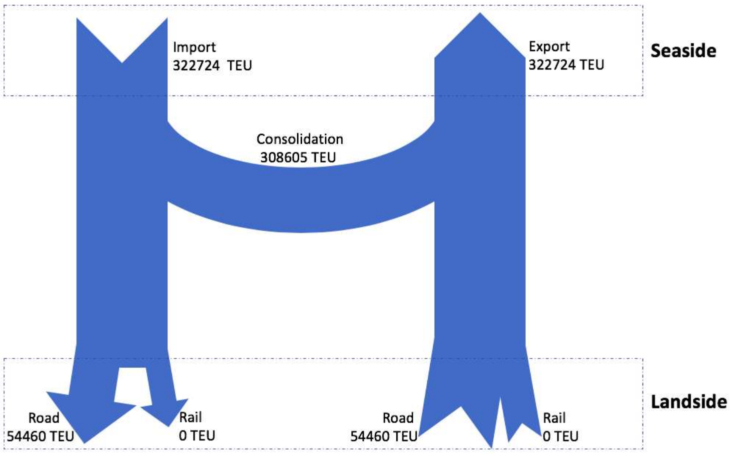


Figure E.9: Container flow in San Vicente port forecast 2025, 45 percent market share

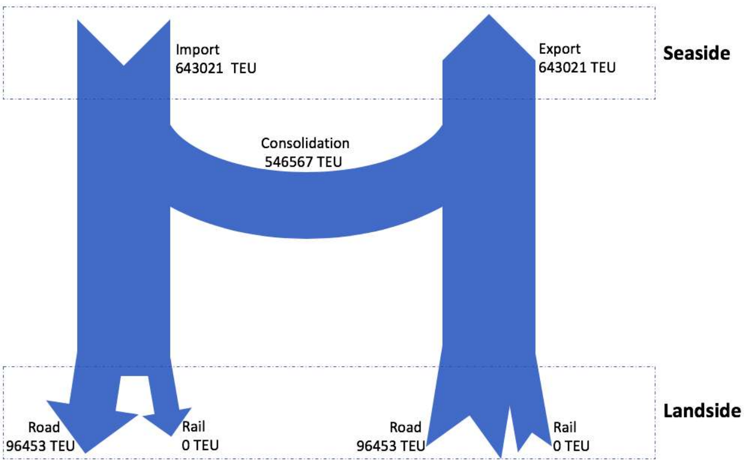


Figure E.10: Container flow in San Vicente port forecast 2045, 50 percent market share

E.4.2. Dispersion of traffic across routes

As explained in Appendix A, the MAPA project is one of the major causes related to the expected future growth. As a result of the MAPA project the inbound hinterland traffic on the 160 route will increase substantially. The other ports of Coronel and Lirquen will also benefit from this MAPA project. Both ports are restricted to use route 160 since no good alternatives are available. This means that route 160 should be ready to accommodate for all extra traffic related to the MAPA project. Coming from route 160, there is only one way to approach the San Vicente port as pointed out in Section E.1.3. This route is visualized in Figure E.11. Because the expected increasing demand of San Vicente port is mainly caused by the MAPA project the effect on the other three main routes is expected to be limited. The other routes have also more possibilities to spread out when approaching the urban area, resulting in even more dispersion of the traffic.

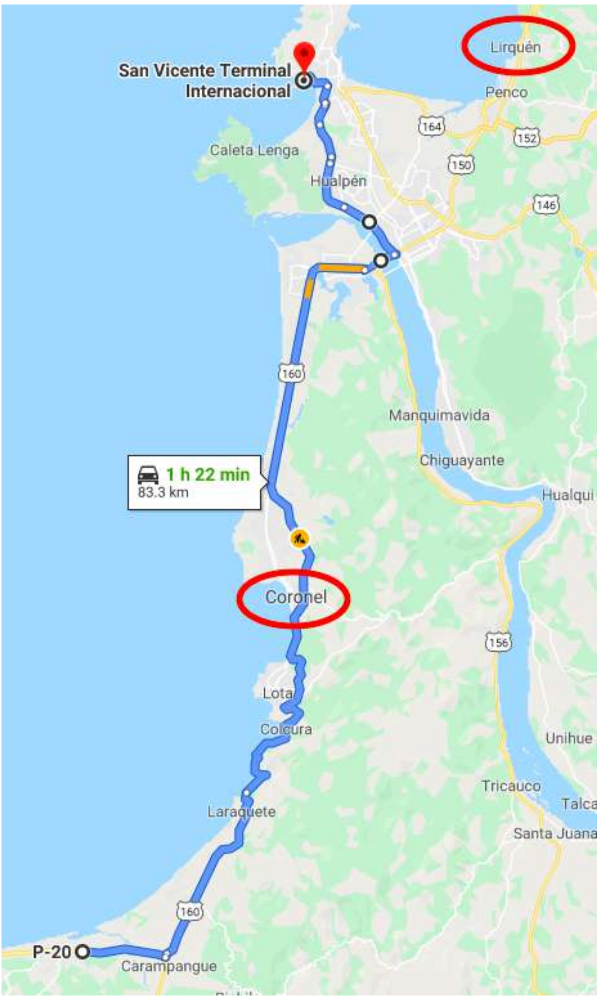


Figure E.11: Route used coming from the MAPA project, other ports indicated with red circle

E.4.3. EFFECT ON TRAFFIC FLOWS

ROUTES 152, 146 AND 156

Considering the information about the total extra expected traffic towards the port in combination with the dispersion between the routes, an estimation can be made about the effect on the traffic flows. In 2025 it is expected that the incoming traffic flow to the port will increase with 375 vehicles per day. Given this number, the effect on the main routes 152, 146 and 156 is expected to be negligible. As explained in Section E.4.2 most extra flow will come from route 160. In order to illustrate the negligible effect on the other main routes a simple calculation (only an illustration, so it is not based on real data) can be performed. Assuming that at least half of the extra vehicles will come from route 160, then remaining part of the 375 vehicles could be divided over the other three routes. This would result in 62.5 extra movements per day on each road. Even when all this extra vehicle movements would take place during the same hour this would not give problems to the high capacity roads (which are completely free flowing at this point). Using the same calculation for the situation in 2045, it would lead to around 200 extra vehicle movements towards the port each day on routes 152, 146 and 156. Assuming that the extra traffic is spread out over the day (safe assumption since the appointment system of the port) this is still an negligible number of extra vehicle movements.

ROUTE 160

The situation gets more interesting when analysing route 160. Route 160 appeared in the analysis of the current traffic conditions in Section E.2.1 already the most congested route. Furthermore this route is expected to have the biggest increase in traffic flow towards the port. The usage of this road by the other Biobío region ports is also expected to increase significantly because of the MAPA project. If the damaged road of the 160 route is not recovered, the future prospect for hinterland transport using the 160 route is a point of attention. On the bright side, in the near future a new bridge crossing the Biobio river will be built (Villagrán, 2019). It is expected that this will slightly reduce congestion around the Concepcion metropolitan area. For this research there are to many unknowns in order to formulate accurate expectations about the congestion in the future. However it can be easily illustrated that more future research to this road is necessary by using the fundamental diagrams represented in Figure E.12. This diagram represents a typical relationship between speed (km/hour), flow veh/hour) and density (veh/km) on an aggregated level. There is a stable , not congested, state when the density on the road is lower then the critical density (K_C). In this part of the diagram traffic flows are increasing with higher densities. Once the density becomes higher than the critical density, the situation becomes unstable. This is called the congested branch of the graph. In this part the traffic flow decreases with higher traffic densities. The speed corresponding to the point of critical density is called the critical speed (V_C). (Knoop et al., 2018)

Figure E.12 displays Wu's fundamental diagrams which are a relatively advanced version because they consider a capacity drop and a speed decrease in the free flow branch of the diagram (Knoop and Daamen, 2017). It is not possible to say that one diagram is in all cases more realistic than the other ones. The diagrams are only used as an example, no further investigation is done in order to establish if these diagrams are most suited to represent the traffic conditions for the routes of this research. Also the values that are used are not based on the real situation. Since the road around San Pedro has two lanes it is expected to have higher capacity values then the ones indicated in the diagrams.

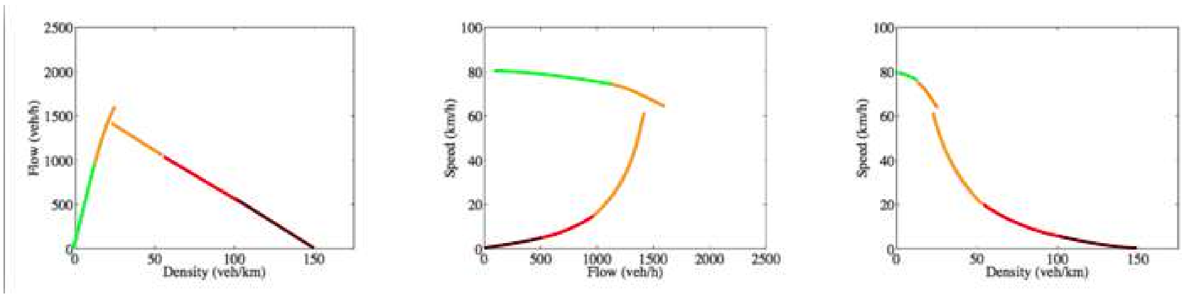


Figure E.12: Fundamental diagrams; flow/density, speed/flow and speed/density(Knoop et al., 2018) colours represent Google traffic states

In Figure E.12 the different colours represent the Google traffic states. Figure E.13 displays that during the middle of the day the speed conditions around the city of San Pedro are reduced (orange). The problem is that it is not known in which orange part of the above diagrams the speed conditions are situated. As example, when the traffic flow is 1100 (veh/hour) the flow could increase with approximately 500 (veh/hour) before the critical density is reached and the traffic becomes unstable. But when the flow is already 1500 (veh/hour) (also an orange part of the diagram), an extra flow of 100 (veh/hour) would already result in unstable traffic conditions. These unstable conditions could eventually result in congested roads.

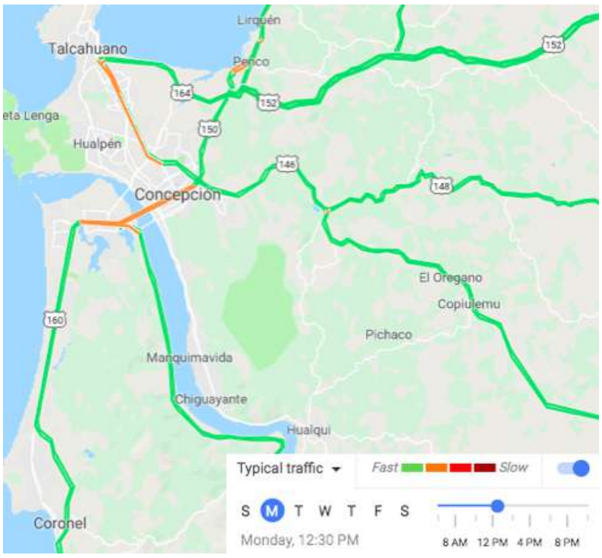


Figure E.13: Traffic conditions Hinterland routes middle of the day

When it is expected that half of the extra traffic flow towards port San Vicente comes from route 160, at least 200 extra vehicles would be present on this road every day. If this traffic is spread out nicely over the operational hours of the port, the effect of the extra traffic would be minimal. However, during rush hours the traffic conditions are already congested, so the port authority probably wants to avoid extra movements during this part of the day. Extra traffic flowing to the other ports due to the MAPA project is not considered yet. Especially truck movements to Lirquen will be an issue since this traffic also needs to pass the critical section in and around San Pedro. Because it is unclear how critical the current situation around San Pedro is during the middle of the day, the extra traffic flow in 2025 could already lead to an unstable traffic situation. The road would in that case also suffer from the capacity drop represented in the fundamental diagrams. Once the traffic situation is in an unstable congested state the capacity of the road is lower (queue discharge rate) than when the traffic situation is stable (Yuan et al., 2017). As can be seen from the rush hour situations in Figure E.4, congestion around San Pedro has a large feedback effect on the remain part of route 160. Therefore preventing unstable traffic in San Pedro is crucial.

When the situation in 2045 is considered the urgency of further research becomes even more clear. In Section E.4.1 it was established that an extra flow of 1250 vehicles per year is a realistic perspective. Assuming that at least 50 % of the extra flow is due to the MAPA project, an extra traffic flow of 600 vehicles per day on route 160 is expected. When the extra traffic to Lirquen is added it is likely that the capacity of route 160 is not sufficient anymore and the traffic situation will be unstable during the whole day.

All in all it can be concluded that the situation of route 160 around San Pedro requires some further investigation. A brief proposal for this research will be provided in the next section.

Connection routes

For the connecting routes the situation is different compared to route 160. Nowadays the traffic flows on these roads are not critical. However almost all extra traffic due to the expansion comes together on these roads with relatively low capacity. The traffic situation during normal conditions can be seen in Figure E.14. Most important roads are the La Marina and Juan Antonio Rios. Those roads act as the main entrance to the port of San Vicente. All extra traffic towards the port is obligated to use these roads. Therefore they should be able to accommodate 375 extra vehicles per day in 2025 and 1250 in 2040. If this will lead to a critical situation depends on a few factors which are listed below.

- The road capacity and corresponding fundamental diagram
- The current traffic flows
- To what extend the port is able to spread traffic across the operation hours

According to the port authority La Marina has a capacity of 1400 vehicles per hour (Empresa Portuaria Talcahuano San Vicente, 2017). This means that the fundamental diagrams in Figure E.12 should be adjusted to have a maximal flow of 1400 vehicles per hour, which would lead to a narrower diagram. The extra traffic flow caused by the expansion will therefore likely have influence on the state of the traffic situation.

The current traffic flow is in the free flowing state indicated with the green colour. Only exception is the curve in the La Marina street which is situated in the orange part of the diagram. This is probably mainly caused by truck movements coming from the external storage yard as shown in Figure E.7. The fact that the remaining part of the road is in the green state indicates that there is some room in the fundamental diagram to accommodate more vehicles per hour before the critical intensity is reached. However, the current flow could still vary from zero till more than 700 moves per hour in this free flowing state. Because the orange state in the curve of La Marina it is expected that the traffic flow situation is more towards the 700 moves per hour.

The extent to which the port is able to spread the traffic over the operations hours will influence the amount of movements per hour significantly. When the 375 extra expected movements in 2025 are not equally distributed over the day it is still not likely that this amount of extra vehicles would cause an unstable state of traffic. This is because the road is currently in the free flowing state (even when considering the fact that the fundamental diagram is smaller for this road). The situation in 2045, with 1250 extra vehicle movements per day towards the port is more concerning. In this case the port must be able to spread the traffic equally over the day, otherwise it is likely that it would result in an unstable traffic situation. Therefore it can be concluded that future research about expected traffic flows for the La Marina and Juan Antonio Rios is not necessary till 2025. If there is extensive growth in this period the advice would be to analyze the future traffic flows more in depth in order to prevent possible unstable traffic situations.

There are two ways to approach the Juan Antonio Rios road. One is by using the Gran Bretana road which is depicted in Figure E.3a. During the day this road is situated in the free flowing state as can be seen in Figure E.14. This road has more capacity since it has two lanes. Therefore it is expected that the entrance roads will have congestion issues earlier than the Gran Bretana road itself. One should keep in mind that this road faces congestion during the morning peak. Extra operation at this time of the day should therefore be avoided.

From Figure E.3c it could be seen that another way of approaching Juan Antonio Rios is by using the Alto Homo street. This road does face some slowed down traffic in the current situation. The extra traffic on this road is expected to be minimal since only a part of the traffic coming from route 152 will take this road. The total expected extra traffic on road 152 was established at 62.5 movements per day in 2025. When only a part of this will use the Alto Homo street no significant change in traffic flow will occur. The expected 200 extra movements per day in 2045 could lead to problems at the Alto Homo street.

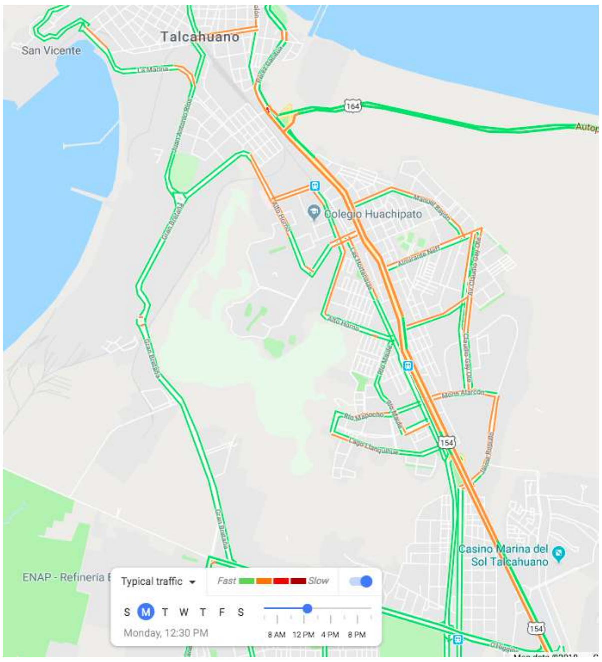


Figure E.14: Traffic conditions connecting roads during midday

E.4.4. Recommendations for future research

It can be concluded that the present situation deals with one important congestion issue that requires an in depth investigation. On the short term the situation at route 160 is already alarming. Nowadays this route is the most import access road to San Vicente port and in the future it will become even more important due to the MAPA project. The main points of attention for a proposed research are listed below.

- What is the current capacity of the road?
- What is the current traffic flow at route 160?
- What will be the extra traffic flow because of the MAPA project?
- What is nowadays the main bottleneck causing the congestion at this road?
- Will the new bridge help solving this bottleneck?

The first point of attention is about the capacity. The route varies from one to two lanes along the section and has a lot of damage. Therefore it will be a challenge to establish this value. When the capacity is determined current traffic flows can be investigated. In the current research only Google traffic provides information about the traffic states on the road. Because lack of detail it is not possible to say how much extra traffic could be accommodated on the route before it becomes an unstable congested state.

The next step is determining what the extra traffic flow will be on the route. This will go hand in hand with the MAPA project. The MAPA project will result in traffic flows to all of the ports in the Biobío region. For the effect on route 160 it is important to know what share of the MAPA project will go to port Coronel and what share to San Vicente and Lirquen together. The road section coming from Arauco and going to Coronel is not critical at this moment. When a big part of the goods would go to the port of Coronel it would result in less congestion problems.

When more traffic data is available about traffic flows in combination with traffic speeds along the route, an analysis can be made in order to determine what the origin of the congestion is. This can be helpful when establishing the bottleneck causing the current congestion and it could provide information on how the congestion spills back along the route. When the bottlenecks are identified also expectations can be made about the effects of the new bridge that will be built. If the current bridge is nowadays not part of a bottleneck building a new bridge is of course less essential. The obtained information could be used in a static way by using the fundamental diagrams. When the extra flows are added to the current flows, fundamental diagrams could give an estimation of the expected traffic state in the future. This can include expectations about spill back effects and capacity drops. Another option would be to analyze the future situation with a traffic simulation model. This is the preferred option as it also takes into account the dynamical part of traffic flows. In such a simulation it would also be possible to include the new bridge into the model.

F

MULTI-CRITERIA ANALYSIS

In this Appendix the Multi-Criteria Analysis is performed. This section begins with some theory about the Multi-Criteria Analysis, abbreviated as MCA. Thereafter, the criteria that are used in this report to assess the port expansion are elaborated. Next in this appendix the ranking of the different criteria is discussed. At the end the alternatives are weighted along the criteria resulting in an overview of the score of each alternative.

F.1. THEORY

The goal of the Multi-Criteria Analysis *(MCA)* is to provide an overview of the alternatives ranking from most preferred to least preferred (Dodgson et al., 2009). In a *MCA* both non-monetary and monetary criteria are used to review different alternatives. The *MCA* takes into account diverse and possible conflicting criteria and enables these for comparison. Every alternative is scored per criteria for example on costs, time and flexibility. These criteria all have different units, to enable these for comparison the criteria can be standardised or compared to each other in a qualitative way. In this research the MCA will be done qualitative, with scores from 1 to 7. To compute the best alternative the different criteria will be labelled with a weight. Some criteria will weigh more than others, as these are more important for determining a successful alternative. The final scores for the alternatives are computed by multiplying the scores per alternative and the weight of the criteria and then finally summing all scores per alternative. Below the formula is stated which is used to generate the final scores of each alternative.

$$A_X = C_1 \cdot (W_{C_1} \cdot SCORE_{C_1}) + C_2 \cdot (W_{C_2} \cdot SCORE_{C_2}) + ... + + C_N \cdot (W_{C_N} \cdot SCORE_{C_N})$$

$$A_X = \sum C_N \cdot (W_{C_N} \cdot SCORE_{C_N}) \tag{F.1}$$

with A_x = Alternative X
C_N = Criteria N
W_{C_N} = Weight factor of criteria N
$SCORE_{C_N}$ = Score of criteria N

F.2. CRITERIA

As pointed out in the problem description in Chapter 3, the main reason for the port expansion is to increase the shareholders value for the port of San Vicente. Therefore the general objective for the Multi-Criteria Analysis is formulated as follows.

"*What is the optimal design of land reclamation to maximise financial growth of San Vicente port*".

In order to formulate the criteria, the general objective is processed in a Goal Tree in Figure F.1. The Goal Tree is based on a research about the objectives of seaport terminals in general performed by Kemme (2013). The objectives in the research of Kemme (2013) lead to three main classes of performance objectives aiming at cost performance, operational performance and area performance. These performance objectives are also described in a handbook for terminal planning by Rijsenbrij and Wieschemann (2011).

One of the means to reach the general objective is to maximise the container throughput. Optimizing the container throughput is one of the main reasons for the land reclamation. This means that on the supply side the storage capacity in TEU will have to be maximized (Criterion 1) and on the demand side maximising the attractivity of the port. Increasing the attractiveness of a port for clients is having short turnaround times for vessels and fast landside service times. These two things are covered by the operational performance and aims to maximize the handling capacity in moves per hour (Criterion 2).

Optimizing the profitability of the operations is, according to the research of Kemme (2013), possible by minimizing the costs per container. In this research the costs are divided in multiple aspects, as the investment costs of the reclamation is a very important aspect for the port. Within port operations the costs can be differentiated between capital expenditure (CapEx) and operational expenditures (OpEx) (Ligteringen, 2017). All the investments needed for a project are considered in CapEx and with OpEx all the operational costs are meant. Both terms will be discussed in further detail in this chapter. As there is the opportunity to be able to work in different phases for this land reclamation project, the Initial CapEx is an aspect that must be taken into account. Initial CapEx are all the investments needed for only the first phase of the project. CapEx are all the investments for the project as a whole, so it contains the investments for potentially multiple phases. All these costs related aspects coincide in the criteria Costs (Criterion 3), expressed in US dollars ($).

Besides to the general objectives based on the research of Kemme (2013), there are some specific objectives for the land reclamation. After all is done, the port aims to continue to follow the growth of the economy in the region. In order to do so the port needs to be future proof. Being future proof means that the flexibility for expansions should be available for the uncertain future. Flexibility (Criterion 4) will be expressed in a rating from zero to seven. Another element is that there should not be port operations hindrance due to the expansion. Port operations have a landside and a seaside part. Movement and storage of the containers once they are removed of the ship are part of the landside operations. The hindrance to landside port operations will be expressed in a rating from zero to 7. The land reclamation may influence the hydrodynamics around the port, which possibly could result in downtime of operations. As the reclamation option should in no case have a negative influence on the hydrodynamics, it is seen as an condition for every reclamation option instead of a criteria.

In the next section all the criteria are elaborated in more detail with help of an illustration. As can be seen in Figure F.1, the criteria (yellow boxes) all have an unit. However, it will be too time consuming to research all the quantitative values of the alternatives on all criteria, therefore the MCA is analysed in a qualitative way instead of quantitative.

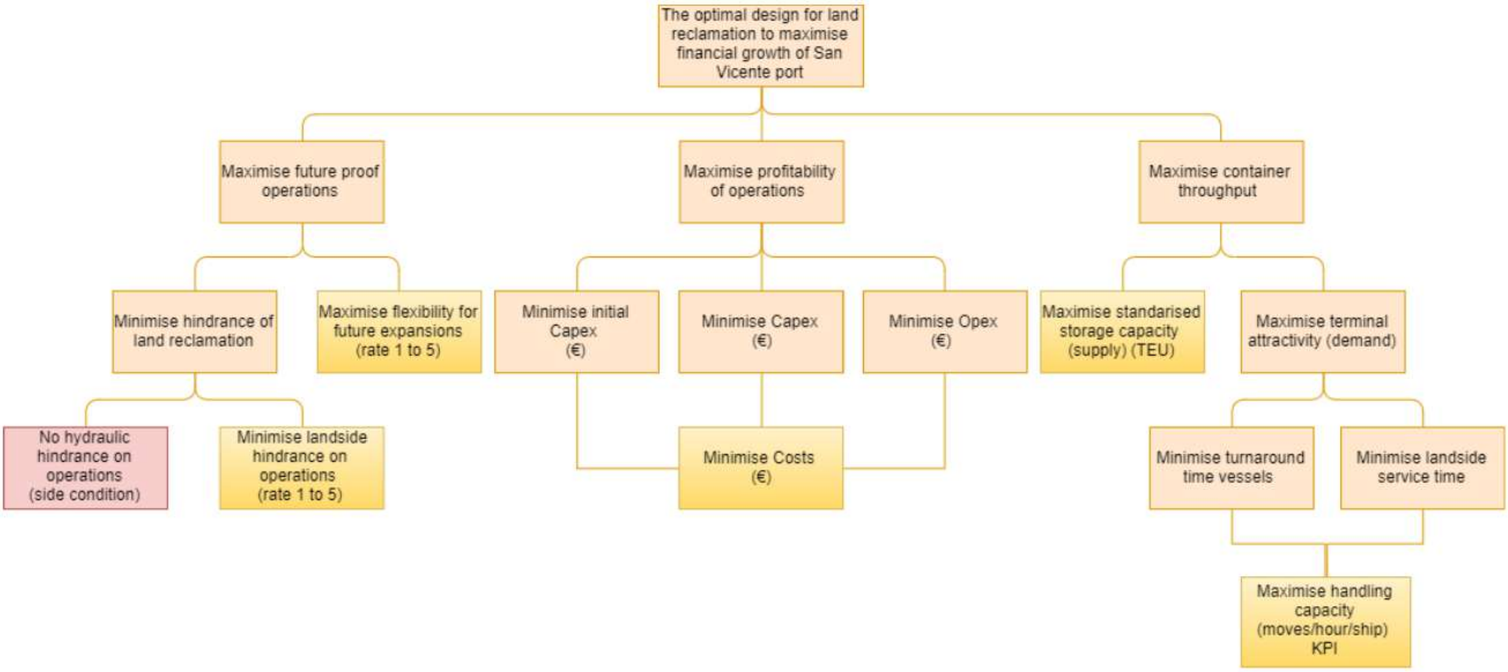


Figure F.1: Goal tree for effective land reclamation

F.2.1. Storage Capacity

The storage capacity of the container terminal is strongly correlated with the throughput that can be handled in a port. This criterion will evaluate whether the proposed alternative will provide sufficient area for the container terminal in order to accommodate expected growth of the port. Using the demand forecast made in Chapter **??**, the required container terminal area is set out against time in Appendix A. The proposed alternatives vary in the reclaimed surface of the land and therefore in the risk taken in the reference year 2025. Some alternatives will reclaim enough land to be able to accommodate the extra demand, while for other alternatives this will be less certain. The score will be given in a qualitative way. When for an alternative with double the amount of land surface is compared to another alternative, it does not necessary result in double score. In Figure F.2 it is illustrated with a circle how the reclaimed area can result in extra storage capacity.

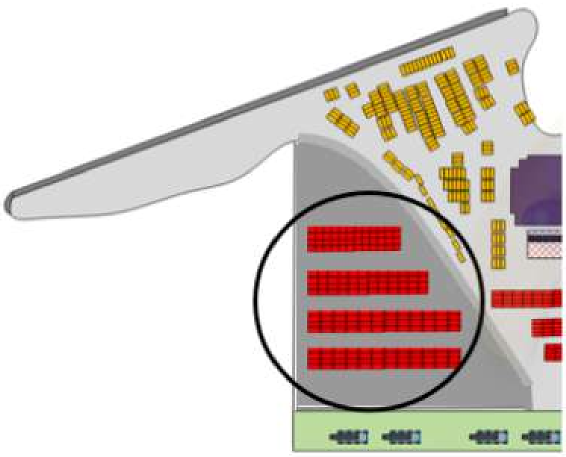
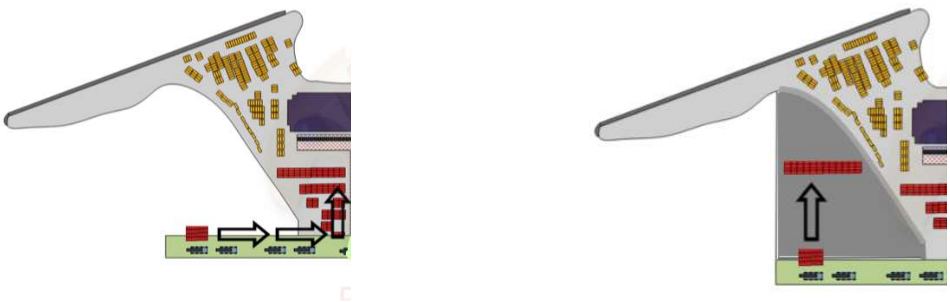


Figure F.2: Representation more Storage capacity, using layout Port San Vicente in (Gribnau et al. (2018))

F.2.2. Handling Capacity

The port has as its main KPI to be able to handle 100 moves per hour in the near future. In the bottleneck analysis it becomes clear that the main problem is not the capacity of the cranes, but with the transport of the containers to the storage yard as well as storage capacity problems it selves. Therefore, the land reclamation alternatives will be tested on the expected effect on the moves per hour the port is able to handle transportation wise. The alternatives with a strategic positioning at the high performance berth (berth 4) will benefit of the higher handling capacities, as represented in Figure F.3



(a) Low handling capacity

(b) High handling capacity

Figure F.3: Representation of high handling capacity

F.2.3. Costs

The criteria costs is, as mentioned in earlier in this section, consists of three elements; CapEx, initial CapEx and OpEx. All these aspects will be described below, but all coincide under the one criteria costs.

Intial CapEx

The initial capital expenditures are all the investments necessary for the first phase to construct the container terminal area. This includes the costs for the land reclamation, revetments, construction materials and equipment, terminal equipment, pavement units and could include plenty more. The initial CapEx is different from the CapEx, since it does not take into account later investments for potential later phases of the project. Therefore the initial CapEx criterion always benefits from starting with a small and relative cheap reclamation.

CapEx

CapEx, also known as the Capital Expenditures, are all the investments that must be made to construct the container terminal area over the whole process. This also includes the startup costs and other concerning costs for phasing. Therefore phasing is from a CapEx point of view not always the most preferred option. On the other hand, CapEx takes into account the preference for investing money in the future instead of the present. This is done by incorporating a discount rate for future investments, resulting in a present day value of the investments in the future Ligteringen (2017). In Figure F.4 a typical cash flow for an infrastructural project is shown.

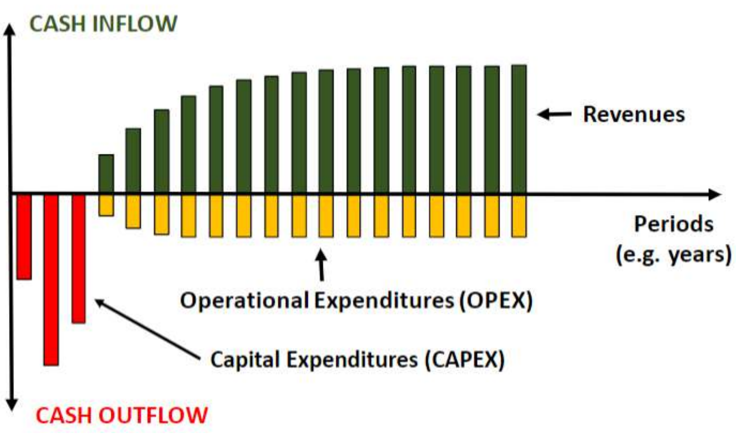


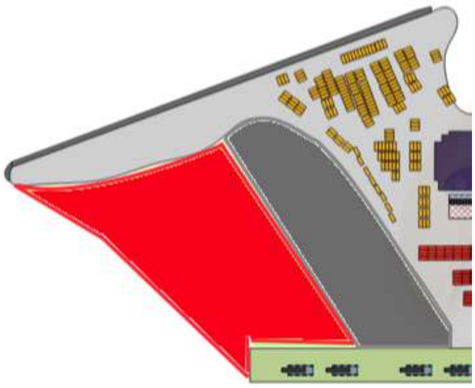
Figure F.4: Typical cash flow for a project van Dorsser (2018)

OpEx

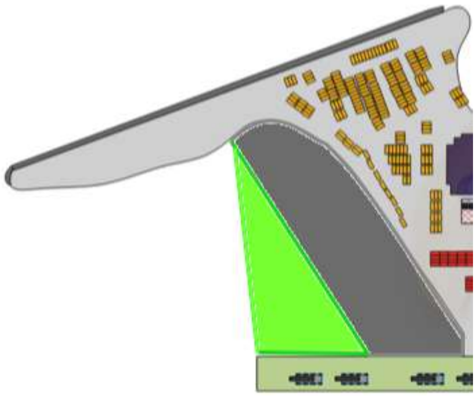
OpEx, also known as the Operating Expenditures, are the annually returning costs for running the port operations. This includes the rent of equipment, fuel, power, personnel and so on. As soon as the reclaimed land is in use, it will have an effect on the OpEx, as also can be seen in Figure F.4. In order to simplify this criterion it is assumed that the OpEx is correlated to the amount of surface of the reclaimed area because more surface means also more maintenance cost. For alternatives with the same surface it is expected that more efficiently located land reclaimed will lead to lower operational costs then less efficient locations.

F.2.4. Flexibility

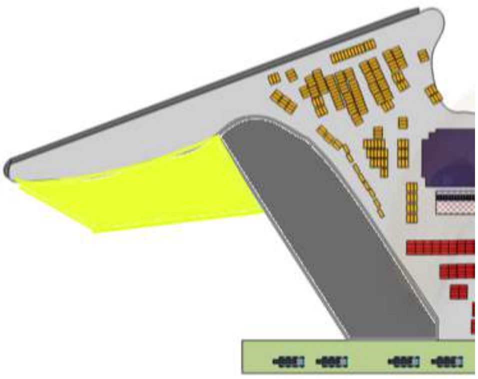
Unfortunately it is not possible to have a 100 % accurate market forecast of the future, which means it is difficult to predict how much area the port of San Vicente exactly will need to accommodate future throughput. This criterion offers the possibility for the port to implement modifications. An alternative, designed in phases, allows the port to adapt to changing conditions or demands. Also the freedom for various types of land reclamation is considered to be a part of flexibility. In Figure F.6 several options for further expansion are visualised after a first reclamation phase.



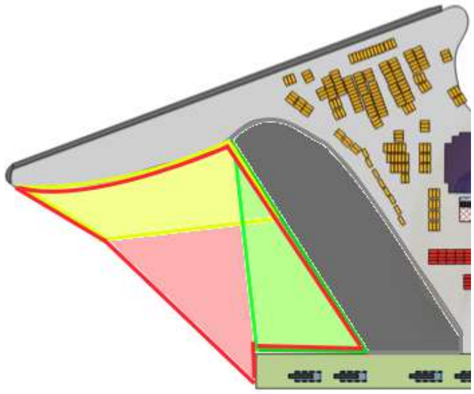
(a) Further expansion option 1



(b) Further expansion option 2



(a) Further expansion option 3

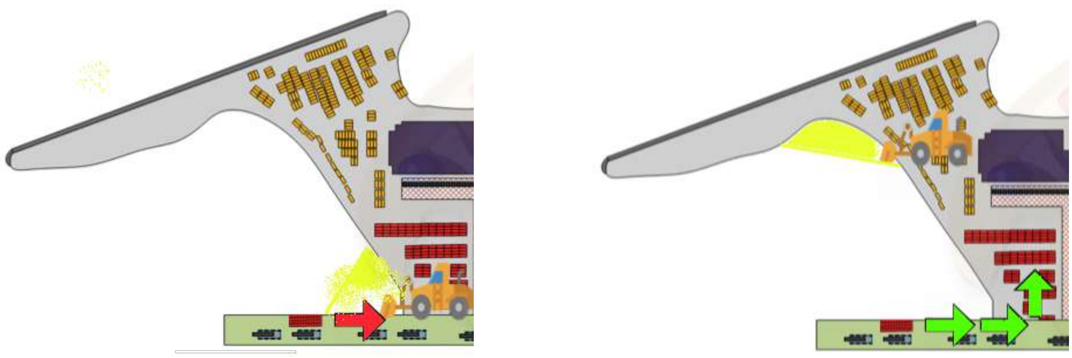


(b) Further expansion options together

Figure F.6: Representation of high flexibility

F.2.5. Landside hindrance to Port Operation

When constructing land reclamation near berth 5, equipment will have to move around and through the port. As the port aims to continue operations during the land reclamation, the construction works are bound to have an influence on traffic inside the port. It is desirable to keep hindrance as low as possible for the port to continue operations to its full potential.



(a) Reclamation with high hindrance on operations

(b) Reclamation with low hindrance on operations

Figure F.7: Representation hindrance to port operations

F.3. Side condition

Subsection F.2 describes all the criteria that will be used in the MCA, an overview is given in Figure F.1. Those criteria will be used to investigate which land reclamation option has the preference. Besides those criteria there is one design requirement which is seen as a side condition instead of a criterion. The side condition is that the hydrodynamics inside the port area should not be influenced by the land reclamation in such a way that the manoeuvring and mooring conditions for incoming vessels become worse. The land reclamation alternative that will score the best during the MCA, will be analysed on the hydrodynamic impact in Chapter 6.

F.4. Ranking the criteria

As can be seen in Table F.1 all criteria are compared with each other to come up with scores, which results in different weightings. In the section below the sequence of the different criteria are elaborated. The assumption is that when criterion A is more important then B, and B more important then C, A is also more important then C.

Storage Capacity and Handling Capacity as main criteria

The storage capacity and handling capacity are the main reasons that the port wants to reclaim land, and therefore are considered the most important. If the storage capacity is not sufficient to accommodate future growth in demand, winning back market position does not make sense. The other way around, there is no hurry in winning back land if the port of San Vicente is not winning back market position. So this two criteria keep each other leveled.

Flexibility

Flexibility is considered the next most important criterion over the rest. Due to the uncertainty of predicting the future, flexibility can be extremely useful for the ability to adapt when needed. *Is the expansion successful and does it result in higher handling speeds? How do other ports react on the changes in the San Vicente port? Do the big clients react on the higher efficiency, or will they wait until other ports react? How is the market of the Biobío region evolving?* These are examples of questions which can not be answered yet. When, after the first phase, there is room to respond to the situation at that time, the risk of the initial investments is smaller.

The flexibility is more important than the Costs criterion. For the CapEx aspect the alternatives are compared with the assumption that all alternatives will end up the same, 13ha of reclaimed land. By giving alternatives where a full reclamation is not completely necessary more points, the flexibility should have a higher weight.
For instance, imagine a situation where there are two expansion possibilities. The first option is to directly invest in reclaiming all the land. The other option is doing this in multiple phases with lower initial investments, however it will have a higher CapEx. Still analysing the second option, after 5 years it became clear that the land reclaimed in phase one was enough to guaranty future proof operations. Therefore it was concluded that the second phase is not necessary anymore, making the second option the cheapest CapEx in the end. To consider this situation the flexibility has a higher weight.

Flexibility is also considered more important than the Initial CapEx. If alternatives have low initial investments but have little opportunity for further expansion or to react to the future demand, these initial investments would only sufficient in the short term. Having flexibility after the low initial investments, makes the initial investments more attractive.

Also the Operating Expenditures are considered less important than the flexibility. As the annually returning costs are seen as less of an advantage than being able to react on future events.

Costs
The costs criterion is considered a more important criterion then the last criteria, landside hindrance to the port operations. This is based on the fact that the port hindrance is very temporary in contradiction to the (returning) costs. Also the construction of the jetty expansion in the past did not cause a lot of trouble in the operations. The port authority does not expect any difficulties in this expansions either.

In the Table F.1 an overview of the determination for the weight factor per criterion is given. As can be seen in this table, the criterion *Hindrance to Port Operations* is the clear loser with a total of zero points, despite this it should certainly be taken into account. In order to properly perform a MCA an option with zero points can not be used. Thus, all total scores of each criterion have been compensated by adding one extra point to ensure that the criterion *Hindrance to Port Operations* can be added in the MCA. In Figure F.8 all the criteria with their corresponding weight factor are depicted. The weight factor is calculated by dividing the score of the compensation score of each criterion by the sum of all compensation scores. The resulted scores are communicated to the port authority and they agreed with the current weightings.

	Criteria	A	B	C	D	E	Total	Compensation	Weight Factor
A	Storage Capacity	-	0.5	1	1	1	3.5	4.5	30%
B	Handling Capacity	0.5	-	1	1	1	3.5	4.5	30%
C	Flexibility	0	0	-	1	1	2	3	20%
D	Costs	0	0	0	-	1	1	2	13.3%
E	Hindrance to Port Operations	0	0	0	0	-	0	1	6.7%

Table F.1: Overview of weight factor determination

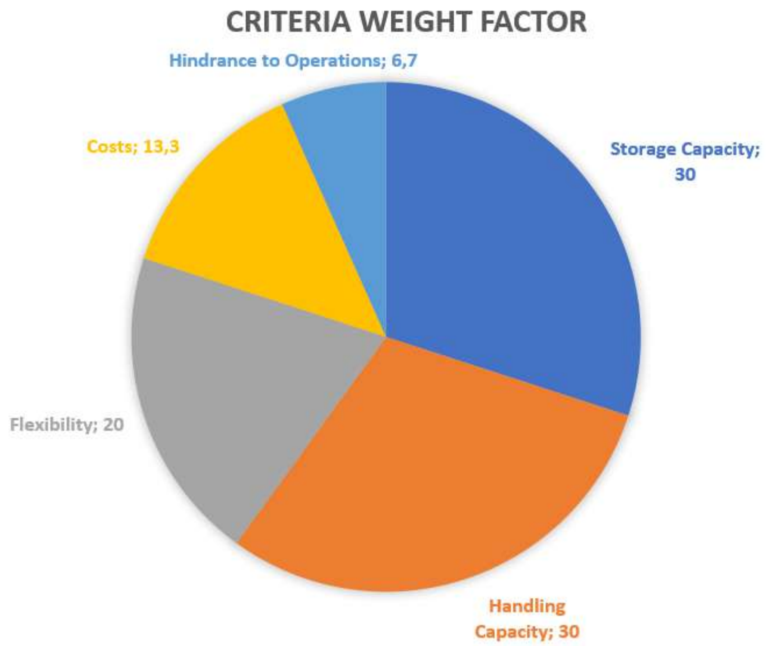


Figure F.8: Pie chart of the weight factor for each criterion

F.5. Determination of the Surface of land

With the demand forecast made in Appendix A it is possible to determine the surface of land that should be reclaimed in the first phase of the project. In order to do this, there are three questions that have to be answered first.

- *Until what year in the future the land that is reclaimed should at least suffice?*
- *What market forecast is used to determine the needed area?*
- *Is the minimal area of reclaimed land also a suitable option?*

First, the question what year will be chosen as a reference point should be answered. The port authority wants to reclaim the land as soon as possible to benefit from the extra efficiency that can be obtained from the land reclamation. However, at the same time looking too far in the future will bring more uncertainties in the market development prediction. It is safer to predict the area needed in 2025 then in 2030. In 2025 the port could analyse the situation again and decide what is necessary until 2030. Having a reference year not too far in the future, gives flexibility to react on the market. The fact the reclamation itself will also take time to build, it is best that the reference year should not be in the near future. Also some time must be available for the port to get used to the new situation with the reclaimed land and to let the market and shipping lines react to the new situation. Therefore, 2025 would be the earliest stage to reconsider the situation and is thus used as point of reference.

Next the ambition level of the port regarding the land reclamation is determined. This analysis is done from a perspective to regain market share by reclaiming land. The land reclaimed should be able to provide room for a situation where the port (re)gained market share. Looking at the past, the market share does not fluctuate as quickly as can be seen in Figure F.9. Therefore it would not be realistic to assume a more than 5 percent increase in market share after the first 5 years. Thus, the 45 percent market share situation is used as reference for the needed area in 2025.

With the reference year and the expected market share, the minimal surface of land is depicted at 23 hectares in 2025 in Figure F.10. Given the current 20.7 hectares of land (Empresa Portuaria Talcahuano San Vicente, 2017) this would mean that minimal 2.3 hectares of land should be reclaimed before 2025. The question remains if it is logical to reclaim this relative small amount of land. In the uncertainty analysis in Section A.4 it became clear that only a small uncertainty in the parameters can already lead to completely different results. Therefore it is suggested to have a relative high safety margin (at least 10 percent). Moreover, there will be high startup costs when performing the reclamation. For this reason it is not attractive to reclaim small areas of land. With all these factors taken into account, it is suggested to reclaim directly four hectares of land. By doing so the reclamation will be even more future proof. Besides, operations can be made more efficient when the port is not working at their full capacity. This for instance will give room to work with lower stacking heights and more driving lanes, to improve accessibility of containers.

A few alternatives will have a suggested surface of four hectares of land. The expectation is that this amount of land is at least sufficient until 2025. This year can be used as a reference point to review if a new expansion phase is needed. From that point, the year 2030 is suggested as new reference year. In order to get an impression of possible further expansion options, some research has been done to investigate the needed area in 2030. As the uncertainties remain on how the market will develop, multiple scenario's are considered for the market share in 2030. In the more negative case there will still be 45 percent market share. In the positive case there will be 50 percent market share. For the negative scenario alternatives are formulated with 7 hectares of land, having a safety margin of 10 percent with 0.7 hectares. In the positive scenario with a safety margin of 10 percent around 10 hectares (9.3 + 9.3 * 0.1 = 10.2) of land is needed. However, because filling everything inside the bay between the breakwater and jetty is 13 hectares, it is suggested in this case to directly reclaim 13 hectares of land in ones. It is imaginable that the port wants at this point already the certainty of being future proof until 2030, so the expansion options are also considered as alternatives for the current reclamation.

In the end this gives suggested alternatives of 4 hectares of land and alternatives of 7 and 13 hectares of land which could also function as expansion options.

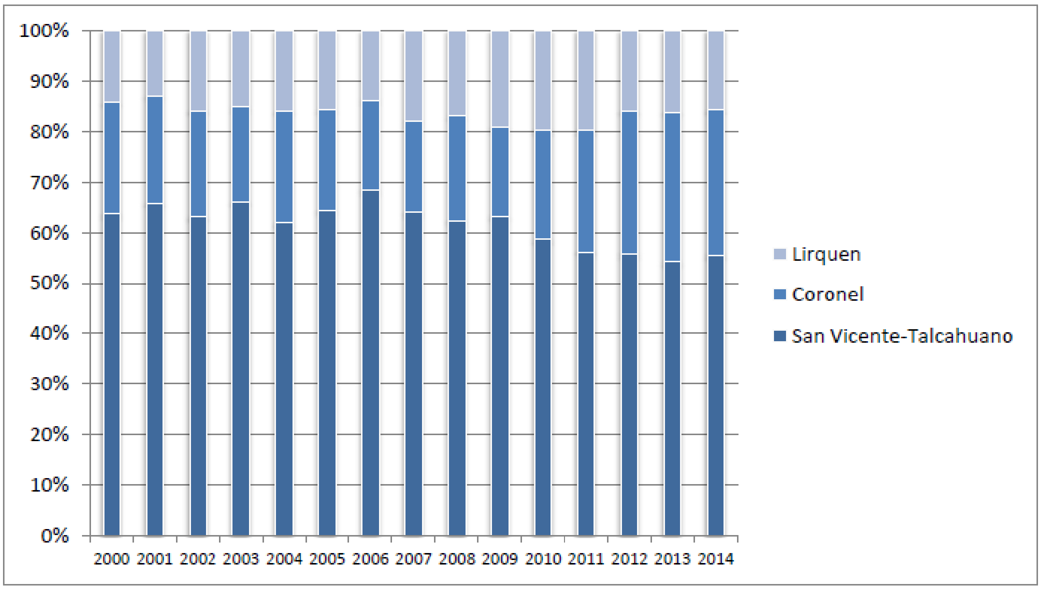


Figure F.9: Market shares ports in Biobío region in tonnes of bulk (Merk, 2016)

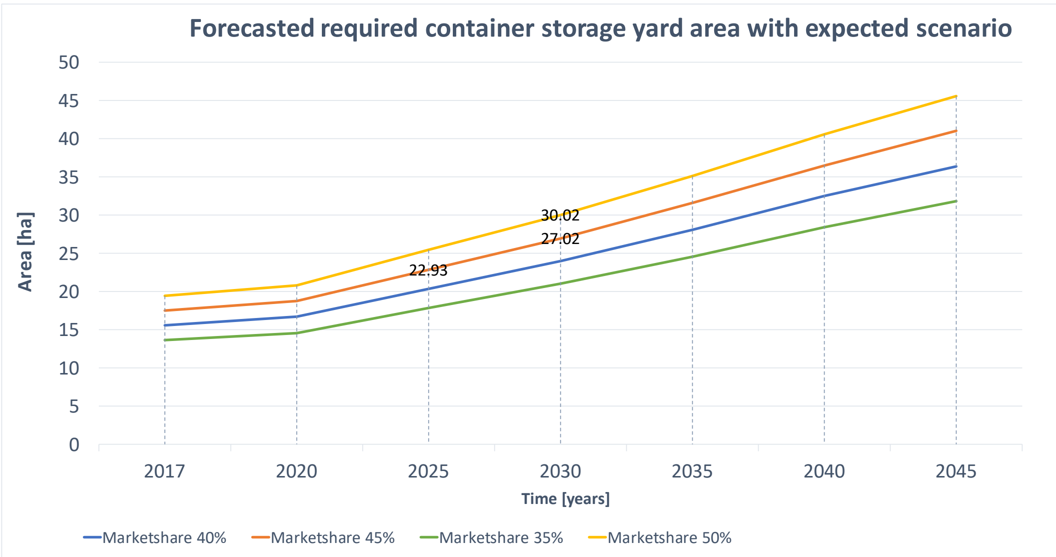


Figure F.10: Projected area for the San Vicente port based on VIII region 2017-2038 projections 45 market share with reference point in 2025

F.6. ALTERNATIVES

In this section the alternatives for land reclamation are introduced as well as the (engineering) challenges and advantages for each alternative are highlighted. The starting point for formulating alternatives is the minimal calculated surface of land, based on the demand forecast according to different scenario's. With the calculated amount of land the criteria are used to formulate the alternatives. For every criterion an ultimate alternative is created and since some criteria will have (nearly) similar ones, not every criterion has its own ultimate option. The main engineering challenges that need to be taken into account for an alternative are listed and briefly elaborated below. These engineering challenges will mainly have an effect on (Initial) CapEx.

- **Amount of sand for land reclamation**
  The amount of sand needed is strongly dependent on the location for land reclamation, since the water depth in the bay varies as can be seen in Figure F.11.

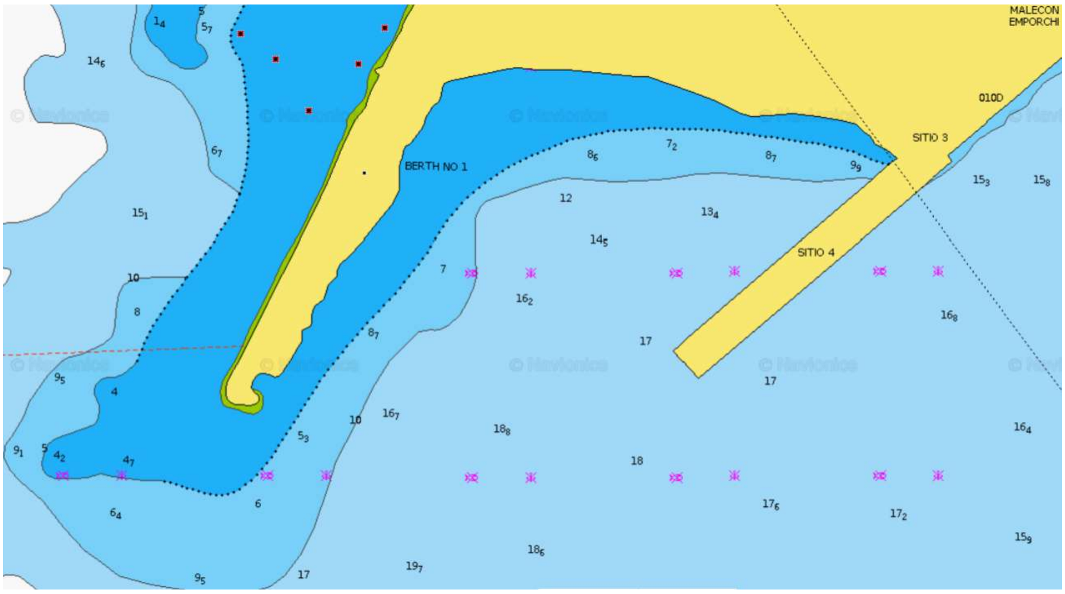


Figure F.11: Overview water depth in San Vicente Bay (Wat)

- **Amount of revetment at reclaimed land**
  The amount of revetment at reclaimed land is dependent on the shape of the reclaimed land. The type of revetment is based on the hydrodynamical conditions in the bay.

- **Length of connection at the jetty construction**
  The length of the connection to the jetty construction is important to consider as this is a difficult part to construct.

All alternatives will described in the next section. For the Multi-Criteria Analyses all the alternatives get a score on each criterion, ranging from one to seven. The reason for a one to seven range is because there are a lot of alternatives, so there must be enough room to distinguish them. The rating will be done in a qualitative manner, since researching all alternatives in depth to obtain real numbers takes a lot of time. Also by using a qualitative way it is already possible to make a choice between the alternatives. The ratings will be based on comparing the alternatives with each other, however it will not serve as a ranking. This means multiple alternatives can have the same score and not necessarily all numbers 1 to 7 are used for each criterion.

Using the determination of the surface of land in Section F.5 and adding a zero alternative as reference point, alternatives can be categorized in 4 different groups;

- 0 Hectare land reclamation - *Alternative A* - (*null option*)
- 4 Hectare land reclamation - *Alternative B to D*
- 7 Hectare land reclamation - *Alternative E to G*
- 13 Hectare land reclamation - *Alternative H* - (*maxed option*)

F.6.1. Alternative A - (0 hectares - null option)

This alternative analyses the situation when no land is reclaimed. Although this option is not a realistic one, since according to the forecast the amount of area should be increased to fulfill the future demand in 2025. But for the sake of a complete research and as a reference point, this alternative is also analysed and taken into the MCA.

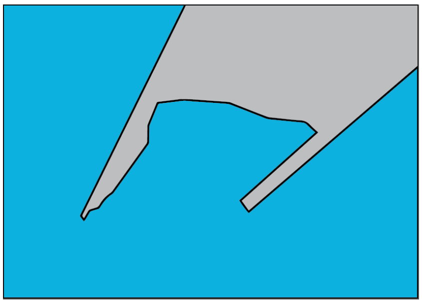


Figure F.12: Alternative A - 0 hectares of land reclamation

Storage Capacity - Score: 1

The storage capacity will not be increased, as no land will be reclaimed for this alternative. Therefore this alternative scores a 1 out of 7 on storage capacity.

Handling Capacity - Score: 1

The handling capacity will not be increased, as no action will be taken in this alternative. Therefore this alternative will score a 1 out of 7 on handling capacity.

Flexibility - Score: 7

The flexibility of this alternative is extremely high. In theory it is still possible to do every land reclamation (all other alternatives) option in the future, However according to the demand forecast the right time to act would be now. This alternative will score a 7 out of 7 on flexibility.

Costs - Score: 7

The Capital Expenditures, initial CapEx and Operational Expenditures for this alternative are equal to zero, as no action will be taken in this alternative. Therefore this alternative scores a 7 out of 7 on the costs criterion.

Hindrance to Port Operations - Score: 7

The hindrance to the port operations will be none, as no action will be taken in this alternative. Therefore this alternative scores a 7 out of 7 on hindrance to port operations.

F.6.2. Alternative B - (4 hectares with full jetty connection)

Alternative B is an alternative of reclaiming 4 hectares near the STS cranes at berth 4. Looking at the engineering challenges as mentioned before, the construction of the complete connection at the jetty construction will be the most difficult part. The amount of sand required for this area will be relatively large, as the water depth is relative large (see Figure F.11). The length of the revetment is relatively small. This alternative is formulated from a high handling capacity point of view, because it reclaims lots of land at the STS cranes.

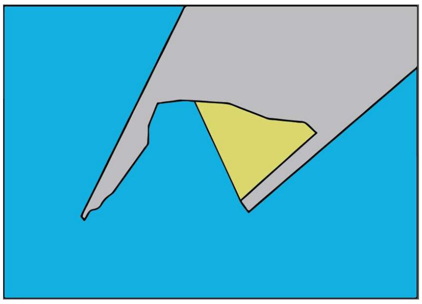


Figure F.13: Alternative B - 4 hectares of land reclamation

Storage Capacity - Score: 4

The storage capacity will be increased, as 4 hectares of land will be reclaimed for this alternative. According to the area forecast with the go-to scenario in Section F.5, this should be enough land. Still there are also (less likely) scenario's possible where 4 hectares would not be sufficient. So this alternative will score a bit above average compared to the other alternatives on the storage capacity. Therefore this alternative scores a 4 out of 7 on storage capacity.

Handling Capacity - Score: 7

The handling capacity will be increased, as the connection at the jetty construction is fully broadened with this alternative. This should contribute to increasing the handling capacity immediately. Therefore this alternative will score a 7 out of 7 on handling capacity.

Flexibility - Score: 5

The flexibility of this alternative is relatively high. By only reclaiming 4 hectares of land, future expansions of the port are very possible with this alternative. However there are other 4 hectares alternatives which are even more flexible. With already having the large investment for the jetty connection, future expansion options are more limited. Only alternative E and H would be possible as expansion. Therefore this alternative will score a 5 out of 7 on flexibility.

Costs - Score: 4

The Capital Expenditures for this alternative are average compared to the other alternatives. As this alternative makes it possible because of the small amount of land and revetment, to do other future investments with an discounted rate. Still the most expensive investment, the jetty connection, is already constructed in this phase.
The initial Capital Expenditures for this alternative are relatively high. As alternative B directly starts with the most expensive investment, the jetty connection.
The Operational Expenditures for this alternative are relatively low. The reason behind this is the small amount of land reclaimed and a small distance that the trucks have to cover, relative to the other options.
With all the cost related aspects mentioned above this alternative will score a 4 out of 7 on average for the costs criterion.

Hindrance to Port Operations - Score: 2

The hindrance to port operations for this alternative is high, as the berth with the 2 STS-cranes are likely to be hindered by the construction of the jetty construction. However, the land reclamation needed for this alternative is relative small. Therefore this alternative will score a 2 out of 7 on hindrance to port operations.

F.6.3. Alternative C - (4 hectares with no jetty connection)

Alternative C is an alternative of reclaiming 4 hectares at the most shallow part of the bay. The engineering challenges of the construction of a connection at the jetty construction is avoided. The amount of sand required for this area will be the fewest of the alternatives. The length of the revetment will be a bit larger for this alternative. This alternative is formulated from a intial CapEx point of view.

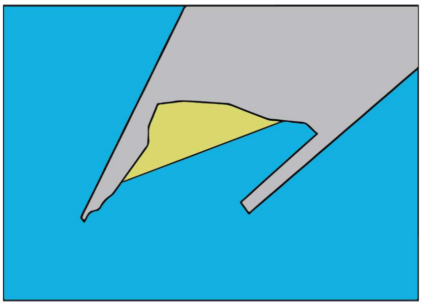


Figure F.14: Alternative C - 4 hectares of land reclamation

Storage Capacity - 4

The storage capacity will be increased, as 4 hectares of land will be reclaimed for this alternative. According to the area forecast with the go-to scenario in Section F.5, this should be enough land. Still there are also (less likely) scenario's possible where 4 hectares would not be sufficient. So this alternative will score a bit above average compared to the other alternatives on the storage capacity. Therefore this alternative scores a 4 out of 7 on storage capacity.

Handling Capacity - 1

The handling capacity of this alternative is low, as the position of alternative C is across the bay from the jetty. This reclamation option does not contribute to increasing the handling capacity, as trucks will have to drive a large distance to reach this area, relative to other options. Therefore this alternative scores a 1 out of 7 on handling capacity.

Flexibility - 6

The flexibility of this alternative is high. By only reclaiming 4 hectares of land, a future expansion of the port is very possible with this alternative as the first phase. Also by postponing constructing the complete jetty connection, the port still has the flexibility to reconsider at a later point if this expensive construction is really needed. With this alternative it is still possible to expand to alternative E, F, G and H. Therefore this alternative will score a 6 out of 7 on flexibility.

Costs - 6

The Capital Expenditures for this alternative are relatively low. As this alternative makes it possible to do all more expensive future investments with a discounted rate. Especially the big investment of the jetty connection will have a discounted price in a future phase.

The initial Capital Expenditures for this alternative are relatively low. This alternative does not require a jetty connection and the amount of sand for the land reclamation is minimal, since the water depth at this location is smallest in the bay (see Figure F.11). However, the amount of revetment is slightly larger relative to other 4 hectares options.

The Operational Expenditures for this alternative are relatively high, compared to other 4 hectares options. Even though having a small amount of land reclaimed, the distance that trucks have to cover in the port is larger relative to the other options. With all the cost related aspects mentioned above this alternative will score a 6 out of 7 on average for the costs criterion.

Hindrance to Port Operations - 6

The hindrance to port operations for this alternative is assumed to be low. As the suggested land reclamation is near a container yard mainly filled with empties and the berth with the 2 STS-cranes will not be hindered in operations. Therefore this alternative will score a 6 out of 7 on hindrance to port operations.

F.6.4. Alternative D - (4 hectares with small jetty connection)

Alternative D is an alternative of reclaiming 4 hectares and is a mixture of Alternative B and C. The engineering challenges of the construction of a connection at the jetty construction remains, but is bounded to just a small part. The amount of sand required for this area is relatively little, since the depth near the shore is smaller. The length of the revetment is comparable to Alternative B.

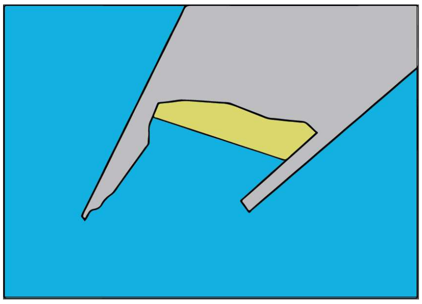


Figure F.15: Alternative D - 4 hectares of land reclamation

Storage Capacity - 4

The storage capacity will be increased, as 4 hectares of land will be reclaimed for this alternative. According to the area forecast with the go-to scenario in Section F.5, this should be enough land. Still there are also (less likely) scenario's possible where 4 hectares would not be sufficient. So this alternative will score a bit above average compared to the other alternatives on the storage capacity. Therefore this alternative scores a 4 out of 7 on storage capacity.

Handling Capacity - 4

The handling capacity will be increased, as the connection at the jetty construction is partly broadened with this alternative. This should contribute to increasing the handling capacity immediately. However, it clearly does not have the capacity as Alternative B, thus it is considered as an average option. Therefore this alternative will score a 4 out of 7 on handling capacity.

Flexibility - 6

The flexibility of this alternative is high. By only reclaiming 4 hectares of land, a future expansion of the port is very possible with this alternative. Also by postponing constructing the last part of the jetty connection, the port still has the flexibility to expand this connection. With this alternative it is still possible to expand to alternative E,G and H. Therefore this alternative will score a 6 out of 7 on flexibility.

Costs - 4

The Capital Expenditures for this alternative are average compared to the other alternatives. This alternative makes it possible to do other future investments with a discounted rate. Especially the investment of finishing the jetty connection will have a discounted price in a future phase. However, splitting the construction for the jetty connection in two phases is probably more expensive in the end then doing it in ones.

The initial Capital Expenditures for this alternative are average. This alternative requires a small connection to the jetty connection, but the amount of sand for the land reclamation is minimal as the water depth at this location is small in the bay (see Figure F.11).

The Operational Expenditures for this alternative are relatively low. The reason behind this is the small amount of land reclaimed and distance the trucks have to cover relative to the other options. Still the distance for the trucks is in general probably bigger then in case of alternative B. With all the cost related aspects mentioned above this alternative will score a 4 out of 7 on average for the costs criterion.

Hindrance to Port Operations - 4

The hindrance to port operations for this alternative is average compared to the other alternatives. As the suggested land reclamation is near a container yard mainly filled with empties, but also near the berth with the 2 STS-cranes, which will be hindered in operations. Therefore this alternative will score a 4 out of 7 on hindrance to port operations.

F.6.5. Alternative E - (7 hectares with full jetty connection)

Alternative E is an alternative of reclaiming 7 hectares near the STS cranes at berth 4. The shape of this alternative is similar to that of alternative B. Looking at the engineering challenges as mentioned before, the construction of the complete connection at the jetty construction will be the most difficult part. The amount of sand required for this area will be relatively large, as it is in an area with a large depth. The length of the revetment is relatively small. This alternative is formulated as 7 hectares option from the point of view of a high handling capacity and as an expansion option from alternative B and D.

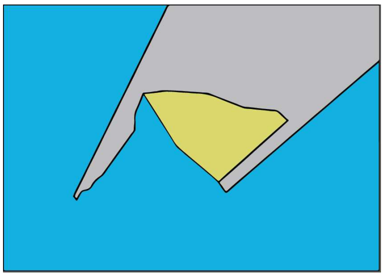


Figure F.16: Alternative E - 7 hectares of land reclamation

Storage Capacity - 5

The storage capacity will be increased, as 7 hectares of land will be reclaimed for this alternative. This alternative scores better on the storage capacity, since with the upper bound scenario illustrated in Figure **??** the land reclaimed is almost enough to store all containers. For the go-to scenario with between 45 and 50 percent of market share this area will be large enough to suffice until 2030, as can be seen in Figure F.10. Therefore this alternative scores a 5 out of 7 on storage capacity.

Handling Capacity - 7

The handling capacity will be increased, as the connection at the jetty construction is fully broadened with this alternative. This should contribute to increasing the handling capacity immediately. Therefore this alternative will score a 7 out of 7 on handling capacity.

Flexibility - 3

The flexibility of this alternative is relatively low. By reclaiming 7 hectares of land, a future expansion of the port is very possible with this alternative as the first phase, but very limited. The only extension option from this alternative is alternative H. Therefore this alternative will score a 3 out of 7 on flexibility.

Costs - 3

The Capital Expenditures for this alternative are relatively high. This alternative makes it possible to do some future investments with a discounted rate. Although the most expensive investment, the jetty connection, is already constructed in this phase and relative a lot of land in the deep part of the bay is needed for the reclamation.
The initial Capital Expenditures for this alternative are relatively high. As alternative E directly starts with the most expensive investment, the jetty connection and relative a lot of land in the deep part of the bay is needed for the reclamation.
The Operational Expenditures for this alternative are relatively high. The reason behind this is the large amount of reclaimed land, however the distance the trucks have to cover are relative small compared to the other options. With all the cost related aspects mentioned above this alternative will score a 3 out of 7 on average for the costs criterion.

Hindrance to Port Operations - 2

The hindrance to port operations for this alternative is high. As the berth with the 2 STS-cranes will be hindered by the construction of the jetty connection. Therefore this alternative will score a 2 out of 7 on hindrance to port operations.

F.6.6. Alternative F - (7 hectares with no jetty connection)

Alternative F is an alternative of reclaiming 7 hectares at the most shallow part of the bay. The shape of this alternative is similar to that of alternative C. The engineering challenges of the construction of a connection at the jetty construction is avoided. The amount of sand required for this area will be the fewest of the alternatives. The length of the revetment will be bigger for this alternative then for alternative E. This alternative is formulated from the (initial) CapEx point of view for the 7 hectares alternatives and as an expansion option for alternative C.

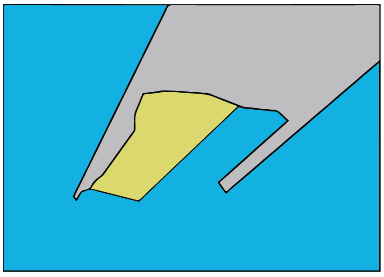


Figure F.17: Alternative F - 7 hectares of land reclamation

Storage Capacity - 5

The storage capacity will be increased, as 7 hectares of land will be reclaimed for this alternative. This alternative scores better on the storage capacity, since with the upper bound scenario in Figure F.10 the land reclaimed is almost enough to store all containers. For the go-to scenario with between 45 and 50 percent of market share this area is large enough to suffice until 2030 as can be seen in Figure F.10. Therefore this alternative scores a 5 out of 7 on storage capacity.

Handling Capacity - 2

The handling capacity of this alternative is low, as the position of alternative F finds itself across the bay from the jetty. The land reclamation option does not contribute to increasing the handling capacity, because the trucks will have to drive a long distance to reach this area, relative to other options. However, due to the the extra land, it is still closer to the berth compared to alternative C. Therefore this alternative scores a 2 out of 7 on storage capacity.

Flexibility - 3

The flexibility of this alternative is relative low. By reclaiming 7 hectares of land, a future expansion of the port is very possible with this alternative as the first phase, but very limited. The only expansion option left is alternative H. Therefore this alternative will score a 3 out of 7 on flexibility.

Costs - 5

The Capital Expenditures for this alternative are relatively low, as this alternative makes it possible to do other future investments with a discounted rate. Especially the big investment of the jetty connection will have a discounted price in the future phase. Due to the fact that the investments for revetment and sand are at an earlier stage then for alternative C it scores a bit worse.
The initial Capital Expenditures for this alternative are relatively low. This alternative does not require a jetty connection and the amount of sand for the land reclamation is minimal, since the water depth at this location is small in the bay (see Figure F.11).
The Operational Expenditures for this alternative are high. The large amount of land reclaimed and distance that trucks have to cover in the port is larger relative to the other options. With all the cost related aspects mentioned above this alternative will score a 5 out of 7 on average for the costs criterion.

Hindrance to Port Operations - 6

The hindrance to port operations for this alternative is low, as the suggested land reclamation is near a container yard mainly filled with empties and the berth with the 2 STS-cranes will not be hindered in opertions. Therefore this alternative will score a 6 out of 7 on hindrance to port operations.

F.6.7. Alternative G - (7 hectares with small jetty connection)

Alternative G is an alternative of reclaiming 7 hectares and is a mixture of Alternative E and F. The shape of this alternative is similar to that of alternative D. The engineering challenges of the connection at the jetty construction remains, but is bounded to just a small part. The amount of sand required for this area is relatively low. The length of the revetment for this alternative is the biggest compared to the rest of the alternatives. This alternative is mainly formulated as expansion variant for alternative D.

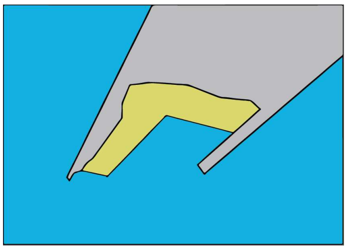


Figure F.18: Alternative G - 7 hectares of land reclamation

Storage Capacity - 5

The storage capacity will be increased, as 7 hectares of land will be reclaimed for this alternative. This alternative scores better on the storage capacity, since with the upper bound scenario in Figure F.10 the land reclaimed is almost enough to store all containers. For the go-to scenario with between 45 and 50 percent of market share this area is large enough to suffice until 2030 as can be seen in Figure F.10. Therefore this alternative scores a 5 out of 7 on storage capacity.

Handling Capacity - 4

The handling capacity will be increased, as the connection at the jetty construction is partly broadened with this alternative. This should contribute to increasing the handling capacity immediately. Compared to alternative D there is more land available, however most land is far away from the jetty construction that it does not contribute to the handling capacity. Therefore this alternative will score a 4 out of 7 on handling capacity.

Flexibility - 4

The flexibility of this alternative is relatively high. By reclaiming 7 hectares of land, a future expansion of the port is very possible with this alternative as the first phase, but very limited. Also by postponing constructing the last part of the jetty connection, the port still has the flexibility to expand this connection. Therefore this alternative will score a 4 out of 7 on flexibility.

Costs - 2

The Capital Expenditures for this alternative are very high, even though it can postpone some of the investments to the future. The problem of this alternative is that in the first phase relative high costs are already made for the extremely long revetment. Further the fact that the jetty connection is split in multiple phases is probably not attractive from a cost perspective. Therefore this is considered the worst alternative for CapEx.
The initial Capital Expenditures for this alternative are high. This alternative requires a small jetty connection and the amount of sand for the land reclamation is minimal, since the water depth at this location is smallest in the bay (see Figure F.11). The amount of revetment for this alternative however is extremely large making it an expensive alternative.
The Operational Expenditures for this alternative are relatively high. The reason behind this is the large amount of land reclaimed and distance the trucks have to cover relative to the other options. With all the cost related aspects mentioned above this alternative will score a 2 out of 7 on average for the costs criterion.

Hindrance to Port Operations - 4

The hindrance to port operations for this alternative is average compared to the other alternatives. The suggested land reclamation is near a container yard mainly filled with empties, but also near the berth with the 2 STS-cranes, which will be hindered in operations. Therefore this alternative will score a 4 out of 7 on hindrance to port operations.

F.6.8. Alternative H - 13 hectares

This alternative analyses the situation where all the area between the breakwater and the jetty construction is reclaimed. The engineering challenges of the construction of a connection at the jetty construction remains. The amount of sand required for this area is the biggest compared to the rest of the alternatives. The length of the revetment for this alternative is the comparable to the length of alternative E. This alternative is formulated from a storage area point of view and as expansion possibility of all other alternatives.

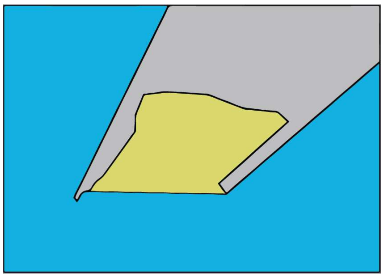


Figure F.19: Alternative H - 13 hectares of land reclamation

Storage Capacity - 7

The storage capacity will be increased to its maximum, as all possible land within the bay will be reclaimed for this alternative. This would be the option if the authority does not want to take any risks in terms of storage capacity as was pointed out in Section F.5. Therefore this alternative scores a 7 out of 7 on storage capacity.

Handling Capacity - 7

The handling capacity will be be increased to its maximum, as the connection at the jetty construction is fully broadened and land reclaimed at the connection can be used for handling. Therefore this alternative will score a 7 out of 7 on handling capacity.

Flexibility - 1

The flexibility of this alternative is extremely low, as it will not be possible to do more land reclamation within the San Vicente bay and all big investments are already done in ones. Therefore this alternative will score a 1 out of 7 on flexibility.

Costs - 1

The Capital Expenditures for this alternative is high. As this alternative does not make it possible to do any future investments with an discounted rate. However, the benefit of constructing everything at once is not having startup costs for each phase.
The initial Capital Expenditures for this alternative are extremely high, as all previous discussed investments will take place at once.
The Operational Expenditures for this alternative are extremely high. The reason behind this is the largest possible amount of land reclaimed relative to the other options. With all the cost related aspects mentioned above this alternative will score a 1 out of 7 on average for the costs criterion.

Hindrance to Port Operations - 1

The hindrance to port operations for this alternative is extremely high. The berth with the 2 STS-cranes will be hindered by the construction of the jetty construction and the largest of land will be reclaimed. Therefore this alternative will score a 1 out of 7 on hindrance to port operations.

F.7. RESULTS MULTI-CRITERIA ANALYSIS

In Table F.2 an overview is given of the criteria scores for each alternative. These criteria scores need to be multiplied with the corresponding weight factor in order to calculate the correct MCA score. The calculation is done in Table F.3 for alternative A to D and in Table F.4 for alternative E to H. The formula to calculate the correct MCA score is mentioned in Section F.1.

Criteria	**Weight Factor**	**Alternatives**							
		4 Hectare				**7 Hectare**			
	WF [%]	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Storage Capacity	30	1	4	4	4	5	5	5	7
Handling Capacity	30	1	7	1	4	7	2	4	7
Flexibility	20	7	5	6	6	3	3	4	1
Costs	13.3	7	4	6	4	3	5	2	1
Hindrance to Port Operations	6.7	7	2	6	4	2	6	4	1

Table F.2: Scores of the alternatives for each criterion

	Criteria	**Weight Factor**	**Alternative A**		**Alternative B**		**Alternative C**		**Alternative D**	
		WF [%]	Score	WF · Score	Score	WF · Score	Score	WF · Score	Score	WF · Score
A	Storage Capacity	30	1	0.300	4	1.200	4	1.200	4	1.200
B	Handling Capacity	30	1	0.300	7	2.100	1	0.300	4	1.200
C	Flexibility	20	7	1.400	5	1.000	6	1.200	6	1.200
D	Costs	13.3	7	0.931	4	0.532	6	0.798	4	0.532
E	Hindrance to Port Operations	6.7	7	0.469	2	0.134	6	0.402	4	0.268
	Total Score	-	-	3.400	-	4.966	-	3.900	-	4.400

Table F.3: Overview 1 of the alternatives A to D with scores of the MCA

	Criteria	**Weight Factor**	**Alternative E**		**Alternative F**		**Alternative G**		**Alternative H**	
		WF [%]	Score	WF · Score	Score	WF · Score	Score	WF · Score	Score	WF · Score
A	Storage Capacity	30	5	1.500	5	1.500	5	1.500	7	2.100
B	Handling Capacity	30	7	2.100	2	0.600	4	1.200	7	2.100
C	Flexibility	20	3	0.600	3	0.600	4	0.800	1	0.200
D	Costs	13.3	3	0.399	5	0.665	2	0.266	1	0.133
E	Hindrance to Port Operations	6.7	2	0.134	6	0.402	4	0.268	1	0.067
	Total Score	-	-	4.733	-	3.767	-	4.034	-	4.600

Table F.4: Overview 2 of the alternatives E to H with scores of the MCA

As can be seen from the previous tables, Alternative B scored the highest for the MCA with a score of **4.966** on a scale of 7. The alternatives with a full jetty construction, B and D, are considered to be the best options compared to the other possibilities. Alternative D or E would be a good second best outcome when alternative B is not possible, for example due to the hydrodynamics.

Based on the MCA, option B would be the expansion to research more in depth. This alternative will be the proposal during the meeting with the port authority. The precise shape and the exact surface of the land could be changed to their liking. The main attribute of this alternative is that it is a relative small expansion option close to the jetty. This means that the full connection at the jetty construction is constructed during the first phase.

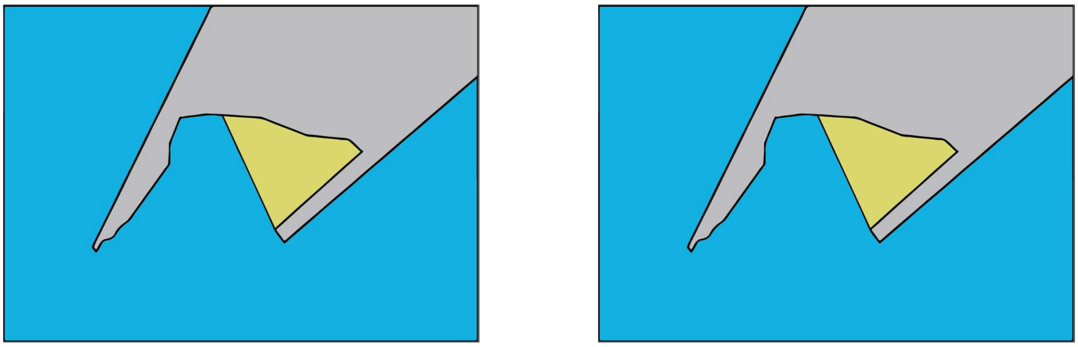
F.7.1. EXPANSION PLAN

Alternative B would be the first phase of the expansion and will suffice for the needs until 2025, according to the demand forecast. Table F.5 shows for each alternative the feasible expansion options. In this table can be seen that the expansion options for B are limited to alternative E and H. It could be also possible that the port authority will decide in 2025 that at that point no further expansion is needed. The port authority will have to make this decision based on how the market develops and on how operations are going after the first phase. Both expansion options

E and H scored the best in the MCA of all expansion options larger than 4 hectares, making these realistic expansion plans. This further expansion plan will be discussed with the port authority during the proposal meeting. What will happens after 2025 is not considered, since this brings too much future demand uncertainties. All expansion options are listed in Figures F.20, F.21 and F.22.

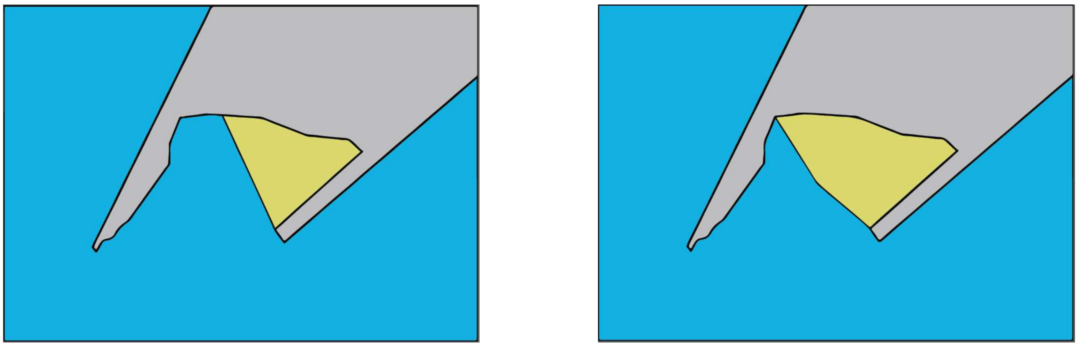
	A	B	C	D	E	F	G	H
A	-	+	+	+	+	+	+	+
B		-			+			+
C			-		+	+	+	+
D				-	+			+
E					-			+
F						-		+
G							-	+
H								-

Table F.5: Expansion possibilities for the alternatives



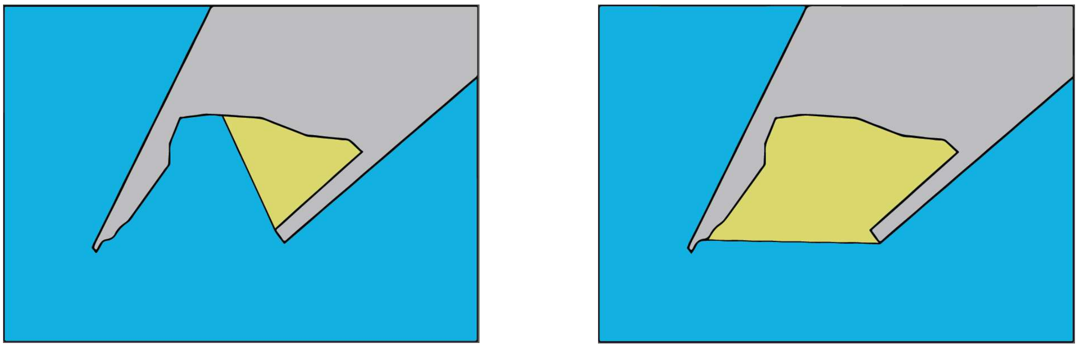
(a) Situation after phase 1 (b) Decision in 2025

Figure F.20: Expansion plan with negative market situation



(a) Situation after phase 1 (b) Decision in 2025

Figure F.21: Expansion plan with normal market situation



(a) Situation after phase 1

(b) Decision in 2025

Figure F.22: Expansion plan with positive market situation

F.7.2. Consultation with the port

On Friday the 27^{th} of September a meeting was arranged with the port authority to present the possible expansion options. Besides the port authority also SVTI and this project supervisor of UCSC were present. In the presentation all possible alternatives, the demand forecast, the criteria and the MCA were shown. The presentation was concluded with the recommendation of the expansion plan, as described in Section F.7.1. The essence of the meeting was to collaboratively come up with a design for the second phase that could be work out in depth.

The port authority concurred with the proposed alternative and the possible expansion plan. However, they provided a few remarks that should be taken into account for the second phase. Firstly, reclaiming all land until the tip of the jetty construction, as suggested in alternative B, might not be possible. The revetment needed will probably have a slanted slope, resulting in a wide cross-section. The vessels and other ships might use that space as a manoeuvring area and could be an obstacle, as indicated in Figure F.23. The port authority has indicated that the revetment should surpass the line indicated in Figure F.23. The red marked area in the design of alternative B should be replaced elsewhere. By reclaiming land this land closer to the breakwater (as in alternative D) the area reclaimed would be relatively cheap as it is located in the shallow part of the bay. Combining both remarks would give a proposed design that has the best of both alternative B and D.

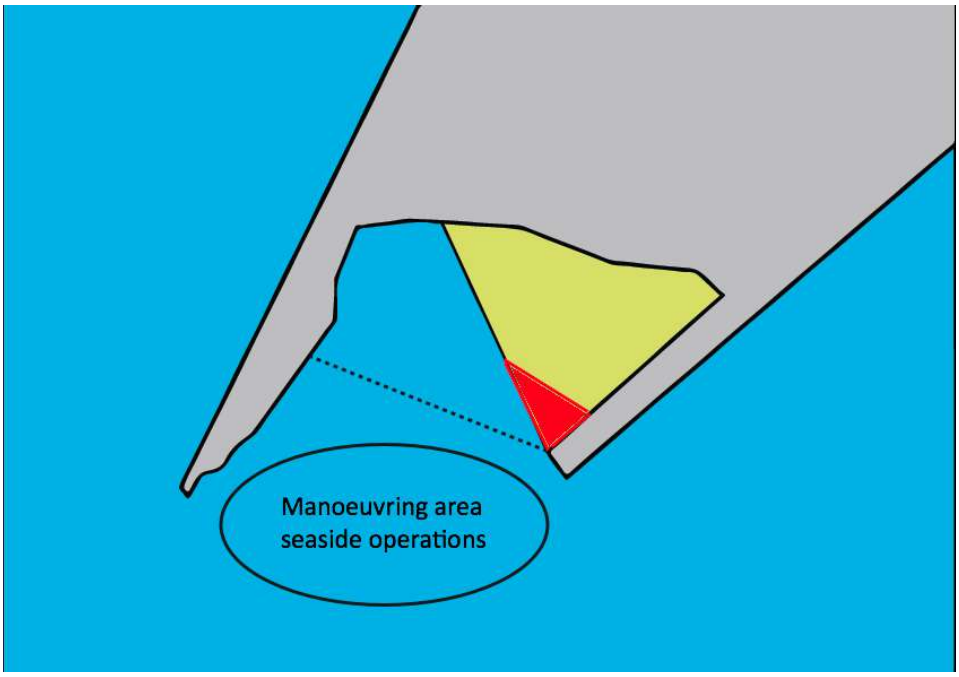


Figure F.23: Remark about manoeuvring area by port authority, the scattered line resembles the boarder of the area for manoeuvring, the red part points out what part of the reclamation might be scratched because of this remark

Secondly, when constructing the connection to the jetty construction it is necessary that the jetty is able to move slightly. In the act of mooring ships to the jetty connection a small displacement is present. The construction between the reclaimed land and the jetty construction needs to facilitate this movement.

According to the operational manager of SVTI (Pablo), rectangular container areas are more convenient. Rectangular shapes will make it easier to construct roads and storage places. This will be be considered in the final design. Having rectangular shapes would probably mean more revetment, resulting in higher costs. Therefore a good balance should be established between the two.

The line illustrated in Figure F.23 is the maximum expansion line according the port authority and SVTI. A bigger expansion (13 hectare for instance) would likely have a critical effect on the hydrodynamics if no extension of the breakwater is intended. The port authority has indicated that extending the breakwater is a too costly project which would not be realistic in the near future.

To conclude, the land reclamation to further investigate in the second phase is a combination of alternative B and D. Having the preference to win as much as land possible at the jetty construction, although it strongly depends on the calculations of the slanted revetment. The alternative that will be analysed in more detail is illustrated in Figure F.24.

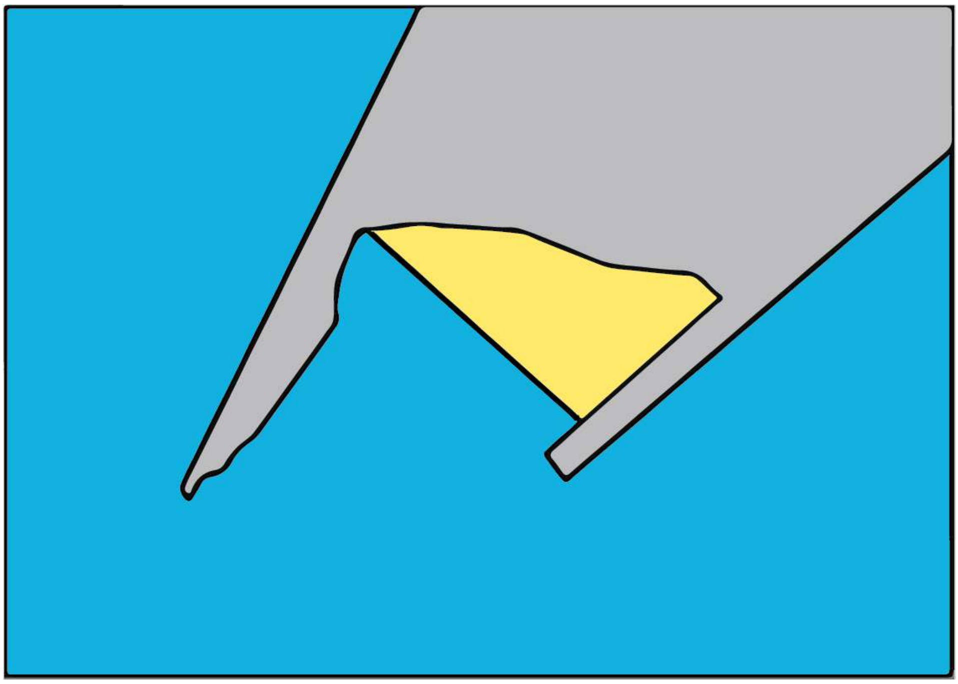
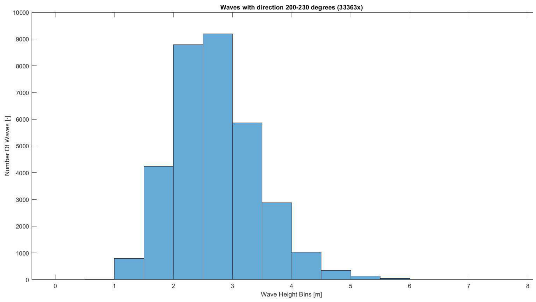


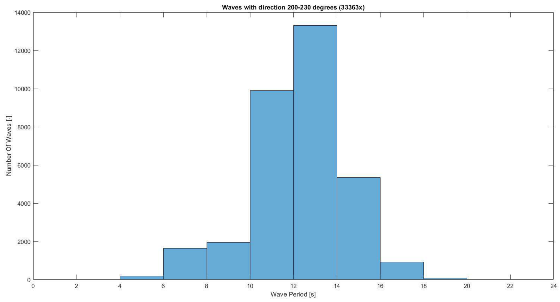
Figure F.24: Alternative B with some adaptations made in accordance with the client

G
WAVE DATA

This Appendix contains additional figures that where used in the process of establishing offshore wave scenarios that represent the governing wave climate near San Vicente bay

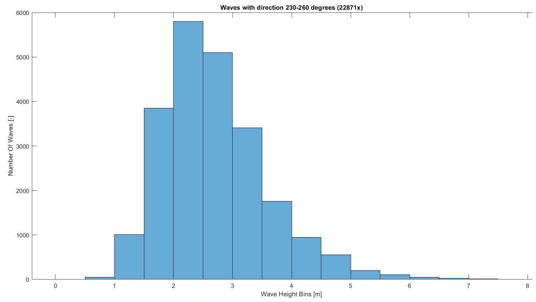


(a) Significant wave heights bin 1

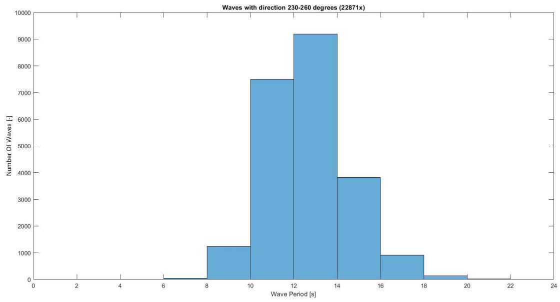


(b) Peak wave periods bin 1

Figure G.1: Analysis Bin 1

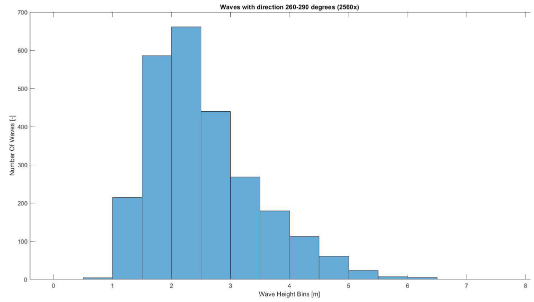


(a) Significant wave heights bin 2

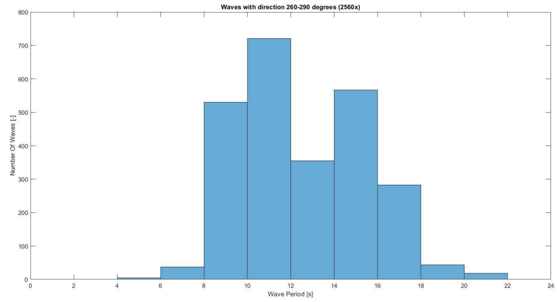


(b) Peak wave periods bin 2

Figure G.2: Analysis Bin 2

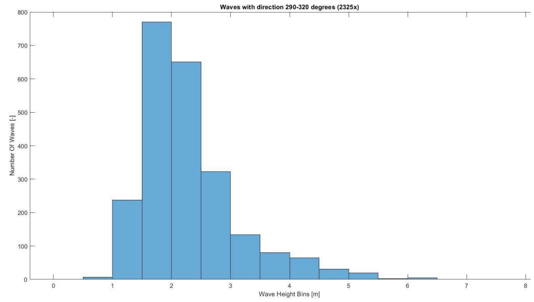


(a) Significant wave heights bin 3

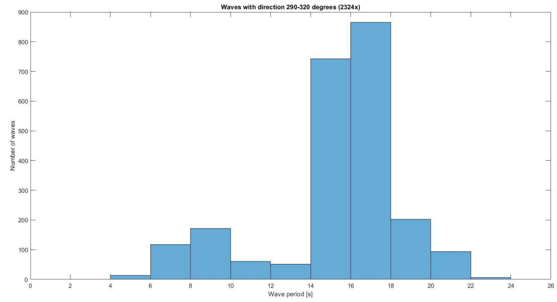


(b) Peak wave periods bin 3

Figure G.3: Analysis Bin 3



(a) Significant wave heights bin 4



(b) Peak wave periods bin 4

Figure G.4: Analysis Bin 4

Figure G.4 shows a clear separation between two wave groups. This separation can be explained by the occurrence of swell and wind waves.

The data which is plotted in the above figures is also displayed in table form. For each combination of classes the percentage of occurrence is calculated. Table 2.2 represents wave height vs wave direction, Table G.1 wave period vs wave direction and Table G.2 represents wave height vs wave period. For the wave direction of each bin the direction in the middle of the bin is chosen, so 205°, 245°, 275° and 305°.

	Wave period [s]														
Wave direction [°]	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	Total	% of total	**Cumulative** [%]
205	0	0	186	1640	1959	9906	13307	5340	925	85	15	0	33363	55%	100%
245	0	0	46	1238	7485	9197	3821	915	142	25	2	0	22871	37%	45%
275	0	5	37	530	721	355	567	283	44	18	0	0	2560	4%	8%
305	0	13	117	172	61	51	743	865	202	94	6	0	2324	4%	4%
Total	0	18	386	3580	10226	19509	18438	7403	1313	222	23	0	61118	100%	0%
	0%	0%	1%	6%	17%	32%	30%	12%	2%	0%	0%	0%			
Cumulative	100%	100%	99.3%	93%	76.7%	44.8%	14.7%	2.5%	0%	0%	0%	0%			

Table G.1: Wave period vs wave direction

	Wave period [s]													
Wave height [m]	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	**Total**	**% of total**
0.0-0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
0.5-1.0	0	0	0	3	6	29	19	17	11	5	1	0	91	0%
1.0-1.5	0	0	4	57	289	762	580	375	156	28	7	0	2258	4%
1.5-2.0	0	0	50	133	1035	3525	2422	1387	692	144	58	4	9450	15%
2.0-2.5	0	0	108	464	1124	5981	5295	1979	769	132	43	3	15898	26%
2.5-3.0	0	0	40	609	636	4621	6369	2082	574	92	32	0	15055	25%
3.0-3.5	0	0	2	436	430	2039	4451	1975	313	26	5	1	9678	16%
3.5-4.0	0	0	0	121	234	745	2203	1392	174	20	4	0	4893	8%
4.0-4.5	0	0	0	14	105	294	917	663	142	14	2	0	2151	4%
4.5-5.0	0	0	0	3	32	118	436	323	74	4	0	0	990	2%
5.0-5.5	0	0	0	0	5	45	134	155	35	3	0	0	377	1%
5.5-6.0	0	0	0	0	2	7	57	77	24	1	0	0	168	0%
6.0-6.5	0	0	0	0	1	7	23	27	10	2	0	0	70	0%
6.5-7.0	0	0	0	0	0	0	3	12	9	2	0	0	26	0%
7.0-7.5	0	0	0	0	0	0	1	7	2	0	0	0	10	0%
7.5-8.0	0	0	0	0	0	0	0	0	3	0	0	0	3	0%
Total	0	0	204	1840	3899	18173	22910	10471	2988	473	152	8	61118	
% of total	0%	0%	0%	3%	6%	30%	37%	17%	5%	1%	0%	0%		

Table G.2: Wave height vs wave period

G.1. Wave Analysis Revetment

In Appendix J an elaboration of the revetment for the land reclamation will be given. In order to make such a design a significant wave height is needed. This section investigates the storm wave height that corresponds to a given return period. Also, a wave period is needed to design the revetment. This wave parameter is determined at the end of this Appendix.

G.1.1. Peak-over-threshold method

First a peak-over-threshold method is performed in order to cancel out most of the offshore waves and only stay left with waves that correspond to single storm events. The duration of a single storm event is defined such that if there are 2 wave height peaks during 4 days of wave data it still represents 1 storm event. In other words, between each single storm event there is a minimum of 4 days of wave height data that is not depicted as a storm. According to Van den Bos and Verhagen (2018) a good rule of thumb is to define a peak wave height such that there are approximately 10 storms per year. Different peak wave thresholds are tested, an overview is given in the table below.

Peak wave height [m]	Number of storms per year [-]
4	23
5	14
5.5	8
6	4
7	2

Table G.3: Peak wave height threshold and corresponding amount of storms per year

Finally 5.5 meters is chosen as the peak wave height. This corresponds to 8 storm events per year. A visualization of each storm event between 1998 and 2018 is given in Figure G.5. Figure G.6 gives the probability of exceedance given that a storm is present. In other words, if there is a storm the chance that the measured offshore waves are bigger than 6.5 meters is about 80 %. Of course the chance that the waves are bigger than 5.5 meters during a storm is 100 % because by definition the threshold for a storm is equal to waves of 5.5 meters.

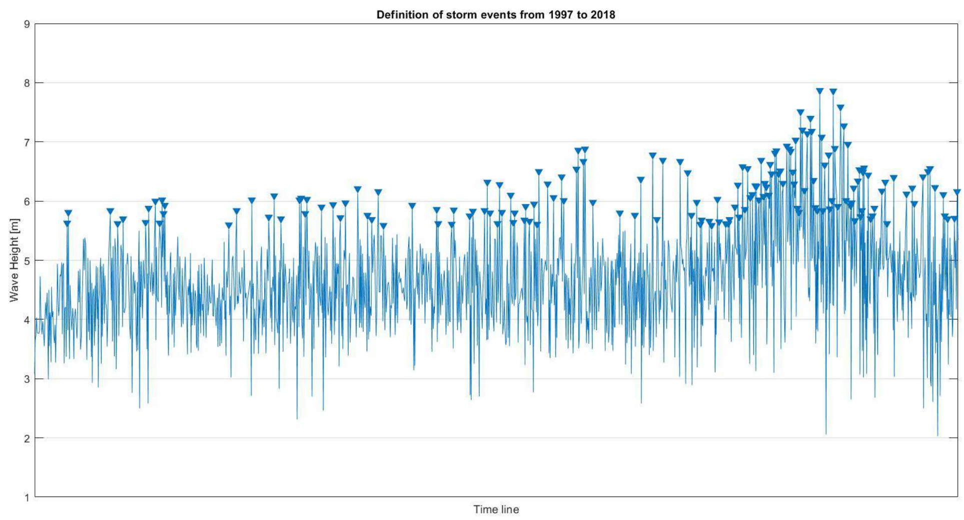


Figure G.5: Storm events between 1998 and 2018

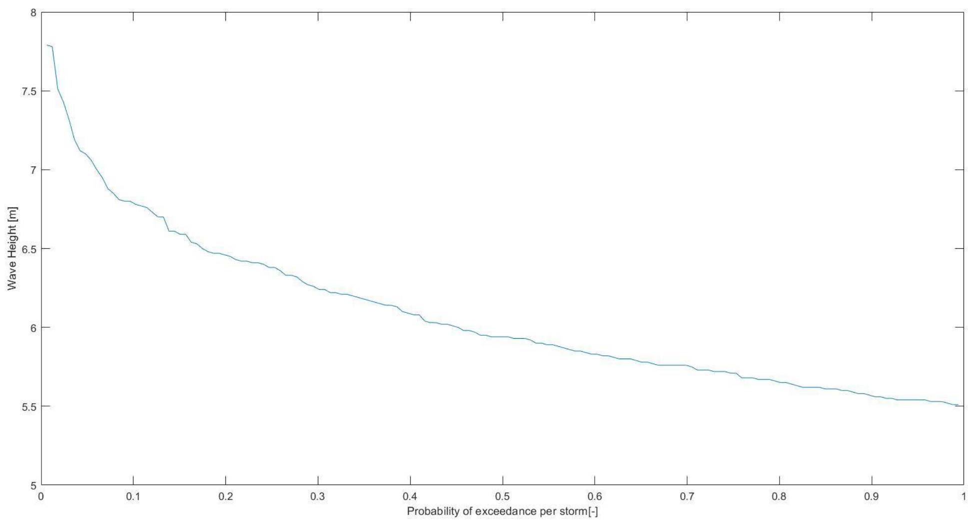


Figure G.6: Probability of exceedance given that a storm is present

The next step is to fit extreme value distributions to the data set containing the storm events and see what distribution fits best. Van den Bos and Verhagen (2018) described the following four extreme value distributions: exponential distribution, Weibull distribution, Gumbel distribution and the Generalized Pareto distribution (GPD). In order to apply these distributions linear regression is applied. Chapter 4 of Van den Bos and Verhagen (2018) contains the equations needed for this. The α factors in the formulas of the Weibull and Generalized Pareto distributions are determined with a root mean square error analysis. The outcome of each fitting procedure is visualized in Figure G.7.

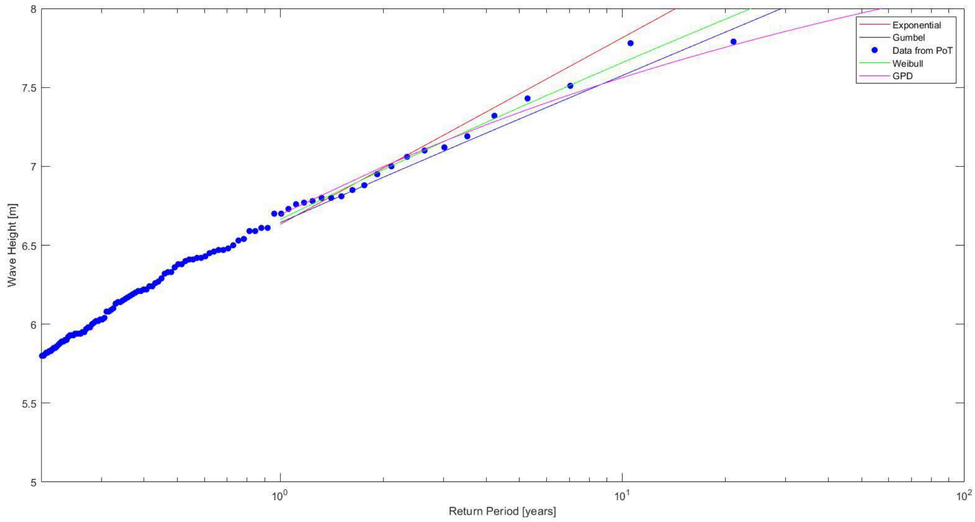


Figure G.7: Extreme value distributions

Figure G.7 does not clearly show what distribution fits the storm data set best. A root mean square error analysis is again performed in order to investigate what extreme value distribution fits best.

Distribution [-]	Error [-]	Wave Height [m]	Return Period [years]
Exponential	0.0574	7.6	10
Weibull	0.0085	8.3	50
Gumbel	0.0627	8.5	100
GPD	0.0250	9.37	1000

Table G.4: Root Mean Square Analysis and the storm wave heights for the Weibull distribution

The Weibull distribution seems to be the best fitted extreme value distribution. An offshore design storm wave height can now be determined for a given return period. Table G.4 gives an overview. The wave height is set corresponding to a target return period of 100 years which seems reasonable for revetments. Therefore the offshore design wave height is equal to 8.5 meters.

G.1.2. Wave period

The wave height is set corresponding to a target return period of 100 years. In order to determine the corresponding wave period the following relation is used:

$$T_m = \alpha \cdot \sqrt{H_{sig}} \tag{G.1}$$

For each peak wave height the value of α is determined through:

$$\alpha = \frac{T_m}{\sqrt{H_{sig}}} \tag{G.2}$$

The average value of α is simply determined by taking the mean of all the values that were found for α. Doing this leads to a value of 5.9 for α. The wave period now simply follows from Equation G.1 and is equal to 17.2 seconds. One should realise that this theoretical relation described in Equation G.1 is a quite rough simplification of reality. Figure G.8 displays the scatter around the theoretical correlation.

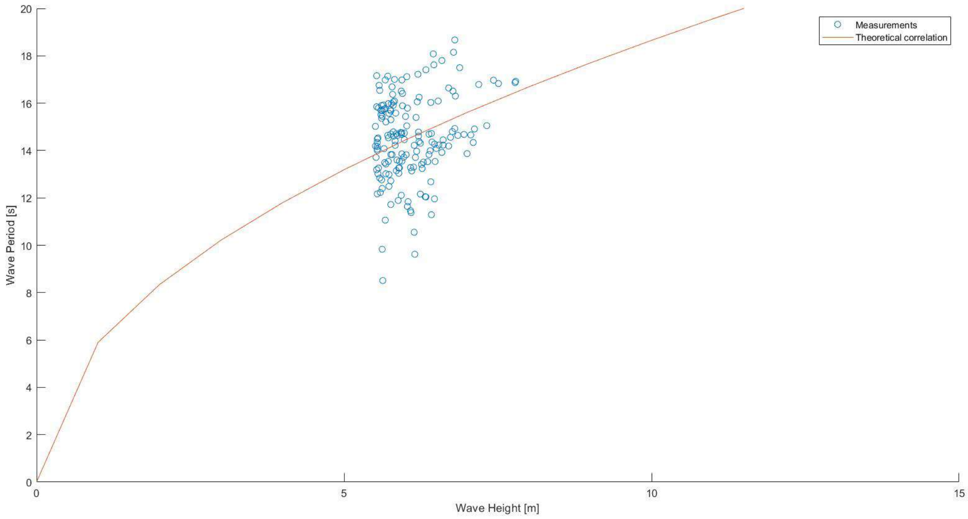


Figure G.8: Correlation between wave height and wave period

H

Numerical Modelling

For hydrodynamic modelling inside the harbour the numerical modelling program Delft3D is used. This appendix elaborates on hydrodynamic wave processes that occur inside the harbour. For each process its relevance will be described and whether the process should be accounted for in the numerical model. For the complete theory concerning these processes one is referred to the book (Holthuijsen, 2007) and MSc thesis (Wong, 2016). A thorough explanation will be given to how the relevant processes are incorporated into Delft3D and to all considerations that were taken into mind. The validation process of the Delft3D model is also described. After that the adjustments that are made to the model used for validating in order to reduce the computational time are listed. Finally some uncertainties and limitations that come with the model will be addressed.

H.1. Hydrodynamic wave related processes in harbours

H.1.1. Shoaling

Shoaling is a process that occurs when waves are propagating into shallow water. When waves are approaching the coast the group velocity becomes smaller because the water depth reduces. The group velocity is equal to the wave energy transport velocity. In order to maintain a constant energy flux the energy density has to increase, hence an increase in wave height. For a harbour shoaling processes are less relevant. Inside a harbour basin a relatively deep profile is maintained, hence surface waves are hardly affected by the bed. Close to the breakwater some shoaling will occur.

H.1.2. Refraction

Refraction is the process in which waves have the tendency to turn towards the coast. Consider a wave traveling in deep water. When the wave is traveling towards the shore it rarely travels perpendicular the the shoreline. As a consequence, when the wave travels into shallower water, a certain part of the wave will 'feel' the bottom earlier, hence the wave speed at that part decreases. The other part of the wave does not travel in shallow water yet, hence the wave speed at that part will be higher. Due to this phenomenon waves have the tendency to turn towards the shoreline. A harbour basin consists of a relatively flat bed with a sufficiently large water depth. Therefore the effects of refraction are often very limited inside harbour basins. However at the tip of the breakwater (where water enters the harbour basin) the bed profile does change rapidly and refraction does occur.

H.1.3. Diffraction

Diffraction is the process in which waves bend around obstacles and openings. Waves then propagate into the shadow zone of these obstacles. Waves propagating into the shadow zone travel in a concentric circular pattern. The amplitude of the waves is progressively decreasing going further away from the obstacle. Diffraction is very likely to occur in a harbour basin due to the presence of a breakwater. Therefore the effects of diffraction should be accounted for when modelling wave heights inside the harbour. Also secondary effects such as reflection of the waves should be checked.

H.1.4. Reflection

Reflection is the phenomenon that occurs when wave energy is reflected of a hard boundary. Reflection is higher for a vertical impermeable wall than for a sloping boundary. When a lot of wave energy is reflected this may lead to unwanted effects such as oscillations within the bay. A harbour basin mainly consists of straight impermeable quay walls. Also for an open jetty structure or a sloping wall reflection is an occurring phenomenon. Reflection therefore occurs within the harbour basin and the effects should therefore be investigated.

H.1.5. Dissipation

Dissipation is the process in which energy in the wave field is dissipated. The process is very complex and includes turbulence and other nonlinear effects. A form of dissipation is bottom friction. Bottom friction mainly occurs in shallow water where orbital flow motions in the water feel the bottom and create small turbulent boundary layers. Another form of dissipation is wave breaking. In shallow water wave breaking can be explained as depth induced breaking, once waves start feeling the bottom shoaling occurs. Eventually waves topple over and due to turbulence energy is dissipated. For deep water wave energy is mainly dissipated in the form of white capping. For a harbour a deep water profile is maintained. This means that depth-induced wave breaking is barely present inside the harbour. Depth-induced breaking is the main form of energy dissipation occurring in waves. The effects of white-capping are assumed to be negligible.

H.1.6. Nonlinear wave-wave interactions

Nonlinear wave-wave interactions is the transport of energy from higher to lower frequencies and vice versa. In order to check for wave-wave interactions one should investigate the wave spectrum, it should contain extra peaks. When wave components collide interactions occur. Nonlinear wave-wave interaction in deep water is called quadruplet wave-wave interaction. In quadruplet wave-wave interaction one pair of wave components interacts with another pair. In shallow water nonlinear wave-wave interaction is called triads wave-wave interaction. In shallow water one pair can interact with a third, freely propagating wave component. A harbour often contains an intermediate water depth. Therefore it is not very clear which form of nonlinear wave-wave interactions will occur within the harbour.

H.2. Delft3D, Wave and Flow module

The numerical modelling program Delft3D contains a Wave module and a Flow module. The Wave module from Delft3D uses the SWAN model to compute the wave height at each node of the computational grid. The SWAN model is a wave-averaged model, it is based on the discrete spectral action balance equation. Wave information is lost during computation because the hydrodynamics are described as an averaged process. The numerical implementation is often explicit, this means that numerical stability is only guaranteed for a certain stability region. Therefore there is a limitation when it comes to time and spatial resolution. This means that the computational grid cannot be very accurate. On the other hand, computational time is limited. The Wave module is therefore very suitable if a vast area is of interest. The Flow module uses the Navier-Stokes equations to compute the flow characteristics at the nodes of the computational grid. The equations are solved with a highly accurate unconditionally stable solution procedure (Deltares, 2019a). Therefore the computational grid can be smaller than for the Wave module.

In order to determine what type of wave computation is preferred an elaboration on the different types of wave computations in Delft3D is given, reference is made to (Deltares, 2019b). Delft3D has the option to run a so-called *wave standalone* computation where the influence of flow characteristics on the waves is not accounted for. Such calculations only use the Wave module which results in the loss of wave information as was described above. Furthermore the corresponding grid size in Delft3D is equal to 40x40m, which is too large when one tries to describe hydrodynamic processes inside the harbour. Therefore a standalone wave computation is not preferred. Besides the wave computation described above there are three types of wave computations within the Delft3D module that include flow properties:

1. The first method is a computation in which the user defines the flow properties. For each wave condition the user specifies a uniform water level and a uniform current velocity. The effect of flow is now accounted for in the waves. However this does not solve the fact that the corresponding grid size is still too large (40x40m) to describe the hydrodynamic processes inside the harbour.
2. The second method is is an offline coupling of the wave and the flow module. First a flow computation is completed on the flow grid. Afterwards the characteristics from the flow computation are used for the wave

computation. In that way the effect of flow on the waves is accounted for. However the wave characteristics are still solely defined on the wave grid, which is too large to accurately describe the hydrodynamic processes inside the harbour.

3. The third method is an online coupling of the wave and flow module. The wave module and the flow module now have a dynamic interaction in which they constantly update each other. As a result the effects of the waves on the current and vice versa are accounted for. Information on the waves is now also calculated on the flow grid, as a result this method describes the hydrodynamic processes in the harbour in much more detail. Hence the results are much more accurate.

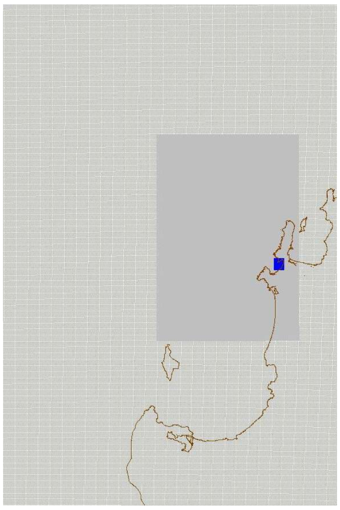
When comparing the different types of computations one can easily conclude that a computation with an online coupling of the wave and flow module is the most accurate and therefore the most preferred. Nonetheless this computation will demand the most computational time. As was previously addressed the Wave module from Delft3D uses the SWAN model. The SWAN model does account for all the relevant physical processes that occur within the harbour, which were mentioned in Section H.1. Those processes include: shoaling, refraction, diffraction, reflection, dissipation and nonlinear wave-wave interactions (both quadruplet and triads). Diffraction and reflection were not available in previous SWAN versions but they are in the latest version (Deltares, 2019b). In the next part the setup will be explained. Also, measures to downscale the computational time have been applied and those will also be explained in the Model Setup.

H.3. Model Setup

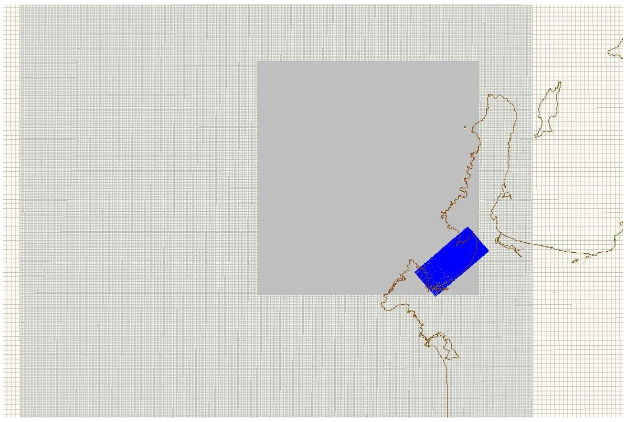
A model for the Chilean coastline around San Vicente Bay is obtained from UCSC. This model is used for modelling in Delft3D. The coastline model can be seen in Figures H.1 and H.2. In order to describe wave heights inside the harbour data from an offshore wave buoy 40 km away from the harbour is used. The location of this wave buoy is 36°5"S 73°5"W. A data set containing the Julian Date, Significant Wave Height (H_s), Peak Period (T_p) and Peak Direction (Θ) was obtained from the National Oceanic and Atmospheric Administration (NOAA) website. The data set consists of 21 years of measurements, from 1997 to 2018. For each consecutive 3 hours the above mentioned parameters are mentioned. In Appendix G one can find an analysis of this data. The Delft3D Flow module is used to translate the offshore wave data to the area of interest, which is the San Vicente Port. Section H.5 will elaborate on verification of the model. For each model run one input value for H_s, T_p and Θ is required. The results from Appendix G will be used to determine these representative boundary conditions. Section H.3.3 elaborates further on the boundary conditions that are finally chosen for the model. The next section will elaborate on how the computational grids have been implemented in the Delft3D model.

H.3.1. Computational Grid

As stated above in Section H.2 a computation solely on the wave grid is less accurate, however such computations demand less computational time. Therefore such computations are very suitable when a vast area is of interest. The wave buoy that is used to predict wave heights inside the harbour lies 40 km from the harbour. In order to limit computational time nesting of several grids is applied. Nesting is a method in which a smaller computational grid area with more detail retrieves boundary information from a larger computational area. In the Delft3D model three wave grids have been applied, each grid having a smaller area and a smaller grid size and therefore containing more detailed information than the previous one. The first three wave grids are highlighted in Figure H.1a. One can easily notice that each consecutive grid is much smaller and more detailed than the previous one. The largest wave grid consists of 401x301 grid points with grid cell that have a dimension of 380x380m. The second largest wave grid consists of 490x355 grid points, each cell with a dimension of 126x126m. The smallest wave grid consists of 463x460 grid points, each cell having a dimension of 42x42m. The blue figure highlighted in Figure H.1a is the smallest wave grid present in the model. Figure H.1b shows the wave grids together with the flow grid. The flow grid is highlighted in blue. The flow grid consists of 197x301 grid points, each cell having a dimension of 10x10m. The orientation of the flow grid is changed so that it lies parallel with the harbour. This makes the implementation of quay walls and a land reclamation in the model easier. Also the land boundary is depicted in both figures.



(a) Wave grids, smallest wave grid in blue

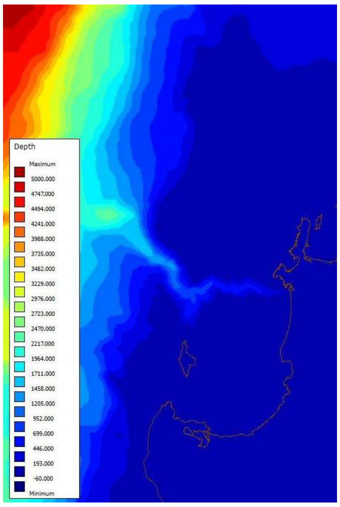


(b) Wave & flow grids, flow grid in blue

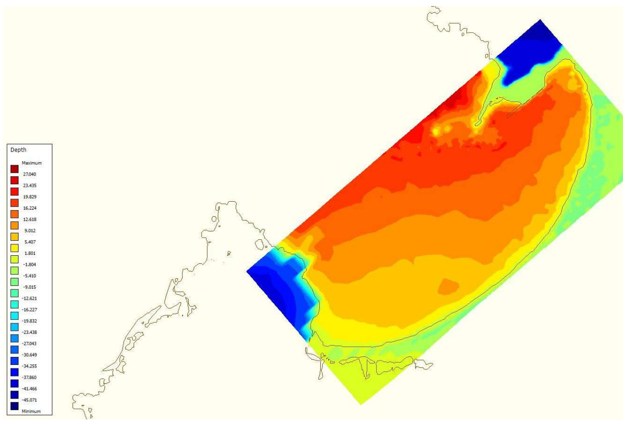
Figure H.1: Computational Grids Delft3D

H.3.2. Bathymetry Grid

Bathymetry maps of the Chilean coastline were supplied by UCSC. For each wave grid an associated bathymetry map is supplied. Figure H.2a shows the bathymetry map that is used for the largest wave grid. This figure shows the underwater canyon near the mouth of the Bio-Bio river very clearly. For the bathymetry inside the harbour a detailed Autocad model was provided by SVTI. This model was used to create a bathymetry map that could be used in Delft3D. This map is shown in Figure H.2b.



(a) Bathymetry map wave grids



(b) Bathymetry map flow grid

Figure H.2: Bathymetry Maps Delft3D

H.3.3. Boundary Conditions

The Delft3D model requires some boundary conditions that need to be determined on forehand. For each model run the boundary conditions for the wave input consist of a significant wave height, a peak period and a direction. Several model runs will be performed with different parameter values in order to mimic the normative wave climate. Appendix G describes how the offshore wave input is determined. Table 2.3 gives an overview of the wave boundary input. The boundary of the flow grid is described with a water level times series that is forced by astronomical constituents. Those constituents are depicted below.

	Amplitude [m]	Phase [°]
M_2	0.4541	75.14
N_1	0.0047	170.74
ϵ_1	0.0075	128.06
η_2	0.0085	85.38
J_1	0.0136	54.21
MSF	0.0179	73.83
Q_1	0.0191	358.47
N_2	0.0869	53.74
O_1	0.1123	2.48
K_1	0.123	62.03
S_2	0.2031	101.31

Table H.1: Astronomical tidal constituents

In order to smoothen the boundaries of the flow grid the astronomic forcing type is chosen. At first just a time series was depicted as forcing type but this led to some boundary instability issues. The amplitude and phase of the astronomical constituents in Table H.1 are determined with a harmonic analysis that is performed by (Gómez, 2019). A Matlab script is used to calculate the constituents of a harmonic signal that correspond to local observations of the water level inside the port as accurate as possible. The figure below shows the difference between the observed sea level data and the simulated one. The largest difference between the two signals is only 7 centimeters. The simulated signal is therefore assumed to model the water level variations because of the tide very well.

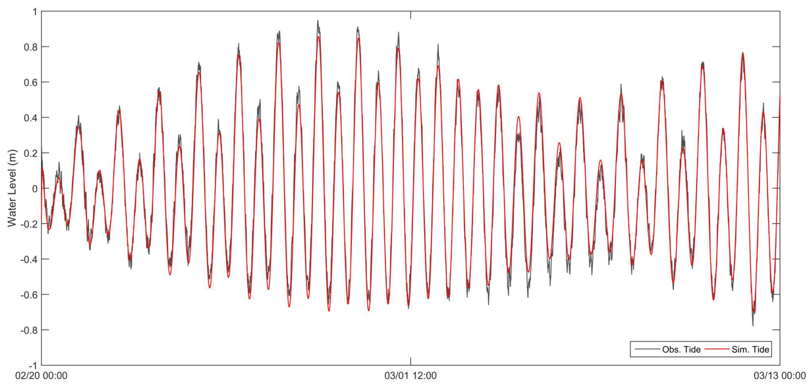


Figure H.3: Observed water level vs simulated water level

H.4. Implementation of structures

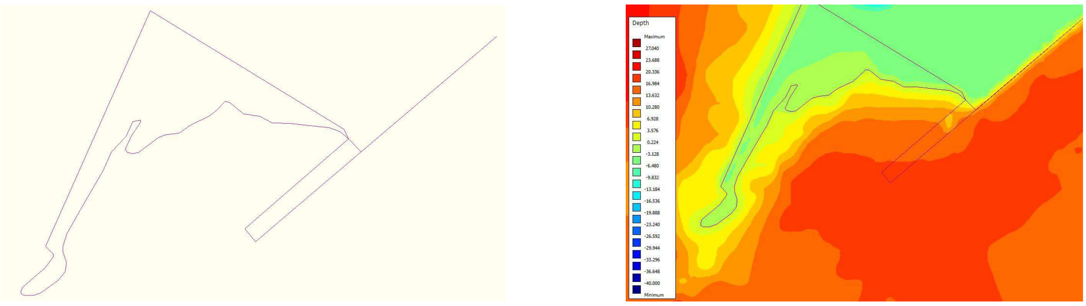
Structures that are present in the port area acts as a boundary as well. These structures therefore need to be implemented into the Delft3D model as well. The breakwater and quay are examples of such structures that need to be implemented in order to run reliable computations. On top of that, the designed land reclamation should also be implemented in the model as well. A brief description to how these elements are implemented in the model will be given below. Eventually Table H.2 gives a small overview.

There are two possibilities when one tries to implement an obstacle into a Delft3D model (Deltares, 2019b). These two options include implementation of a sheet or dam obstacle. The sheet obstacle contains a transmission coefficient that is constant along the obstacle. The dam obstacle has the option the vary the transmission coefficient along the obstacle. The breakwater as well as the quay are uniform in longitudinal direction. Therefore the sheet obstacle is implemented in order to mimic these structures.

H.4.1. Breakwater

The breakwater is implemented in the Delft3D model by adding an obstacle file. The file describes the layout of the breakwater and some other parameters. Figure H.5a displays the layout, which is created with a polygon file using the *Quickin* module of Delft3D. Because the breakwater is a non-permeable structure the transmission coefficient is set to 0. For the reflection coefficient (d'Angremond et al., 2008) is consulted. From figure 10-2 in (d'Angremond et al., 2008) it could be concluded that most of the reflection coefficients for breakwaters made of rock lie between 0.2 and 0.4, eventually of value of 0.3 is used in the model.

The breakwater does not need to be implemented in the flow module. The flow module already includes the breakwater because the depth profile of the flow grid includes the layout of the breakwater, as is visible in Figure H.5b. A negative depth value in this figure corresponds to a surface above the water level. Hence, a boundary is already present.



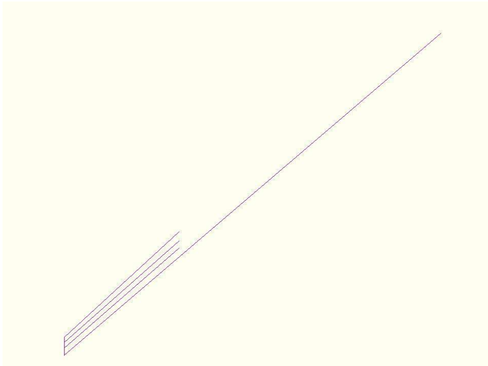
(a) Breakwater and quay obstacle layout

(b) Breakwater and quay obstacle including depth profile

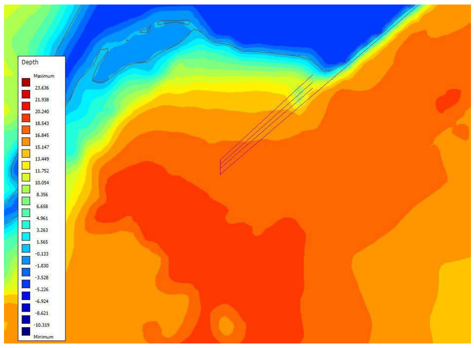
Figure H.4: Implementing breakwater and quay in wave module

H.4.2. Quay

Implementation of the quay in the Wave module is done in the same way as the breakwater was implemented. An obstacle is implemented to mimic the quay. The quay contains an open jetty structure. A technical Autocad model was provided by SVTI which showed that the jetty structure contains supportive piles with different sizes. In order to simplify the model it is assumed that all piles have a radius of 0.6m. The cross sectional area between the piles is relatively large compared to the area covered by the piles. All piles have a circular shape. The hindrance that the piles create with respect to water flows is therefore assumed to be negligible. The reflection coefficient of the quay is therefore set to 0. The transmission coefficient is set to 0.7 because approximately 70 % of the structure is open. The depth profile shown in Figure H.5b shows that the area around the quay does not include the open jetty structure. Implementation of the quay in the flow module is therefore required, in contrast with the breakwater. Consultation with (Luijendijk, 2019) showed that one way to implement the quay is by adding porous plates to the Flow module. Porous plates are partially open structures that have dimensions that can be significantly smaller than the applied grid size (Deltares, 2014). In order to implement the quay a porous plate file is created that describes the layout of the open jetty structure. Such a porous plate file follows the orientation of the grid. As was explained in Section H.3.1 this is the reason why the Flow grid is aligned with the orientation of the jetty structure. A visualization is given in Figure H.1b. The jetty structure is simplified to 4 rows of piles. One of the piles is extended which mimics reality. Behind the extended row of piles a land boundary that corresponds to the depth profile is present. In reality this extended row of piles consists of several rows. However for simplicity it is assumed to be only one row. Simplification of the jetty structure have been done on basis of technical drawings presented in (Bardi, 2013). Figure H.5 is a visualisation of the porous plates that are used to model the open jetty structure in the flow module.



(a) Quay layout



(b) Quay layout including depth profile

Figure H.5: Implementing quay in flow module

H.4.3. Land reclamation

Implementation of the land reclamation into the flow grid requires a change in the depth profile of the flow grid. Resolution of the flow grid is small enough so that the land reclamation can be implemented. An effort is made to mimic the slope of the landfill at the seaward side as good as possible. This slope is determined in Appendix J and will be around 1:3. In the wave grid an obstacle (sheet file) is created to model the hard separation between the reclaimed land and the sea. The characteristics of this separation are the same as the characteristics of the breakwater. It is therefore modelled with a transmission coefficient of 0 and a reflection coefficient of 0.3. Figure H.6 clearly displays the breakwater, the quay, the land boundary and the adjusted depth profile.

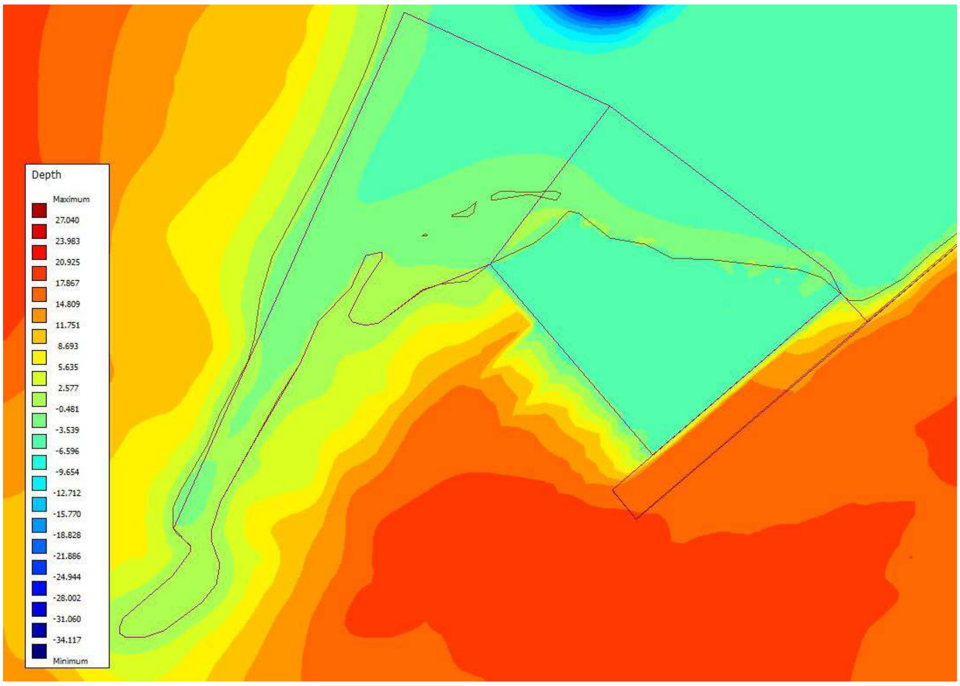


Figure H.6: Modelling of land reclamation

Table H.2 below provides a small overview of how each structure is implemented in the model. Also transmission and reflection coefficients are supplied.

	Wave Module	Flow Module	Transmission	Reflection
Breakwater	Sheet Obstacle	x	0	0.3
Quay	Sheet Obstacle	Porous Plates	0.7	0
Land Reclamation	Sheet Obstacle	Depth Profile	0	0.3

Table H.2: Implementation obstacles

H.5. Model validation

In order to check the reliability of the Delft3D model a model verification is performed. The Delft3D model without implementation of the land reclamation is used for validation. In reality the land reclamation does not exist. The model is therefore validated with a reference signal that was obtained in the current situation. A time series of a wave buoy inside the port is used as reference signal. The time series was provided by SVTI and is part of (Robles, 2017). The location of the wave buoy is depicted in Figure H.7. The time series gives the significant wave height for the period between 17-02-2017 and 21-03-2017 inside the port of San Vicente. The time series is depicted in Figure H.8.

Figure H.7: Wave buoy location

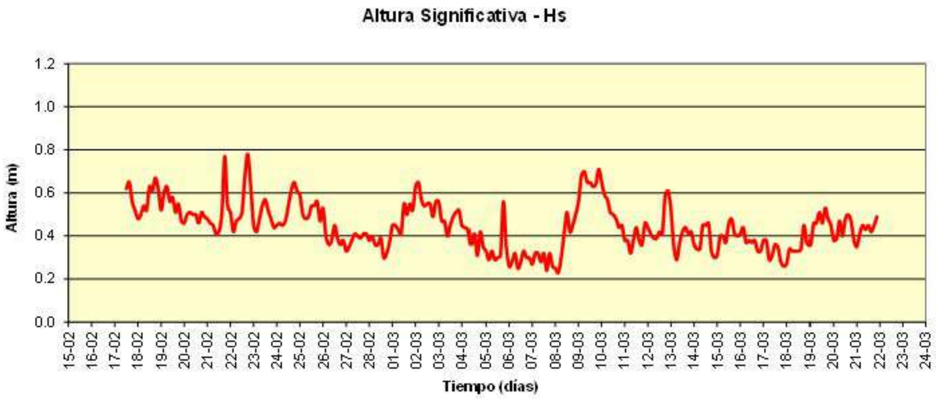


Figure H.8: Water level time series inside port

The offshore wave data that is used for input in the model was analysed, see Appendix G for the analysis. The obtained wave data is depicted in Figure 2.7. In order to validate the Delft3D model, offshore wave data is used as input. The offshore wave data corresponds to the same time period as the time series depicted in Figure H.8 that is used for validation. In order to limit simulation time 4 days of offshore wave data is used. Offshore wave data from 20/02/2017 until 24/2/2017 is chosen. For every 3 hours an offshore significant wave height is given. This data set contains 33 different scenarios each having different values for the significant wave height, peak period and direction. The offshore wave data set is visualised in Figure H.9.

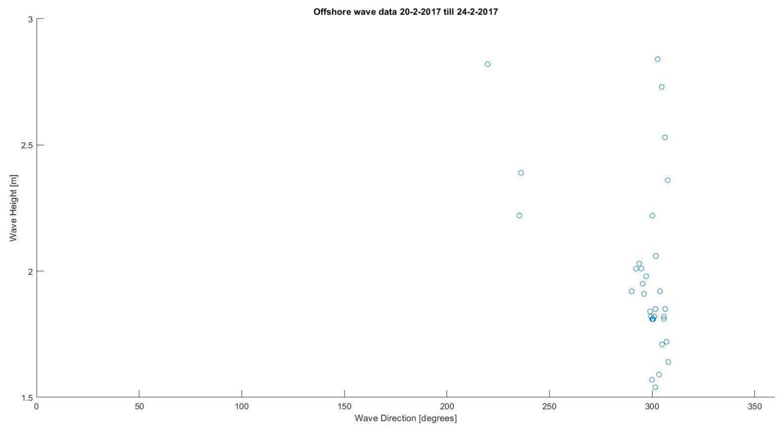


Figure H.9

An observation point is added to the Delft3D model. The location of the observation point is the same as the location of the wave buoy inside the port. A quick calculation is performed in order to investigate whether there is a significant time lag between the offshore data and the nearshore wave buoy data. The wave speed is calculated according to the equations stated below.

$$c = \frac{gT}{2\pi} \tag{H.1}$$

$$c_g = \frac{1}{2} c \tag{H.2}$$

A wave group velocity of 7.81 m/s was obtained. The distance between the offshore wave buoy and the buoy inside the port is roughly 40 kilometers. Therefore the travelling time is about 85 minutes. Both buoys contain measurements for every 3 hours. The travel time can therefore be neglected when comparing the calculated nearshore wave data from the model with the observed data. The computed wave heights by the Delft3 model at this observation point for the period between 20/02/2017 - 24/2/2019 are given in Figure H.10 below.

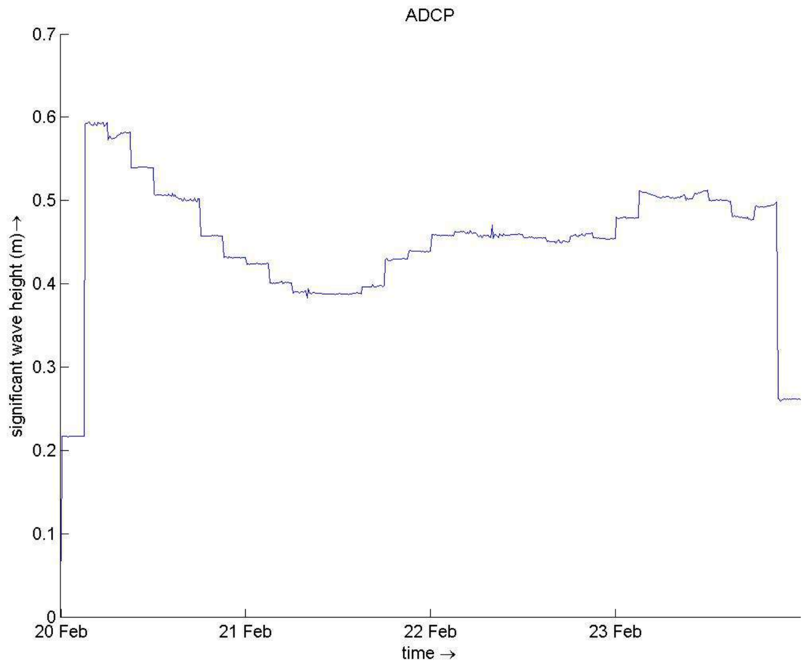


Figure H.10: Calculated wave heights at wave buoy location

A comparison is made between the computed wave heights (depicted in Figure H.10) and the measured wave heights for the period 20/2/2017 - 24/2/2017 (depicted in Figure H.8). The results from the Delft3D model run have the same order of magnitude as the observed values by the wave buoy. The average wave height is roughly the same, about 0.5m. Footnote has to be made that the computed results do definitely not show a 100 % correlation with the measured data. However, in order to quantitatively describe the effects of possible land reclamation the model results are assumed to be good enough.

H.6. Model simplification

The Delft3D model that was used for validation had a computational time of 4 days. Due to time constraint it was not feasible to run the exact same model multiple times to investigate the effect of the land reclamation on the wave heights in the harbour area. The model is therefore simplified compared to the model that was used for validation. The adjustments that were made in order to limit computational time are briefly addressed below. An overview of all adjustments is presented in Table H.3.

H.6.1. Tide

The dynamic astronomical tidal forcing is removed from the model. The water level is now described by a stationary condition. According to (Sea Level Station Monitoring Facility (IOC)) the high and low water levels are +1m MSL and -1m MSL respectively. Data from Coronel station is chosen because this station is closest to the port of San Vicente. Since it is expected that there will be more wave action when the water depth is less, the stationary condition of the water level is set to -1m MSL. However, it should be noted that because of the relatively large water depth compared to the tidal range even the lowest astronomical tide will not have a large influence on the waves because the water depth is hardly affected by the tide. Removing the the tidal motion is also justified since currents do not play a significant role inside the San Vicente Bay area. This is also because the relative large water depth compared to the tidal range and the large entrance width of the bay compared to its length.

H.6.2. Simulation time

Since the tidal motion is removed from the model it is not necessary anymore to have a large simulation time because the model becomes stationary. Therefore the simulation time is reduced from 4 days to 3 hours. The time step remains 1.2 seconds because of numerical stability reasons.

H.6.3. Offshore wave input

The offshore wave input is reduced to 5 scenarios that represent the wave climate in the coastal area of the port of San Vicente best. For elaboration on how the 5 scenarios were determined one is referred to Appendix G.

H.6.4. Wind

The wind influence in both the Delft3D model used for verification and the simplified model is excluded. This is done because previous research already showed that wind hardly has any effect on the wave height and period in the San Vicente Bay area (Gribnau et al., 2018). Because of time constraint the decision is made not to elaborate further on the effects of wind.

	Validation model	Simplified model
Simulation time	4 days	3 hours
Time step	1.2 seconds	1.2 seconds
Offshore wave data	33 scenarios	5 scenarios
Tidal motion	Astronomical forcing	Low water
Wind	Excluded	Excluded

Table H.3: Model used for validation vs simplified model

H.7. Model uncertainties

Modelling of coastal processes comes with uncertainties. Just like with any other model simplifications are made. It is simply not possible to simulate reality without making errors. Apart from the standard limitations of computer models like discretisation issues, there are a few possible errors and uncertainties that may have a significant effect on the results. This section elaborates on these uncertainties and possible errors that play a role in the Delft3D model that is used.

H.7.1. Quay

In Section H.4.2 a description is given on the implementation of the jetty structure and the quay into the Delft3D model. For both structures the assigned transmission and reflection coefficients (defined in the Wave module) are debatable. Implementation of the jetty structure into the Flow module (using porous plates) is less accurately performed when compared to reality. The amount of porous plates in the Flow module is not the same as the amount of rows of piles that are present in the jetty structure. A friction coefficient was assigned to the porous plates. The value of this coefficient is not known on forehand and it is therefore doubtful. According to (Deltares, 2014) the energy loss coefficient of a porous plate should be specified by the user in the corresponding porous plate file. This coefficient is determined according the following equation:

$$c_{loss} = \frac{n \cdot 0.5 \cdot c_d \cdot A_{pile}}{dx \cdot dy} \tag{H.3}$$

In which n is equal to the amount of piles in 1 flow grid element, A_{pile} the area of 1 pile, C_d the drag coefficient and dx/dy represents the grid size dimensions. Using the Autocad model provided by SVTI it is established that n is on average equal to 4. This means that there are 4 piles present in 1 grid element. With a pile radius of 0.6 m the area is equal to 1.13 m^2. The drag coefficient is set to 1.17. Together with the grid dimensions described in Section H.3.1 the energy loss coefficient for the porous plates in the Delft3D model is equal to 0.0264. As mentioned before this value is debatable because it is retrieved in an abstract manner. Further investigation will be needed to determine the correctness of this parameter.

H.7.2. Breakwater and revetment

Both the breakwater and revetment are modelled with a reflection coefficient of 0.3 as described in section H.4.1. Since this is based on empirical data the correctness can be discussed and further investigation is needed.

H.8. Results

The purpose of modelling the port in Delft3D was to investigate whether the significant wave height in the port area would change after land reclamation. If the wave height would significantly increase this would have negative consequences for mooring conditions inside the port, and the proposed land reclamation would not be possible.

I

GEOTECHNICAL ANALYSIS & DESIGN OF HYDRAULIC LANDFILL

First an estimation is made of the amount of sand that will be needed in order to construct the landfill. Since the subsoil should be strong enough to carry the load of the landfill a geotechnical analysis is performed for the area of interest. At the end of this appendix an elaboration is given about the stability of the land reclamation under seismic loading.

I.1. REQUIRED AMOUNT OF SEDIMENT

The land reclamation will be connected to the mainland on the northeastern interface of the port, and to the jetty construction in the southeast. The height of the land reclamation has to coincide with the jetty and the port in order to be accessible for vehicles. From Bardi (2013) it can be found that the height of the jetty is +4.81m relative to MSL. A quick hand calculation has been performed in order to get an idea of the amount of sediment that is required for land reclamation. The required amount of sediment follows from a summation of the following 3 aspects:

1. The required amount of sediment to fill the area
2. The required amount of sediment that has to be removed and replaced
3. The required amount of sediment needed to construct the revetment

An AutoCAD model was provided by SVTI. This model was used to determine the average depth of the land that is to be reclaimed. This is equal to approximately 8.5m. The area of land that is to be reclaimed is equal to approximately 47000 m^2. The total amount of sediment that is required to fill the area now follows from a multiplication and is roughly equal to 400000 m^3.

A substantial part of the soil inside the port needs to be removed because the bearing capacity of the top layer is insufficient (see Section I.4). A rough estimation shows that this is equal to approximately 120000 m^3.

The revetment that will be constructed needs sediment in order to construct the core. For elaboration on the revetment one is referred to Appendix J. A quick estimation shows that the sediment needed for the revetment roughly equals 120000 m^3.

The total amount of sediment that is required for land reclamation now follows from a summation and is found to be approximately 640000 m^3.

I.2. SOIL INVESTIGATION

Several geotechnical surveys have been conducted in the port area as can be seen in Figure I.1.

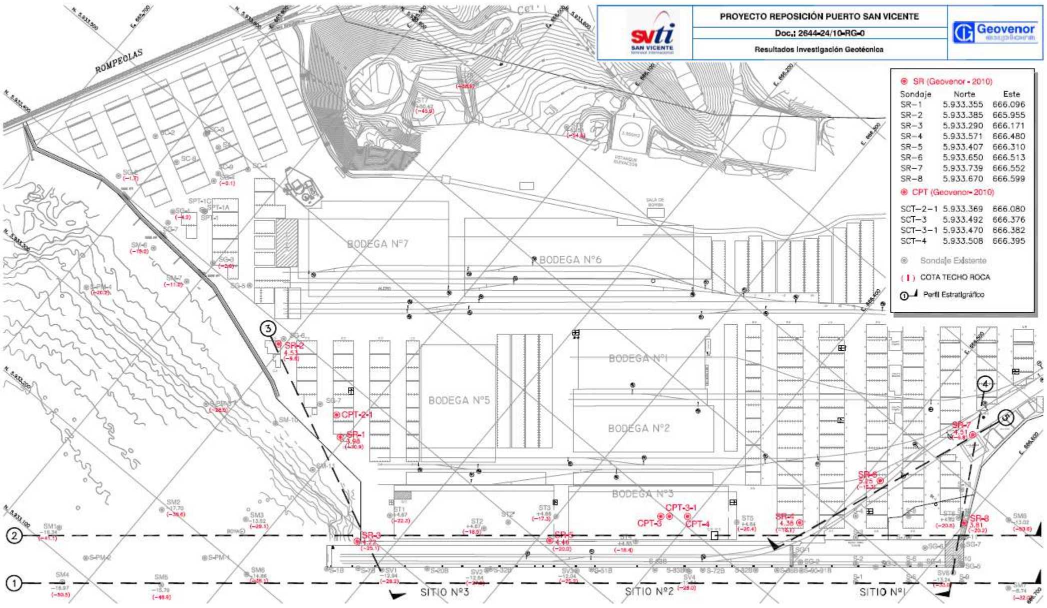


Figure I.1: Overview of San Vicente and locations of geotechnical surveys Geovenor (2010)

Surveys done in the western part, the area around berth 5, are important for this land reclamation study. In Geovenor (2007), marine samples were taken and tested by Geovenor by means of a Standard Penetration Test (SPT) and a uniaxial test on the soil samples. A great downside is that this research stems from 2007, before the construction of the jetty of berth 4 and 5, which makes the data obtained from these surveys not entirely reliable. The dotted line in Figure I.1 represents the jetty structure that nowadays is present in the harbour. A new geotechnical investigation should take place to determine the exact characteristics of the subsoil of the port bathymetry. For this research, the (outdated) data presented in the survey of 2007 Geovenor (2007) will be used to investigate the soil.

A representative survey location for the land reclamation is SM1, which is further elaborated in the sections I.3, I.4, I.4.1 and I.5. This location has a water depth of 18 meters.

I.3. Soil gradings

From Geovenor (2007), the minimal amount of SPT hits to penetrate 15 cm of soil were found in United States Army Corps of Engineers (1992). These values define the soils to be fine to medium sand, silty or clayey medium to coarse sand. This varies throughout the depth profile. The sediment in the port is mainly marine sand and can be characterised as stated in Table I.1. Geovenor (2007) provides data from a sieve test was used to create Figure I.2. This Figure shows that the sediment is relatively fine sand, as sand is defined in a range from 0.06mm to 2mm.

Survey	USCS classification
SM1	SM
SM2	SM
SM3	SM
SM4	SM
SM-6	SM
SM-7	SM

Table I.1: List of important measurements from Geovenor (2010).

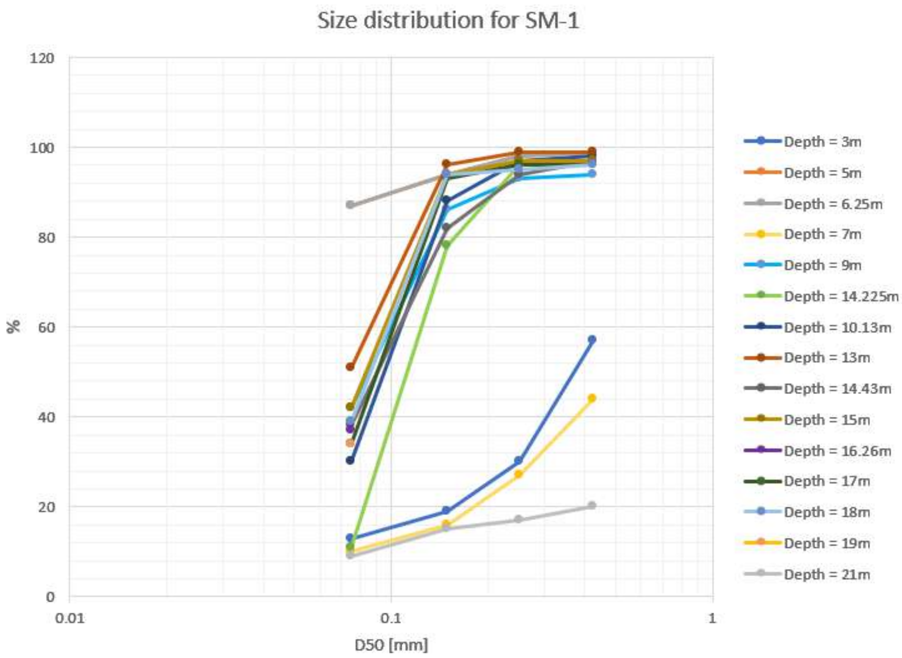


Figure I.2: Soil grading at site SM1, layers from I.3

I.4. Bearing capacity

In the SPT tests that have been conducted the first three meters of the bottom profile are penetrated without any resistance (Geovenor, 2007). From the successive three meters of soil no data was available in terms of bearing capacity. This layer was classified to be ML (silt) and no real bearing capacity can be attributed to this layer because of the small amount of SPT hits needed to penetrate this layer. Therefore it is chosen to remove the first six meters of weak soil. As can be seen in Figure I.3, the subsequent layers have a bearing capacity that is capable of carrying loads. The data on q_u is found in the data set from Geovenor (2007).

Figure I.3: Layering of subsoil layers at survey point SM1

I.4.1. Loading

In order to check which soil layers can carry the desired loading first the design loading needs to be established. This loading consists of the loading by the newly created services of the terminal as well as the necessary material for the landfill. From ASCE (2010), a generic load factor of 11.97 kN/m^2 for a container terminal is used. The load off the landfill is calculated according the formula for self-weight:

$$q_{landfill} = \gamma' \cdot h \tag{I.1}$$

Where γ' is the specific dry weight of the landfill which is equal to 1.65 kN/m^3 for regular sand and h being the height of the landfill (18 meters depth at the deepest point, 6 meters of soil that is disregarded and 4.81 meters above

MSL makes h to be 28.81m). Figure I.4 visualizes the design load and the bearing capacity of the subsoil, by plotting the bearing capacity of the subsoil against the loading of the terminal and the landfill.

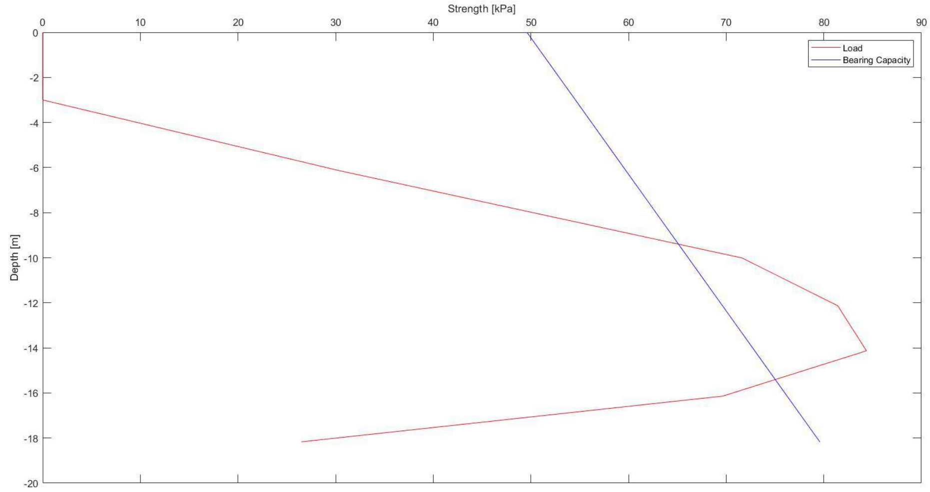


Figure I.4: Bearing capacity of the subsoil in the bay area behind berth 5 at survey location SM1Geovenor (2007)

As is shown in Figure I.4, layer number 2 from Figure I.3 is capable of carrying the load of the terminal and the landfill, as it matches the area the red line crosses the blue line in Figure I.4. This means the resistance is higher than the loading, in other words the soil layer will be strong enough to carry the load. The layers below this layer are not as strong as the layers upon which the land reclamation is constructed, but this loading will be carried by the layers 2-4 as indicated in Figure I.3.

I.5. Allowable residual settlement

After the land reclamation has been carried out, the sediment will undergo a natural primary settlement as the sediment gradually drains of water, reducing pore pressures and thus reducing in volume (Voorendt and Molenaar, 2019). The reducing volume could inflict damage to pavements and structures on top of the land reclamation and is therefore important to calculate. For container terminal areas, a long-term approach is often chosen (20-30 years) with indicative values of 150 to 300mm of settlement (Van 't Hoff and Van der Kolff, 2013).

In order to calculate the settlement the method of Koppejan is applied. This method produces the primary settlement as well as the creep. The relative compression according to Koppejan is given by:

$$\epsilon = \left(\frac{1}{C_p'} + \frac{1}{C_s'} log(t)\right) \cdot ln\left(\frac{\sigma'_{v;i} + \Delta\sigma'_v}{\sigma'_{v;i}}\right) \tag{I.2}$$

With:

$$\sigma'_{v;i} = h \cdot \gamma_s - h \cdot \gamma_w \tag{I.3}$$

with	ϵ	= Relative compression	$[-]$
	H	= Layer thickness	$[m]$
	C_p'	= Primary compression coefficient	$[-]$
	C_s'	= Secondary compression coefficient	$[-]$
	t	= Duration after the application of the additional loading	$[day]$
	$\Delta\sigma'_{v;i}$	= Increase of the vertical effective stress in the weak layer	$[kPa]$
	$\sigma'_{v;i}$	= Initial vertical effective stress from Table I.3	$[kPa]$

$$\sigma'_{v;i} = h \cdot \gamma_s - h \cdot \gamma_w \tag{I.4}$$

Where the specific weights are found in Voorendt and Molenaar (2019).

- γ_w = 18-19 $\frac{kN}{m3}$
- γ_s = 20-21 $\frac{kN}{m3}$

Using these values and $\sigma'_{v;i}$= 45.62 kPa

Variable	Value
H	22.81m
C'_p	200-400 [1]
C'_s	∞ [1]
t	30 years
$\Delta\sigma'_{v;i}$	11.97 kPa ASCE (2010)
$\sigma'_{v;i}$	45.62 kPa from Equation I.3

Table I.2: Values obtained for the Koppejan calculation from Formula I.2, [1]Obtained from Voorendt and Molenaar (2019)

Filling in the above parameters gives a relative compression of $\epsilon = 7.767 * 10^{-4}$. Together with a layer thickness of 28.81m, the settlement will be 0.022m in 30 years. This amount of settlement is assumed to be acceptable.

I.6. Slope stability

Designing a slope incorporates a design procedure that is based on computer modelling Van 't Hoff and Van der Kolff (2013) and is relevant when designing a landfill that is constructed and not protected at the interface between the fill and another medium, like atmosphere conditions or water. In this study, a revetment is placed on the interface to protect the land reclamation from hydrodynamic conditions present. This revetment is investigated in Appendix J, where stability of the slope including revetment is studied. Therefore a study on slope stability is not conducted in this Appendix.

I.7. Seismic design

The coast of Chile is situated on top of a deep subduction zone, where the Nazca plate and the South American plate are converging at a rate of 80 mm per year (Guinnessey, 2010). This means the seismic activity is very frequent, with large seismic events happening in the recent past (in 2010 a earthquake of 8.8 on Richter scale struck the San Vicente coastline). Hence, it is paramount to investigate stability of the land reclamation under seismic loading. An earthquake influences a land reclamation by inducing lateral stresses on soil layers. As a result the pore pressures could increase which eventually could lead to soil movements (Van 't Hoff and Van der Kolff, 2013) like:

- Slope movements: downslope displacements of soils
- Lateral spreads: near level ground is extended laterally
- Settlements of soil

The process of an excessive increase of pore pressures leading to failure is called liquefaction. This happens when the pore pressure is larger than the total pressure of the soil, reducing the effective stress and therefore reducing the ability of the soil to carry load.

According to the EC8-5 (EC-8), a factor of safety against liquefaction of $FS_L > 1.25 - 1.5$ is recommended (Van 't Hoff and Van der Kolff, 2013). The ratio $FS_L = \frac{CRR}{CSR}$ is the cyclic resistance ratio over cyclic stress ratio. This ratio will be used in verifying whether the constructed land reclamation is sufficiently capable of resisting seismic loading, by calculating the maximum allowed effective stress through the cyclic stress ratio.

I.7.1. Cyclic stress ratio

The CSR represents the stresses imposed on the ground by the earthquake, and is calculated using Equation I.5:

$$CSR = 0.65 \cdot \frac{a_{max}}{g} \cdot \frac{\sigma_v}{\overline{\sigma_v}} \cdot r_d \tag{I.5}$$

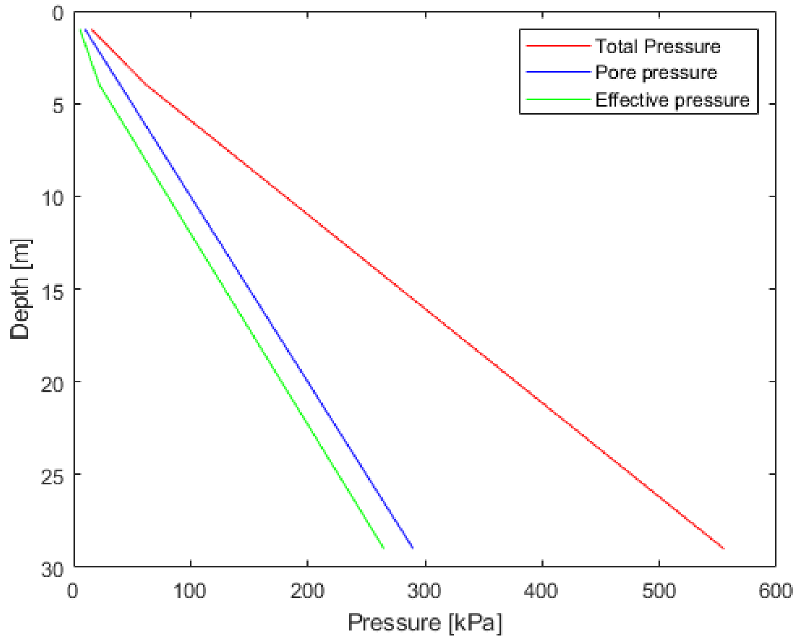


Figure I.5: Development of stresses in the subsoil at survey location SM1 Geovenor (2007)

with	a_{max}	= Peak ground acceleration, following Instituto Nacional de Normalizacion - INN	$[m/s^2]$
	σ_v	= Total overburden stress provided in Figure I.5, without hydrostatic load	$[kPa]$
	$\overline{\sigma_v}$	= Effective stress	$[kPa]$
	r_d	= Response coefficient	$[-]$

a_{max} is set equal to 0.4g following the Chilean building code Instituto Nacional de Normalizacion - INN for the Concepcíon region. Both the total stress of the soil as well as the effective stress have been laid out in Figure I.5. For the total overburden stress the pressures induced by the hydrostatic pressure is neglected as water does not transmit shear stresses Rauch. This gives σ_v=452 kPa. The response coefficient is usually determined using a site assessment (Van 't Hoff and Van der Kolff, 2013) which will not be conducted in this study. This factor has also given cause to discussion about its biases and uncertainties, as it is a simplified method, which is not necessarily conservative (Van 't Hoff and Van der Kolff, 2013). From Figure I.6 it can be seen that for large earthquakes and r_d ranging between 0.76 and 1, a wide range of depths can be found.

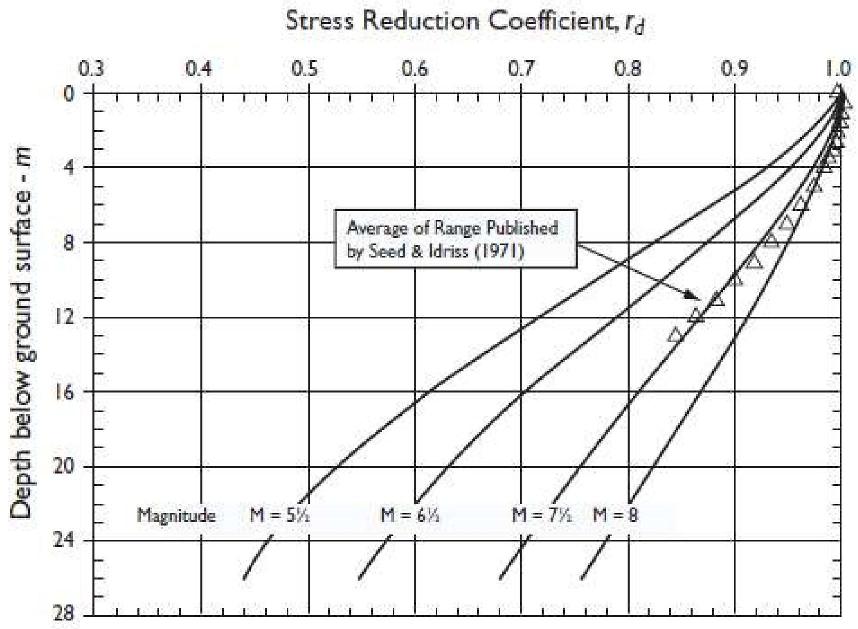


Figure I.6: Response coefficient versus depth by Idriss (1999)

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The cyclic stress ratio is dependent on the effective stress in the soil layer and will serve as a verification for seismic design of the land reclamation.

I.7.2. Cyclic resistance ratio

The cyclic resistance ratio is the equivalent available strength of the ground. It is estimated by checking if the landfill is sufficiently strong to make a calculation of a CRR meaningful, and the strength for assessing the vulnerability of the works to cyclically induced softening. Both are usually done by laboratory testing of undisturbed samples, or the method by the National Center for Earthquake Engineering Research (NCEER) Rauch is used. In this study no laboratory tests are conducted. These are advised to carry out in further research on geotechnical stability under seismic conditions. From Rauch the following relation for the base curve of the method by NCEER is found:

$$100 \cdot CRR_{M=7.5} = \frac{95}{34-(N_1)_{60}} + \frac{(N_1)_{60}}{1.3} - \frac{1}{2} \tag{I.6}$$

Where $CRR_{M=7.5}$ is the cyclic resistance ratio for an earthquake of 7.5 on the scale of Richter, $(N_1)_{60}$ is the clean-sand equivalent part of the correction factor $\Delta(N_1)_{60}$ using the following relation from Rauch:

$$(N_1)_{60} = N_{SPT} \cdot C_N \cdot C_E \cdot C_B \cdot C_S \cdot C_R \tag{I.7}$$

with:

$$C_N = \sqrt{\frac{P_a}{\sigma'_{v0}}} \leq 2.0 = 0.62 \tag{I.8}$$

Where P_a is the atmospheric pressure (101.125 kPa) and σ'_{v0} from Figure I.5 is the effective stress of the soil.

The following parameters are found in Rauch

- C_E = 1 for a rope and pulley system
- C_B = 1 for a borehole of 65 to 115mm
- C_S = 1 for a standard sampler
- C_R = 1 for depths larger than 9 meter deep

For this situation, the layer of soil with the lowest bearing capacity is used, the layer from -6m to -8m beneath the sea bottom, where the bearing resistance is very little and liquefaction is more likely to occur than

in lower lying layers. Using this data and N_{SPT} from Geovenor (2007), the calculation of the CRR can be performed:
$(N_1)_{60} = 42 \cdot 0.62 \cdot 1 \cdot 1 \cdot 1 \cdot 1 = 26.04$

The clean-sand equivalent is subsequently found by the following relation from Rauch:

$$(N_1)_{60} = (N_1)_{60} + \Delta(N_1)_{60} \tag{I.9}$$

where $\Delta(N_1)_{60}$ is a correction factor, which is found at 2.33 for 15% of fines content (percent finer than 0.075mm Figure I.2 This gives $(N_1)_{60}$= 28.37. Now Equation I.6 can be used to find $CRR_{M=7.5}$= 0.3819. This can be corrected to an earthquake that is used for design criteria in the region. From Instituto Nacional de Normalizacion - INN, it can be found that for the Concepcíon region, the design criteria is a peak ground acceleration of a=0.4g. This is translated to a Local Magnitude earthquake between 7 and 8. This means the $CRR_{M=7.5}$ suffices as a design criterium for the cyclic resistance ratio.

I.7.3. Design effective soil stress

Using the aforementioned factor of safety and the cyclic resistance ratio, the cyclic stress ratio can be found. This ratio can be used to find the desired effective stress.

$$\frac{CRR}{CSR} = 1.25 \tag{I.10}$$

$$\frac{CRR}{CSR} = \frac{0.2198}{0.65 \cdot \frac{a_{max}}{g} \cdot \frac{\sigma_v}{\bar{\sigma}_v} \cdot r_d} = 1.25 \tag{I.11}$$

The parameters for CSR are presented in Section I.5, and can be used in Equation I.11. This gives a desired effective stress at a depth of 29 meters of 292.3 kPa to meet the set factor of safety. According to Figure I.5, the effective stress at 29m is currently approximately 305 kPa, which makes the current layout abide the earthquake factor of safety. It is however closer to the lower boundary of 1.25 for FS_L than to the upper boundary of 1.5, so deep soil compaction techniques could be used to increase the effective stress of the soil.

J

Revetment

This Appendix focuses on the design of the revetment for the reclaimed land. The revetment should be able to withstand all forces exerted by the waves. Parameters obtained from Appendix G will be used to design the revetment. Afterwards, a comparison will be made with the current revetment in order to find out whether rocks from the current revetment can be reused. Lastly, a technical drawing of the revetment will be provided.

J.1. Wave Analysis

Offshore wind data was analysed using a peak-over-threshold method. That resulted in 8 storm events. An extreme value distribution was applied to the retrieved data and finally a storm event with an offshore wave height of 8.5m was chosen. This corresponds to a storm event with a return period of 100 years. The corresponding wave period is equal to 17.2s. The data was used as input in the Delft3D model to investigate what the wave height would be inside the harbour during such a storm event. Results are listed below. An extensive elaboration on the wave data can be found in Appendix G. Section G.1 elaborates on the wave analysis used for the design of the revetment.

- $H_s = 0.8$m
- $T_m = 17.2$s

J.2. Armour Layer

In order to determine what type of armour layer is needed, one must first investigate the possible alternatives. The first and most applied form of armour layer is natural rock armour. Other options include concrete armour units such as cubes, tetrapods and doloses (Van der Meer, 1998). A different approach is the implementation of soft measures, like a beach. However, such measures are unsuitable because of the erosive wave climate and the fact that a depth profile within the port must be maintained. The availability of concrete units is low in Chile. Moreover, they are also more expensive, which makes those options even less attractive (Granco et al., 2007). Natural rock armour has been used before inside the harbour basin and it is relative easy to require. It is therefore favorable to design the revetment with a natural rock armour layer. After a calculation has been performed on the required rocks for the armour layer, a comparison will be made with the rocks that currently form the revetment. It would be convenient if some rocks can be reused.

The port of San Vicente has a small tidal range and a relatively deep basin. Flow currents inside the port are therefore relatively small which is also stated in Section 2.2.2. For the design of the revetment inside the port the currents can be assumed to be negligible when compared to the forces exerted by waves. In order to evaluate what type of natural rock must be applied, one needs to find out which nominal median block diameter (D_{n50}) is needed. Various equations are supplied to evaluate on this matter (Iribarren Cavanilles, 1965; Hudson, 1959; Van der Meer, 1988a). For the Iribarren formula a lot of assumptions need to be made and certain parameters (μ and N) include various influences such as the effect of the shape of blocks. It is also a function of the damage level. Suggestions for these parameters are given by (Iribarren Cavanilles, 1965). Nonetheless, a lot of physical processes are included in these parameters which makes it very hard to determine realistic values for these parameters. The Hudson formula is not often used anymore for rocks. Tests that were performed in order to determine the Hudson formula included a limited range of structure types, slope angles and wave conditions (Van den Bos and Verhagen, 2018). Other effects such as wave periods and the permeability of the core are also not included. In

Van der Meer (1988a) and Van der Meer (1988b) a set of equations was derived that overcome the limitations of the Hudson formula and are more generally applicable for rock armour stability. These equations are listed below.

For plunging waves:

$$\frac{H_s}{\Delta \cdot D_{n50}} = c_{pl} \cdot P^{0.18} \cdot \left(\frac{S}{\sqrt{N}}\right)^{0.2} \cdot \xi_m^{-0.5} \qquad if \quad \xi_m \leq \xi_{tr} \tag{J.1}$$

For surging waves:

$$\frac{H_s}{\Delta \cdot D_{n50}} = c_s \cdot P^{-0.13} \cdot \left(\frac{S}{\sqrt{N}}\right)^{0.2} \cdot \sqrt{cot(\alpha)} \cdot \xi_m^P \qquad if \quad \xi_m > \xi_{tr} \tag{J.2}$$

with	H_s	= Significant wave height in the (short term) wave distribution	[m]
	Δ	= Relative mass density	[-]
	D_{n50}	= Nominal median block diameter	[m]
	c_{pl}	= Plunging coefficient	[-]
	c_s	= Surging coefficient	[-]
	P	= Notional permeability coefficient	[-]
	S	= Damage level	[-]
	N	= Number of waves	[-]
	α	= Angle of the seaward slope of the structure	[°]
	ξ_m	= Surf similarity parameter	[-]
	ξ_{tr}	= Surf similarity parameter at transmission	[-]

In order to use the van der Meer equations correctly one must first establish whether the waves hitting the revetment can be classified as plunging or as surging waves. Using the equation stated below this matter can be investigated.

$$\xi_{tr} = \left(\frac{c_{pl}}{c_s} \cdot P^{0.31} \cdot \sqrt{tan(\alpha)}\right)^{\frac{1}{P+0.5}} \tag{J.3}$$

The model coefficients for plunging and surging waves have mean values with a standard deviation. The plunging coefficient, c_{pl}, has a mean value of 6.2 and a standard deviation (σ) of 0.4, resulting in $c_{pl} = 6.2 \pm 0.4$. The surging coefficient, c_s, has a mean value of 1.0 and a standard deviation (σ) of 0.08, resulting in $c_s = 1.0 \pm 0.08$ (Van den Bos and Verhagen, 2018). The notional permeability coefficient is given in (Van der Meer, 1998) and is equal to 0.4 for a revetment with an armour and filter layer.

A revetment typically has a slope of 1:1.5 - 1:2. Chile is a country that is known for its seismic activity. The revetment therefore needs to be designed against earthquakes as well. When seismic activity needs to be taken into account, the slopes should generally be more gentle (1:3 to 1:7) in order to allow for the expected horizontal accelerations to be absorbed without damage (The Rock Manual, 2007). An Autocad model was supplied by SVTI. This model shows that the current revetment has a slope of 1:2. In order to take unexpected horizontal displacements of soil into account an angle (α) of 1:3 is assumed for the design, which corresponds to an angle of 18.43°.

With Formula J.3 the surf similarity parameter at the transmission between plunging waves and surging waves is the following.

$$\xi_{tr} = \left(\frac{6.2}{1} \cdot 0.4^{0.31} \cdot \sqrt{tan(18.43°)}\right)^{\frac{1}{0.4+0.5}} = 3.01$$

The surf similarity parameter is determined with Equation J.4.

$$\xi_m = \frac{tan(\alpha)}{\sqrt{s_{0m}}} = \frac{tan(18.43°)}{\sqrt{1.73 \cdot 10^{-3}}} = 8.01 \tag{J.4}$$

In which s_{0m} is the wave steepness, this is referred to as fictitious, as it combines the wave height at the location of the breakwater together with the deep water wave length. The locations of the both parameters are not the same, which therefore will not lead to a physical steepness of a wave. Although this formula calculates something fictitious, it is still often used as the local wave length because this is often not easy to determine.

$$s_{0m} = \frac{H_s}{L_{0m}} = \frac{2 \cdot \pi \cdot H_s}{g \cdot T_m^2} = \frac{2 \cdot \pi \cdot 0.8}{9.81 \cdot 17.2^2} = 1.73 \cdot 10^{-3} \tag{J.5}$$

With ξ_m equal to 5.13 and ξ_{tr} equal to 2.56, it can be verified that we are dealing with surging waves, since the following condition stands; $\xi_{0m} > \xi_{tr}$.

The significant wave height was determined in Section J.1 and is given to be 0.8m. The damage level S is stated to be 2 for a slope of 1:3 and for a situation in which no repair is required Van der Meer (1998). For the number of waves N a normative value of 3000 is taken. The relative mass density is determined by Formula J.6 below:

$$\Delta = \frac{\rho_s - \rho_w}{\rho_w} = \frac{2650 - 1000}{1000} = 1.65 \tag{J.6}$$

With all the variables known, D_{n50} can be calculated with Equation J.2.

$$\frac{0.8}{1.65 \cdot D_{n50}} = 1.0 \cdot 0.4^{-0.13} \cdot \left(\frac{2}{\sqrt{3000}}\right)^{0.2} \cdot \sqrt{\cot(18.43)} \cdot 8.01^{0.4} \quad \Rightarrow \quad D_{n50} = 0.21m$$

The armour layer will be supported by a toe. Elaboration on the toe can be found in Section J.3. The effect of incoming waves is not felt over the whole depth of the armour layer. As a rule of thumb one could say that the influence of the waves can be neglected at 1.0 times the wave height below water level (h_t = 1.0 H_s) (Van den Bos and Verhagen, 2018). Therefore the minimal required depth that the armour layer should reach can be determined by subtracting the incoming wave height from the lowest water level. For the incoming wave height a value of H_s = 0.8m is established. For the tidal elevation a conservative value of in total 2m is taken (Sea Level Station Monitoring Facility (IOC)). At still water level the revetment lies 4.8m above the water. The minimal required vertical height of the armour layer can now be determined by adding the required height above water, the height of the significant wave height and the amplitude of the tidal elevation. The minimal height of the armour layer is therefore equal to 4.8 + 0.8 + 0.5 · 2.0 = 6.6m. However, it is not possible to construct a toe that high without taking into account that the structure will be undermined. Also, since the revetment will be constructed under water it is very difficult to perform checks on whether the revetment was placed correctly. The armour layer should therefore reach much lower. For simplicity it is assumed that the armour layer reaches until the bed level.

Autocad models that were supplied by SVTI show that the current revetment that is used inside the harbour has a double layer of riprap, with a D_{n50} of 1.0m. According to the calculations executed above a D_{n50} larger than 0.21m will suffice. A large part of the old revetment needs to be removed when land is going to be reclaimed. In order to optimise the economical aspect it is therefore advised to reuse the current armour layer. A D_{n50} of 1.0m is therefore used for the design.

J.3. Toe Design

A toe is designed to provide protection against scouring and undermining of the armour layer. Scour due to wave attack mainly occurs when a toe is located near the water level. As elaborated in Section J.2 the armour layer reaches to the bed level. The bed level is located approximately 16 m below still water level. Scour due to wave attack does therefore not occur.

Various options for toe design are given in Chapter 6.3.4.1 of (The Rock Manual, 2007). As was briefly discussed in Appendix I the bed does not consist of rock. Moreover, at least the first 6m of soil needs to be removed because it consists of marine silt that lacks bearing capacity. Thus, an impermeable layer cannot be found close to the bed. The expected scour near the toe is assumed to be negligible, since the toe will be located far beneath still water level. Therefore a toe design displayed in Figure J.1 is assumed to be most applicable.

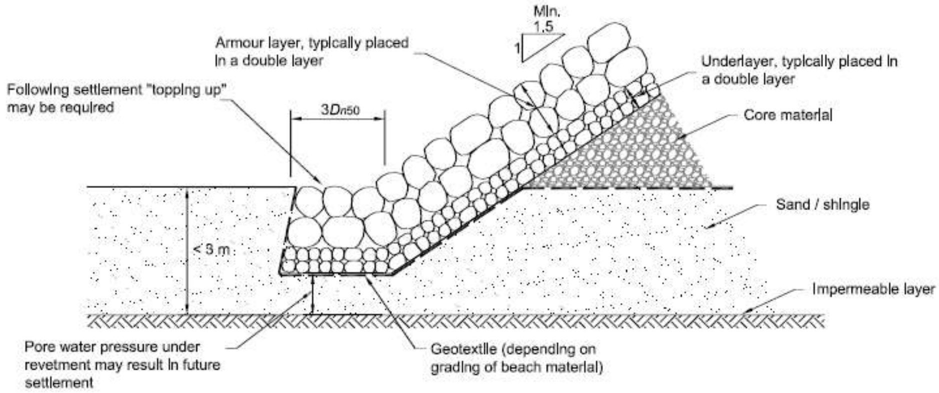


Figure J.1: Toe detail, obtained from The Rock Manual (2007)

J.4. Under layer

Design conditions for the under layer include that the units forming the under layer are not able to pass through the voids of the armour layer. This means that the filter must be geometrically impermeable. Guidelines therefore suggest that the weight ratio of subsequent layers of quarry stone must be kept between 1/10 and 1/25, or D_{n50} ratio between 2 and 3 (Van den Bos and Verhagen, 2018). As will be elaborated in Section J.5 there is the need to apply a geotextile around the core. Placing larger armour stones directly on geotextile likely punctures the geotextile during placement or later during settling (Slinn, 2009). The need for a filter between the core and the armour layer therefore still remains.

Autocad models that were supplied by SVTI show that the current filter layer has a double layer of riprap, with a D_{n50} of 0.5m. According to the theory explained above a D_{n50} between 0.34 and 0.50m will suffice. A large part of the old revetment needs to be removed when land is going to be reclaimed. In order to optimise the economical aspect it is therefore advised to reuse the current filter layer. A D_{n50} of 0.50m is therefore used for the design.

J.5. Core

Design conditions for the core prescribe a weight ratio of 1/10 to 1/25 for subsequent layers (Van den Bos and Verhagen, 2018), just like with the design conditions for the underlayer. This ratio is again prescribed to ensure a geometrically impermeable core. Consultation with (Villagrán, 2019) has given the insight that sediment from the Biobío river is likely to be used for land reclamation. Previous research indicates that D_{n50} values for sediment in the Biobío river vary between 0.85 - 1.0mm (Weller et al., 2012) with a permeability of $1.0 \cdot 10^{-4}$ m/s (De Fockert et al., 2005). The core will therefore not meet the prescribed condition with respect to the weight ratio. Hence, there is the need to apply a geotextile around the core to prevent material loss.

J.6. Geotextile

As was stated in Section J.5, there is the need to apply a geotextile between the filter and the core layer to prevent matrial loss from the core. Geotextile can only be applied on slopes with an angle of 1:2.5 or less slanting (The Rock Manual, 2007). The current design has a slope of 1:3, therefore geotextile is applicable. Other advantages of using geotextile include the limitation of material loss at the toe, and the decrease in differential settlement due to its sheet like qualities. When placing geotextile it is most important to not place the geotextile on a highly permeable core. During high currents and wave attack pressure differences can cause uplift on the geotextile resulting in tearing or displacement of the geotextile (The Rock Manual, 2007). The core that will be used is not highly permeable, geotextile is therefore applicable.

The are two different types of geotextiles; woven and non-woven. The non-woven geotextiles are manufactured by bonding materials together and it provides a planar water flow in addition to stabilization of soil. The woven geotextiles consist of interlocking fabric strips together on a large uniform piece. The woven pieces have a higher load capacity, which is why they are preferred for applications where high strength properties are required (Ashis, 2015). As for the designed revetment, the main purpose of the geotextile is to keep the soil in place. Therefore it is recommended to use the cheaper non-woven geotextile type.

The permeability of the geotextile has to be great enough to prevent the development of excessive pore pressures. According to Chapter 5 of the book by Allsop (2005), the permeability of the geotextile must be at least 10 times that of the permeability of the fill material it is filtering. With the permeability of the sand for the landfill being $1.0 \cdot 10^{-4}$ m/s, the permeability for the geotextile will be at least $1.0 \cdot 10^{-3}$ m/s.

According to the datasheet's of all types of HPS (High Performance Square) non-woven geotextile available at the company Geofabrics (Geofabric), which is a big manufacturer for geotextile, all types have a sufficient permeability ($>1.7 \cdot 10^{-3}$ m/s), as can be seen in the Figure J.2.

	Test	Unit	MEAN VALUES																		
4. MECHANICAL PROPERTIES			HPS2.5	HPS3	HPS3.3	HPS4	HPS5	HPS6	HPS7	HPS8	HPS9	HPS11	HPS12	HPS14	HPS17	HPS19	HPS22	HPS25	HPS30	HPS35	HPS40
Static puncture (CBR)	EN ISO 12236	kN	2.5	3	3.3	4	5	6	7	8	9	11	12	14	17	19	22	25	30	35	40
Push through displacement		mm	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65
Tensile strength (MD/CMD)	EN ISO 10319	kN/m	15	20	22	25	30	35	40	45	50	60	65	75	90	100	115	130	160	180	210
Tensile elongation (MD/CMD)		%	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
Cone drop	EN ISO 13433	mm	10	6	13	5	5	4	3	2	2	1	1	0	0	0	0	0	0	0	0
Protection efficiency (10^3)	EN ISO 13719	kN/m²	-	-	-	-	14	20	25	30	33	39	42	48	56	60	90	100	139	175	210
5. FILTER PROPERTIES																					
Apparent opening size	EN ISO 12956	µm	150	130	60	100	80	80	80	70	70	<69	<69	<69	<69	<69	<69	<69	<69	<69	<69
Water permeability v_{H50}	EN ISO 11058	l/(m²·s)	100	85	85	75	65	55	50	45	40	35	30	30	15	10	9	8	8	5	5
Coefficient of permeability		m/s 10^{-3}	7.0	6.6	6.6	6.6	6.4	5.7	5.5	5.2	4.8	4.7	4.2	3.9	2.6	1.9	1.9	2.2	2.4	1.7	1.7
6. PHYSICAL PROPERTIES																					
Thickness @ 2kPa (nominal)	EN ISO 9863-1	mm	3.5	3.9	3.0	4.4	4.9	5.2	5.5	5.8	6.0	6.7	7.0	7.8	8.8	9.5	10.5	14.0	15.0	16.5	17.0

Figure J.2: Overview of available geotextiles at Geofabric, obtained from Geofabric

J.7. Cross section

All elements of the revetment have been designed. A cross section is given in Figure J.3 below.

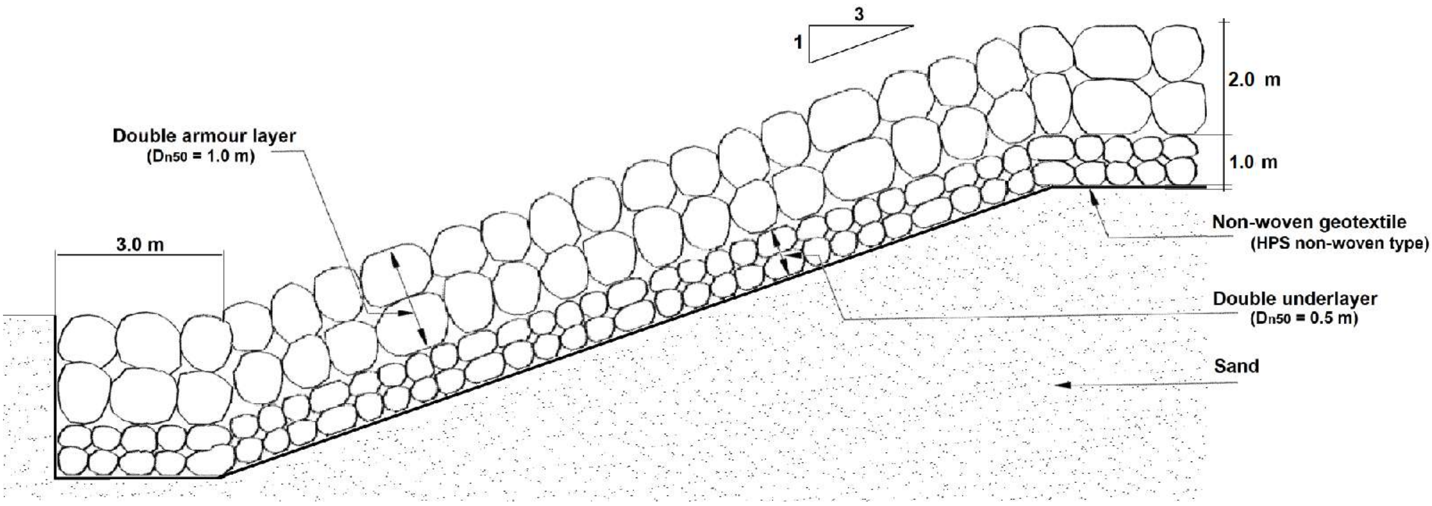


Figure J.3: Overview of the designed revetment at the land reclamation

J.8. Overtopping

The maximum overtopping rate can be determined with the following formula (Jonkman et al., 2018)

$$\frac{q}{\sqrt{g \cdot H_{m0}^3}} = 0.09 \cdot exp\left(-\left(1.5 \cdot \frac{R_c}{H_{m0} \cdot \gamma_f \cdot \gamma_\beta}\right)^{1.3}\right) \tag{J.7}$$

with			
	q	= Maximum overtopping rate	$[\frac{m^3}{s \cdot m}]$
	H_{m0}	= Wave height	$[m]$
	R_c	= Freeboard, defined as the difference between the crest level and the still water level	$[m]$
	γ_f	= Reduction due to friction caused by roughness of the slope	[-]
	γ_β	= Reduction due to oblique waves	[-]

The above stated equation is based on a theoretical basis for the shape of the formula. According to Van Der Meer and Bruce (2014) the reliability of the coefficients values varies as can be seen in Table J.1.

	Equation J.8	
general shape $\frac{q}{\sqrt{g \cdot H_{m0}^3}} = \mathbf{A} exp\left(-\left(\mathbf{B} \cdot \frac{R_c}{H_{m0} \cdot \gamma_f \cdot \gamma_\beta}\right)^{1.3}\right)$	**A**	**B**
Mean value	0.09	1.5
Standard deviation	0.013	0.15
Characteristic value	0.103	1.35

Table J.1: Coefficient values for Equation J.8

For design purposes it is recommended to use the characteristic values for Equation J.8. Meaning the overtopping formula used will be as follows:

$$\frac{q}{\sqrt{g \cdot H_{m0}^3}} = 0.103 \cdot exp\left(-\left(1.35 \cdot \frac{R_c}{H_{m0} \cdot \gamma_f \cdot \gamma_\beta}\right)^{1.3}\right) \tag{J.8}$$

The friction reduction caused by the slope, γ_β, is equal to 0.55 for a double layer of riprap (Jonkman et al., 2018). The reduction factor due to obliques waves, γ_β, is assumed to be oblique and therefore has a value of 1. With all the variables known for Equation J.8, the overtopping can be calculated as follows:

$$\frac{q}{\sqrt{9.81 \cdot 0.8^3}} = 0.103 \cdot exp\left(-\left(1.35 \cdot \frac{4.8}{0.8 \cdot 0.55 \cdot 1}\right)^{1.3}\right) \quad \Rightarrow \quad q = 1.07 \cdot 10^{-15} \frac{l}{s \cdot m} \quad = \quad 1.07 \cdot 10^{-12} \frac{m^3}{s \cdot m}$$

As can be seen in the calculation performed above, there will be no overtopping of the revetment.

K

JETTY CONNECTION

In this Appendix the connection between the existing port infrastructure and the newly designed land reclamation will be investigated. A connection structure is proposed by means of a preliminary design.

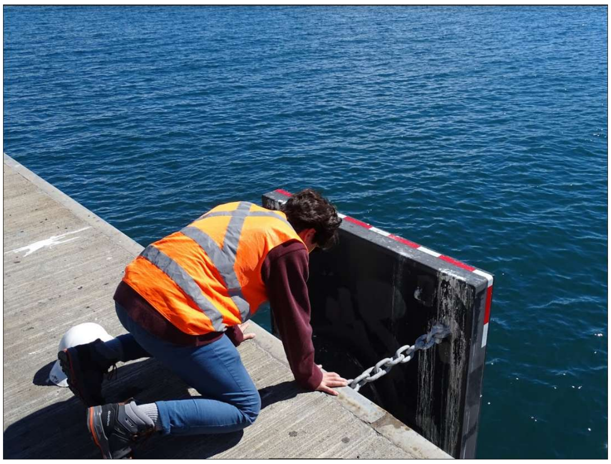


Figure K.1: Location of the proposed jetty connection at berth 5

K.1. PROBLEM DEFINITION

The area that is selected for land reclamation is situated behind the jetty that harbours berth 4 and 5. The reclamation has been placed directly behind the jetty, in order to increase handling capacity in the future (see Appendix F). In order to facilitate this connection, a solution must be found for connecting the land reclamation to the jetty infrastructure.

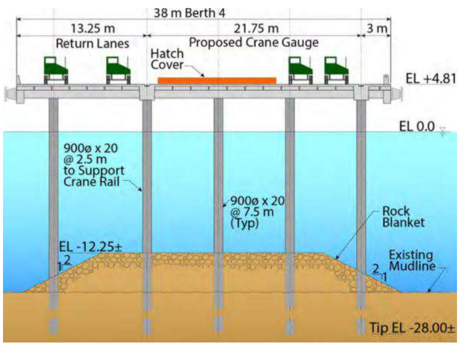


Figure K.2: Cross-section jetty structure berth 4 (right) and 5 (left)

The jetty construction is flexible because of its open-piled structure. It is also open for waves and currents and therefore also for sediment transport. This means the land reclamation needs to be carefully designed, as during land reclamation, sand could flow between the piles towards berth4, impairing the water depth for vessels. This will reduce the maximum draught, which is undesired. A new design should counteract this phenomena. This appendix will elaborate on evaluating engineering strategies for solving these problems. The stability of a preliminary design will be analysed, internal forces and deflection will be tested by means of a structural analysis through the simulation program MatrixFrame. This software is suitable for structural calculations that have to meet building norms MatrixFrame (2019).

K.2. Solution strategies for retaining sediment

To prevent the flow of sediment into the waters of berth 4, several solution strategies can be conceived. This section will discuss possible solution strategies. An obvious choice is to place a structure between the landfill in front of the jetty. This will prevent sand from flowing into the berthing area. An example of such a structure could be a retaining wall. However there are more solutions that can be thought of. A few possible solutions will be given.

K.2.1. Gravity walls

A gravity wall is the most basic example of a strengthened wall that uses its sheer mass to carry loads from the soil. Essential are the stability and stress analyses to check whether the gravitational force can compensate lateral earth pressures and surcharge loads. These structures are generally quite expansive as they rely fully on their own mass to resists lateral loads.

Caisson wall

A pre-fabricated caisson can be floated into place. In this way a retaining wall can be constructed relatively quickly, simply by sinking a concrete caisson on top of a layer of soil capable of bearing the caisson. This will form a type of gravity wall. The caisson will then stop sediments from flowing from the bay area into the berth area. Settlements are dangerous to caisson structures. The soil beneath the caisson structure therefore will have to be compacted thoroughly to prevent uneven settlements. Uneven settlements can be detrimental to the structural integrity.

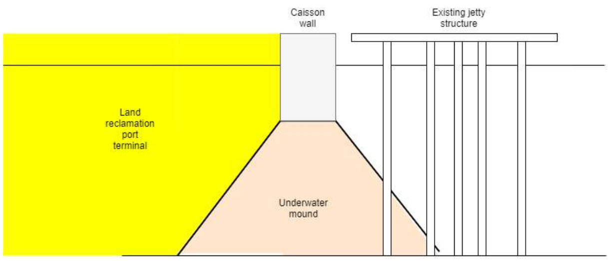


Figure K.3: Schematic cross-section of a retaining wall constructed with a caisson

Underwater mound

An underwater mound can be constructed using various rock sizes. Filter principles will be used to prevent winnowing of sediment to the berthing side. A separate study should be conducted for the side facing the jetty structure in order to establish rock sizes for this revetment. This is because the revetment will be under constant wave attack and high currents due to the mooring of ships on berth 4. This type of structure would require a large amount of relatively large sized rocks. These will be expensive to move and prove to be difficult to find in the region. For this reason, the underwater mound is deemed to be less suitable for solving the retaining problem.

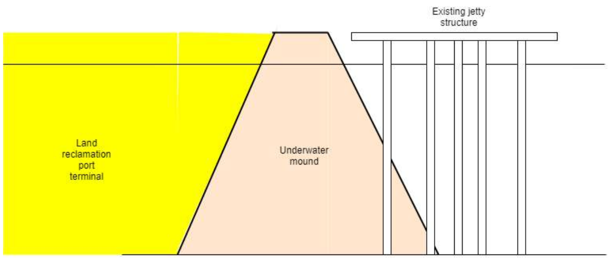


Figure K.4: Schematic cross-section of a retaining wall constructed with an underwater mound

GEOTUBES
An underwater mound constructed from geotubes filled with sediment could be considered. This can be a cheap solution, but little is known about the ability of geotubes to act as a permanent submarine support structure. After consultation with TenCate geosynthetics, it became known that the tubes could be produced up to 5 meter in diameter. This makes these tubes particularly interesting as fill material for an underwater mound. The tubes are however not suitable for bearing foundations Zengerink (2019).

K.2.2. CANTILEVER WALLS
A cantilever wall consists of a vertical stem, that is designed to withstand the lateral pressures of the soil that it has to retain. This is combined with a base block that is loaded with the soil. This works to counter the lateral pressures on the vertical stem.

UNDERWATER WALL
An underwater wall could provide a separation between the two areas. A sand mound has to be created on the soil layer that has been identified in Appendix I. On top of this mound, a T-shaped concrete wall is constructed. This option uses the weight of the landfill to stabilise the concrete construction by using a cantilever construction.

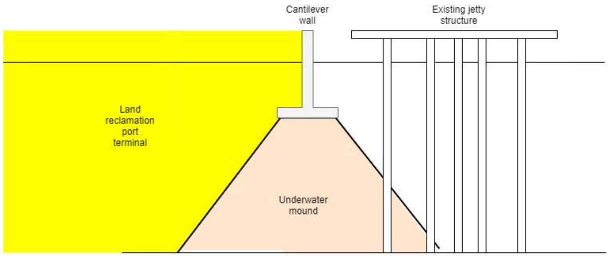


Figure K.5: A submarine T-wall constructed on top of an underwater ground

EXTENDING THE JETTY
Another solution for solving the problem is to make sure the soil from the landfill does not need to be retained. This can be done by increasing the distance from the landfill to the berth. The jetty could be extended northwards. This might solve the problem of retaining sand. However, the jetty structure would have to be connected to the existing jetty structure. With both structures being somewhat flexible during lateral loading, this could give rise to problems. The connecting element between the jetties as well as the connecting element between the jetty and the reclaimed land might form a problem.

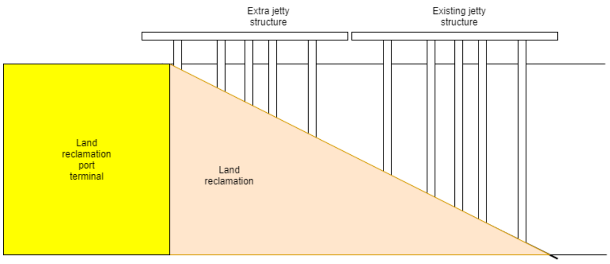


Figure K.6:
Construction of an extra jetty next to the existing jetty structure will give the land reclamation the needed space to develop a natural slope.

K.3. EVALUATION
In this section, the various solution strategies will be ranked according to various criteria. Two requirements are critical for success in this design, the ability of the structure to retain sediment and the ability to connect to the existing jetty.

K.3.1. CRITERIA
In this subsection the criteria will be explained and a qualitative description of each solution strategy is formulated.

Costs
An estimation of the total costs of the project are considered in these criteria. The costs will be made in one go, so no distinction will be made between CapEx or initial CapEx.

- Caisson wall: Simple solution, but expensive on placement.
- Cantilever wall: Efficient design lowers costs in materials, construction can be done near site.
- Underwater mound: A lot of material necessary, rocks are expensive.
- Jetty extension: Constructing a new jetty will have high costs.

Hydrodynamic effects
The connecting side to the jetty will be subjected to incoming waves. It is important to consider the detrimental effect of the jetty connection interface to the conditions of mooring.

- Caisson wall: Straight wall has a lot of reflection.
- Cantilever wall: Large slope which dampens waves, but also a straight wall section.
- Underwater mound: A full slope, though steeper than a sandy beach and covered in armour.
- Jetty extension: By extending the jetty, the entire land reclamation can extend itself in the shape of a sandy beach beneath the jetty structures, this dampens the waves.

Availability of materials
Availability of materials, for example the presence of large rocks or caissons in the vicinity of the San Vicente port.

- Caisson wall: No dry docks available in the San Vicente bay for caisson construction.
- Cantilever wall: Basic materials needed.
- Underwater mound: Large quarry rocks required.
- Jetty extension: Has already been constructed, but large variety of materials necessary and equipment needed.

Construction Convenience
This criterium evaluates how easy the construction method is, taking into consideration expected construction time and the difficulty of placement.

- Caisson wall: Easy to construct unit, standardised units can be used.
- Cantilever wall: Concrete casting site might prove difficult to find, otherwise easy and known construction method.
- Underwater mound: Difficulty in constructing next to the operational jetty, placement of rock elements beneath jetty particularly hard.
- Jetty extension: Will severely impair port operations at berth 4.

Type	Cost	Hydrodynamics	Availability of material	Construction convenience	Total
Caisson wall	–	-	–	++	—
Cantilever wall	+	+ / -	+	+/-	++
Underwater mound	-	+	–	-	—
Jetty extension	–	++	+/-	–	—

Table K.1: Evaluation construction strategies

Table K.1 stated above shows that the cantilever wall comes out as the best solution to retain the landfill. Therefore this option will be studied and designed later on in this Appendix.

K.4. Design of cantilever wall
This section will cover the design of the cantilever wall as proposed in the previous section. The cantilever wall will be placed on an earthen submarine mound. This is schematically shown in Figure K.5.
Appendix I shows the soil layer that is suitable to build on. On this layer, the soil mound will be constructed. Figure K.2 shows a small mound beneath the jetty, at -12.25m. In order to retain the sediment from the landfill, a flow over the mound must be prevented. It also provides a good base to situate the submarine mound on, as

the mound that is in place is constructed of rock. This will significantly contribute to slope stability of the submarine mound as it provides a counterweight to failure along a sliding circle. Sand is much cheaper than the construction of a cantilever wall. However a retaining structure completely fabricated from sediment, as described in Section K.2.1, would cause sediment flow into the berth. Since the sediment is also subject to bow thrusters from the vessels, scour pits along the slope could occur. This would threaten the stability of the entire jetty connection.

In Appendix J, a slope of 1:3 is found to be suitable for slope design in areas with seismic activity. This gives a parameter for the design height of the underwater mound. To take the scour effect of the bow thrusters into account, the average distance between the bow thruster propeller and the slope has to be found. This is found by taking half the beam size of a Panamax class vessel and the distance of the slope beneath the jetty, that is governed by the height of the underwater mound and the proposed slope. An investigation into the effects of scour by the bow thrusters is not conducted in this study. Therefore it is recommended to check whether the distance between the slope at thruster height is situated far enough from the thruster it self to prevent entrainment of sediment, and possibly the requirement for a type of revetment. The distance will now be set at halfway the jetty, 19 meter from the edge of the quay wall. Taking into account the half beam length of a Panamax class vessel (approximately 16 meters) Maritime Connector (2019), the distance between the slope and the thruster is 34 meters. The height of the underwater mound is found through the slope and the horizontal distance from the start of the slope until the point where the land reclamation will connect with the jetty. This point is 0.3m away from the jetty structure.

The wall has to bridge the remaining height of 10,4m, which will be loaded by the land fill on one side and sea water on the other side. It will also have to bear the loads from the connecting slab between the land reclamation and the jetty structure.

Figure K.7 shows the dimensions of the concrete slab. As a preliminary design, slab thickness of the horizontal slab and vertical slab is set at 1m, the horizontal slab length is 10m long. These dimensions will be tested for stability in the next section.

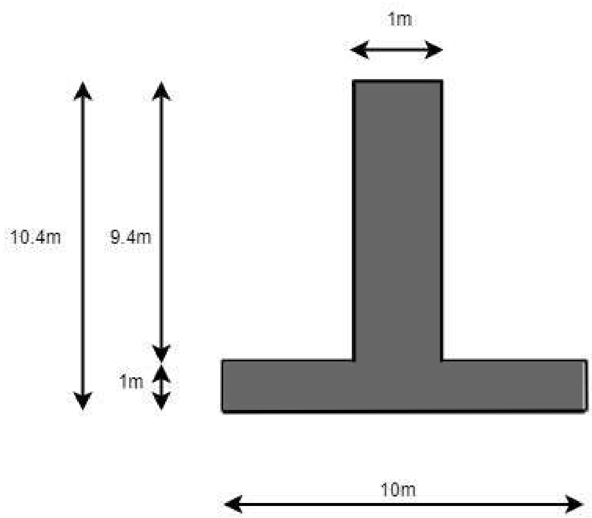


Figure K.7: Loading situation cantilever wall

K.5. Stability

K.5.1. Vertical forces

Bearing capacity

The cantilever wall is founded on a submarine mound. The bearing capacity is therefore calculated for undrained conditions with the following equation:

$$p'_{max,undrained} = c_n \cdot N_c \cdot s_c \cdot i_c + \sigma'_q \tag{K.1}$$

The soil will be made out of sand. Therefore no cohesion will be present, dropping out the first term. The term σ'_q is found by looking at the surcharge on the soil layer Voorendt and Molenaar (2019). As no soil is excavated upon which the wall is build, this only consists of the hydrostatic pressure and the weight of the soil at the landfill side. This is calculated as follows: the depth of the under water mound is multiplied by the specific weight of water and the height of the landfill from the toe of the structure to the top of the landfill is multiplied by the specific weight of the soil. This gives:

$$\sigma'_q = h \cdot \gamma_w + = 5.4 \cdot 10 = 54 kPa \tag{K.2}$$

Water & Soil pressures

The water column on top of the right side of the cantilever wall is calculated as follows:

$$\sigma_{water} = h * \gamma_w = 4.4 * 10 = 44 kPa \tag{K.3}$$

The pressure exerted on the cantilever wall is calculated as follows:

$$\sigma_{soil} = h_{landfill,submarine} \cdot \gamma_{wet} + h_{landfill,dry} \cdot \gamma_{dry} = 4.4 \cdot 19.7 + 4.81 \cdot 15.6 = 161.72 kPa \tag{K.4}$$

K.5.2. Horizontal forces

Active soil pressure

On the bay side of the structure, a landfill will be placed. This landfill is discussed in Appendix I. The landfill gives a lateral stress on the retaining structure.

$$\sigma'_h = K \cdot \sigma'_v \tag{K.5}$$

K is the soil pressure coefficient, that can be either active or passive. This depends on the type of lateral pressure. Active soil pressure is defined as the process where the soil pushes the structure. Passive soil pressure is the pressure where the structure pushes the soil. In the present case, active soil pressure is exerted onto the structure. The coefficient K_a is defined as follows:

$$K_a = \frac{1 - sin(\phi'}{1 + sin(\phi'} \tag{K.6}$$

For the angle of internal friction a standard value for sand of 30 degrees is used, K_a is found to be $\frac{1}{3}$. From Appendix I, the height and the specific weights of the land fill can be used to determine the vertical effective stress: $\sigma'_v = 547.98 kPa$. This is converted using Equation K.5 to σ'_h - 182.66 kPa.

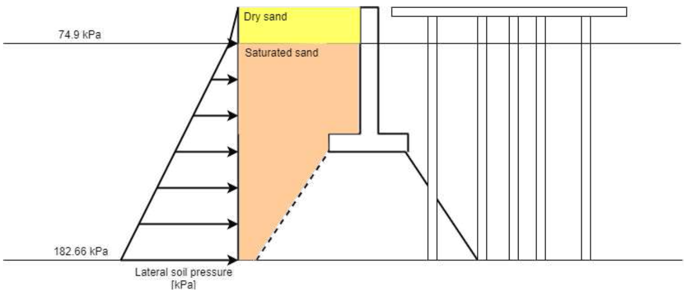


Figure K.8: Lateral soil pressure on a retaining soil

Hydrostatic forces

Hydrostatic forces are calculated the same way as done for the horizontal and vertical forces:

$$\sigma_{water} = h * \gamma_w = 5.4 * 10 = 54 kPa \tag{K.7}$$

Table K.2 shows the result of the hydrostatic pressure calculations.

Plane	Loading	Pressure [kPa]	Value [kN]	Arm [m]	Moment [kN*m]
Horizontal					
	Lateral soil pressure F1		180.1	7.2	-1296.7
	Lateral soil pressure F2		419.4	2.8	-419.4
	Lateral soil pressure F3		152.3	1.9	-289.4
	Total lateral soil pressure	129.3	751.8		
	Hydrostatic pressure	-54	-118.8	1.8	213.8
	Total	75.3	633		-1791.7
Vertical					
	Connecting slab		500	0.5	-250
	Soil self weight	161.7	727.65	2.75	2001
	Self weight wall	45.7	456.7	0	0
	Self weight water	44	198	2.75	544.5
	Soil pressure	-54	-540	0	0
	Total		1342.35		2295.5

Table K.2: Forces on the cantilever wall,

K.5.3. Horizontal stability

In order to check horizontal stability a test for sliding of the structure is performed. This can be done with the following equation:

$$\Sigma H \leq f \cdot \Sigma V \tag{K.8}$$

$$\Sigma H - f \cdot \Sigma V = -633 + 671.18 = 38.2 kN \tag{K.9}$$

The sum of horizontal forces needs to be less than the friction induced by the vertical forces. For the friction factor f a value of 0.5 is used (From Voorendt and Molenaar (2019) for clean fine to medium sand), and the values for the forces from Table K.2, shows that the friction is 38 kN larger than the lateral forces by the soil. This is not much, so a second design iteration is advised where the vertical slab could be moved to the right a little, increasing the self-weight of the soil on the horizontal slab, which will lead to a higher friction value to ensure safety.

K.5.4. Vertical stability

Vertical stability is reached for the following criterion:

$$\sigma_{k,max} \leq p'_{max} \tag{K.10}$$

With $\sigma_{k,max}$:

$$\sigma_{k,max} = \frac{\Sigma V}{b \cdot l} - \frac{\Sigma M}{\frac{1}{6} l b^2} \tag{K.11}$$

Using the values that were obtained in Table K.2 for unit length of 1 meter, $\sigma_{k,max}$ is found to be 13.87 kPa. From Section K.5.1, the bearing capacity is found to be 54 kPa, which far exceeds the loading so vertical stability is achieved.

K.5.5. Rotational stability

Rotational stability is tested with the following equation:

$$e_R = \frac{\Sigma M}{\Sigma V} \leq \frac{1}{6} b \tag{K.12}$$

Values that were obtained with Equation K.2 were used. One now obtains a ratio $\frac{\frac{\Sigma M}{\Sigma V}}{\frac{1}{6}b} = 0.22$, which makes the equation valid, and thus the structure is assumed to be stable with respect to rotation.

As the structure is stable under these loads, the preliminary design is found to be sufficiently strong for this study.

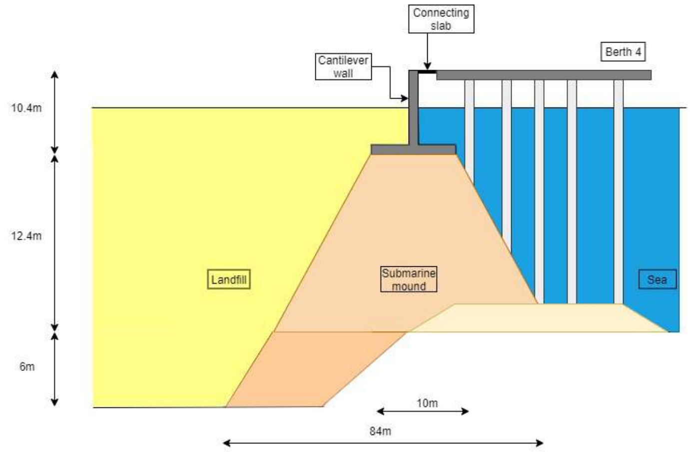


Figure K.9: Layout of the proposed retaining structure near the jetty

K.6. Connecting jetty to reclaimed land

In order to increase the handling capacity, the area behind berth 5 needs to be connected to the jetty. By doing this trucks are able to cross with their cargo. The jetty structure is a flexible structure, that will have deflections when a large vessel is moored to the structure. This means, some kind of flexible joint has to connect the land reclamation to the jetty structure.

For this part of the study, the retaining structure is not particularly relevant, except for being able to carry the load diverted through the connection towards the subsoil.

The flexibility of the jetty structure determines the deviation in the gap that is to be bridged. An analogy to bridges can be made to evaluate solution strategies, where a bridge needs a form of expansion joint to cope with bridge movements and thermal stresses. In this case the connection slab purely needs to accommodate possible movements and stay in position while being able to carry traffic loads.

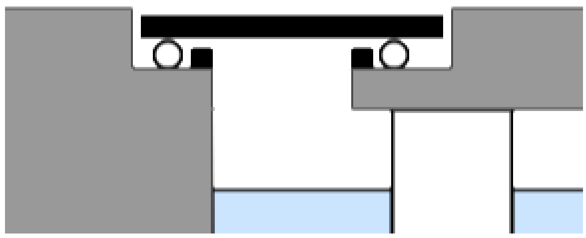


Figure K.10: Schematic of connection between land reclamation and jetty structure

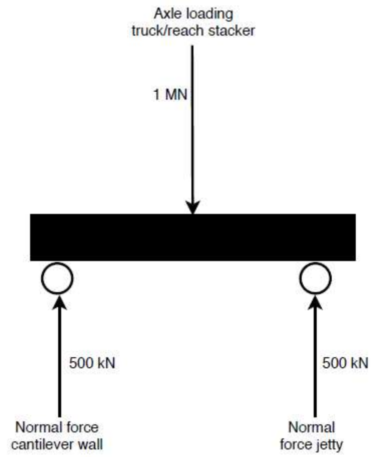
The design of this connecting piece is highly dependent on the lateral deflection that the jetty can have and the distance between the land reclamation and the jetty structure without deflections. Load of trucks and port equipment will be modelled as a point loading in MatrixFrame.

K.6.1. Loads on connecting slab

The loads transferred from the connecting slab to the cantilever wall are determined by which types of load can occur on top of the slab. As its primary function is to facilitate trucks to transfer their cargo to the terminal area from the quay apron, this is the design load. As the slab will be 500 mm wide and 300 mm thick, only one axle will be used as a design load, as the slab is too short for carrying multiple axles.

In the port, both regular trucks as reach stackers are present. These have axle loads that will decide the load on top of the cantilever wall through the connecting slab. For a loaded truck with a container, this maximum axle load is 12 metric tonnes Evofenedex (2019), for a reach stacker, this amounts to 98.6 tonnes by Di Mascio, Paola and Loprencipe, Giuseppe and Moretti, Laura (2019) and 102 tonnes by Hyster (2019). This introduces a 500 kN load on top of the cantilever wall in the worst case scenario that a reach stacker is positioned right on top of the slab while lifting a container to its farthest point.

(a) Preliminary dimensions of connecting slab



(b) Loading situation connecting slab

K.7. Conclusion on jetty connection design evaluation

In this section, the design on the jetty connection is evaluated using Matrixframe and testing if the deflections are in line with Eurocode 2. This states that the deflection of a beam cannot exceed the span divided by 250 due to quasi-permanent loads in order to avoid impairment of appearance and general utility, which is 0.0376mm. In the case of the cantilever wall, the deflection of the upright piece is equal to 0.0226m, as can be seen in Figure K.13.

K.7.1. Connecting slab

The cantilever wall is tested including the load from the connecting slab. The structural analysis program Matrixframe is used. The cantilever wall will be analysed for deflections and stresses. The loads on the wall can be seen in Figure K.12.

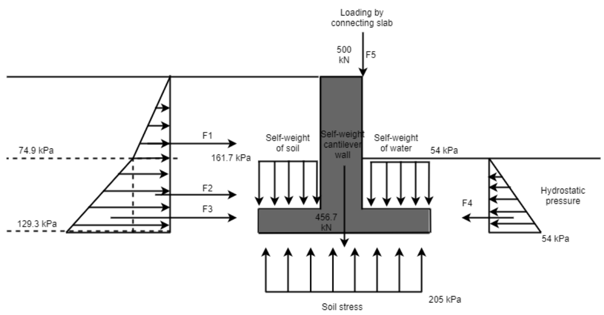


Figure K.12: Loadings on cantilever wall

Figures K.13, K.14 and K.15 show that the deflections in the cantilever wall are very small. The design is thus sufficiently resistant against the load conditions.

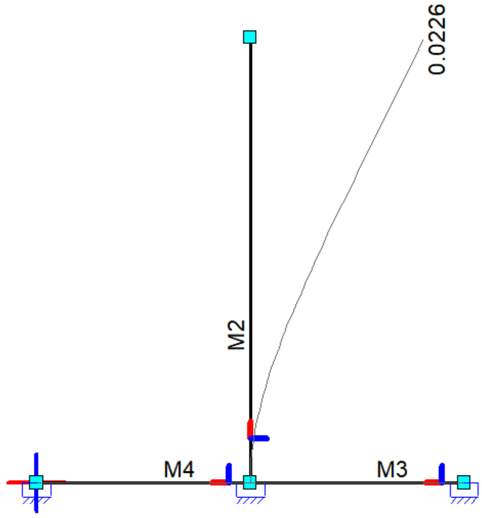


Figure K.13: Deflections in cantilever wall

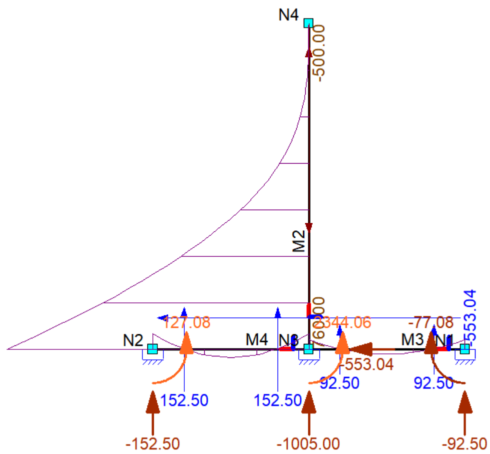


Figure K.14: Loading situation connecting slab

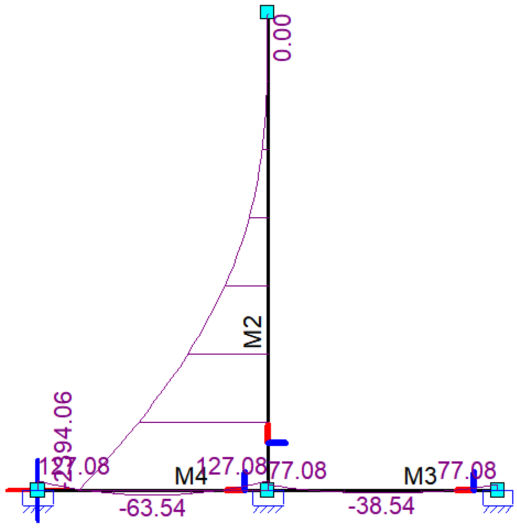


Figure K.15: Loading situation connecting slab

K.7.2. Connecting slab

With the help of MatrixFrame, the internal forces and deflections of the connecting slab are calculated. These are found to be small enough for a valid and working design.

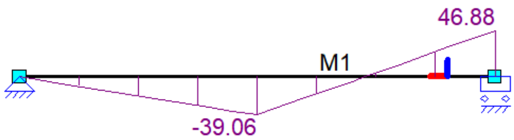


Figure K.16: Loading situation connecting slab

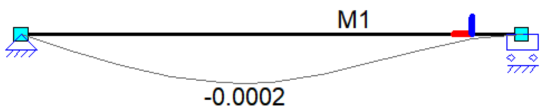


Figure K.17: Loading situation connecting slab

L

TSUNAMI SIMULATIONS

This Appendix focuses on possible effects of a tsunami on the port. Tsunami numerical simulations have been performed by Civil Engineering student Valentina Valdivia at UCSC under supervision of Dr. Rafael Aránguiz. The results were analyzed and used to compute the flood risk in the port of San Vicente due to a tsunami.

L.1. SIMULATION ANALYSIS

The Civil Engineering student V. Valdivia generated 50 stochastic earthquake scenarios of magnitude M_w 9.0 by means of the Karhunen-Loeve expansion (Melgar et al., 2016). The 50 scenarios were generated in the seismic region of Central Chile, which goes from Coquimbo in the north to Arauco Penisnsula in the south. Then, the 50 tsunami scenarios were simulated using the Non-hydrostatic Evolution of Ocean Waves (NEOWAVE) model. Analysis of the data was done using Matlab.

The results of the earthquake simulations are very useful for the project. An analysis can be made on what the effects of such an earthquake and the generated tsunami will be for the port of San Vicente. A total of 4 locations near the port will be analysed. The first location is just in front of the harbour if a full land reclamation would be realized. The second location is in front of the breakwater. The third location is within the bay of San Vicente, in front of the quay. And the fourth location is outside the bay and consequently the furthest away from the port. In Table L.1 the latitudinal and longitudinal coordinates are given for each location. Figure L.1 gives a satellite map overview of the given locations.

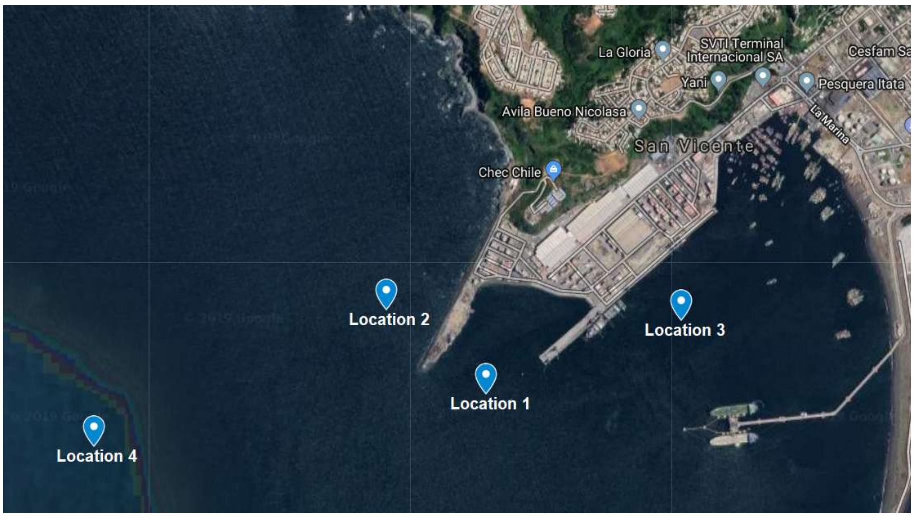


Figure L.1: Satellite map overview with the four locations

	Latitude coordinates	Longitude coordinates
Location 1	-36.734476	-73.143848
Location 2	-36.731667	-73.148056
Location 3	-36.732008	-73.135651
Location 4	-36.736253	-73.160340

Table L.1: Coordinates of the four chosen locations

The data mapping and modelling software Surfer was used to create the grids. Nesting is applied in order to assess the effect of a tsunami wave on the port of San Vicente. Figure L.2 shows the four grids that were used. Table L.2 displays the resolution and integration time of each grid. The smallest wave grid was used to evaluate the effect of a possible earthquake. The resolution of the smallest wave grid is roughly 30m. Information on the water level is only computed at the nodes of the grid cell. The locations that are assessed therefore lie a couple of meters from the port.

Level	Resolution of grid	Integration time
Grid A	~ 3700 m	2 sec
Grid B	925 m	1 sec
Grid C	185 m	0.25 sec
Grid D	30.8 m	0.125 / 0.0625 / 0.03125 sec

Table L.2: Overview of grid characteristics

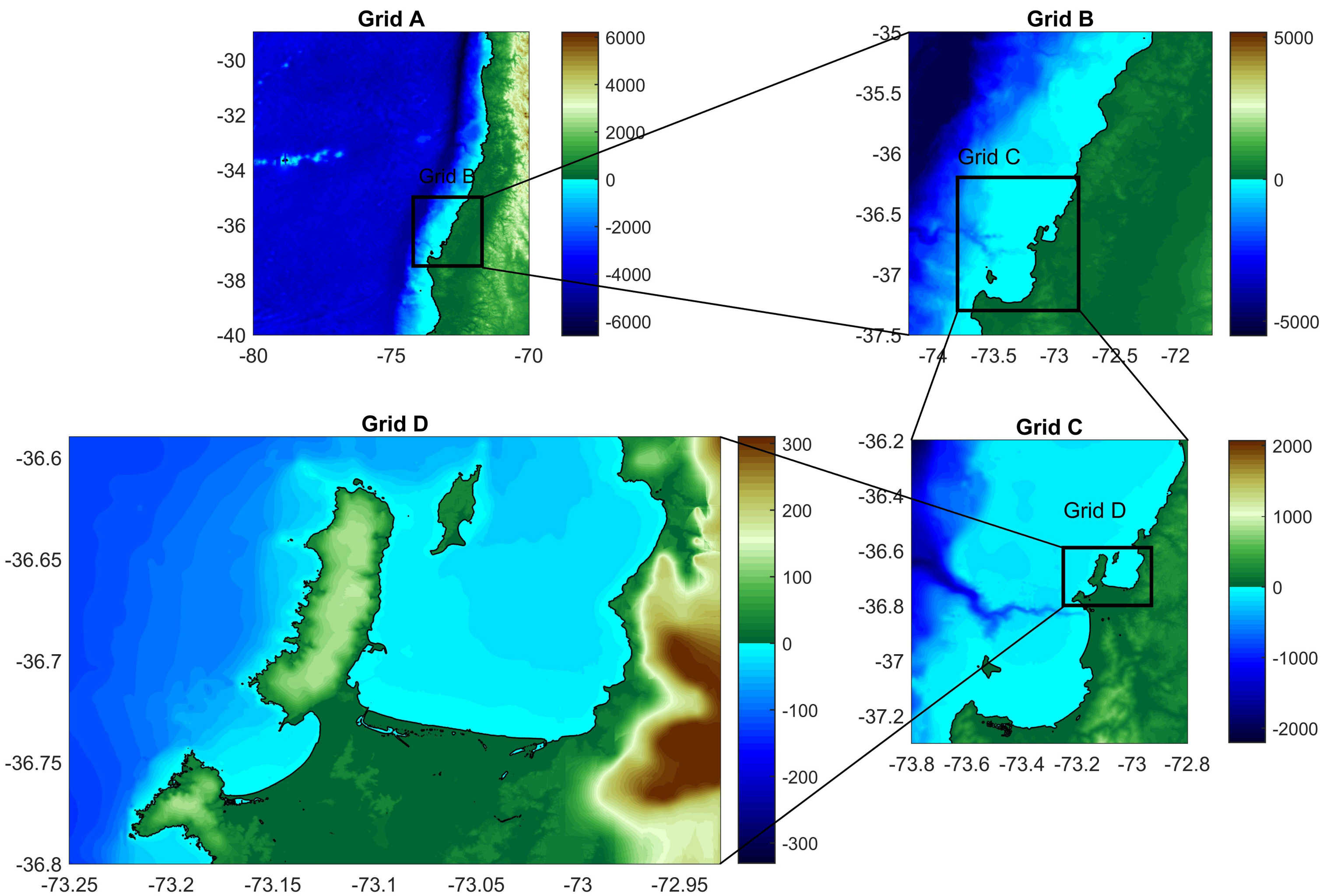


Figure L.2: Overview of the four grids used created with Surfer

In order to simulate, the determination of the return period of an earthquake has to be done first. There are two methods for this determination. Firstly, it can be found through analysis based on the prehistoric earthquake record of the examined area. According to Dura et al. (2014), the seismic recurrence rate ($1/\lambda$) of a great earthquake (magnitude equal or larger than 9.0) in the region of San Vicente is stated to be once every 500 years.

Secondly, the occurrence of earthquakes can be modelled through a Poisson process in the PTHA (*Probabilistic Tsunami Hazard Assessment*) approach (Selpúlveda et al., 2019). The PTHA approach combines many seismogenic regions and earthquakes magnitudes to estimate a probabilistic measure of the overall tsunami hazard in assessed locations (Geist and Parsons, 2006). The Poisson model computes the average earthquake recurrence rate through the Gutenberg-Richter Law. This law expresses the relation between the magnitude and the total number of events in a given region and time period of *at least* that magnitude (Gutenberg and Richter, 1954). With the equation stated below, the average return period can be calculated. This return time combines the probability of an earthquake, of in this case a magnitude 9.0, and the probability the given location is flooded.

$$T_R(h_c) = \frac{1}{\sum_j \sum_i \lambda^{EQ}_{M'_{Wj},x_i} \cdot P_h(h > h_c | M'_{Wj}, x_i)} \tag{L.1}$$

with

$T_R(h_c)$	= Joint mean return period of exceeding h_c	[years]
$\lambda^{EQ}_{M'_{Wj},x_i}$	= Average recurrence rate of earthquakes of magnitude within M'_{Wj} in seismogenic region x_i	[1/year]
$P_h(h > h_c \| M'_{Wj}, x_i)$	= Probability the water level height h_c will be exceeded h with earthquakes with magnitude M'_{Wj} in seismogenic region x_i	[-]

As mentioned above, the PTHA approach using the Gutenberg-Richter law expresses only a relation for earthquakes with at least a certain magnitude. In the simulations performed by V. Valdivia only earthquakes with a magnitude of 9.0 are used. Furthermore, the determination of the average earthquake recurrence rate also contains uncertainty since the long interseismic period between two great earthquake events and the short record length of an existing earthquake (Selpúlveda et al., 2019). For these reasons, the recurrence rate is assumed to be 500 years in the simulations of V. Valdivia, according the paper of Dura et al. (2014).

L.2. Data

With the aforementioned equations three types of diagrams could be generated for all the four chosen locations;

- **Water level vs. Time** (see Figure L.3 - L.6)
  The time series from the diagrams Water level vs Time is used to determine the exceedance curves.

- **Exceedance probability vs. Water level** (see Figure L.7 - L.10)
  The probability of exceedance is calculated using empirical CDF.

- **Water level vs. Return period** (see Figure L.11 - L.14)
  For the return period Equation L.2 is used, where the recurrence rate is set at 500 years (Dura et al., 2014).

$$T_r = \frac{1}{\frac{1}{\lambda} \cdot P_{exc}} = \frac{1}{\frac{1}{500} \cdot P_{exc}} = \frac{500}{P_{exc}} \tag{L.2}$$

The freeboard (R_c) in the port has been determined as 4.81 meters in Bardi (2013). Knowing the maximum allowable water level before the port will be flooded, this can be closely analysed in the simulations. In the following figures this maximum allowable water level is marked with a line so the relevant parameters can easily be read from the diagrams.

Water level versus Time

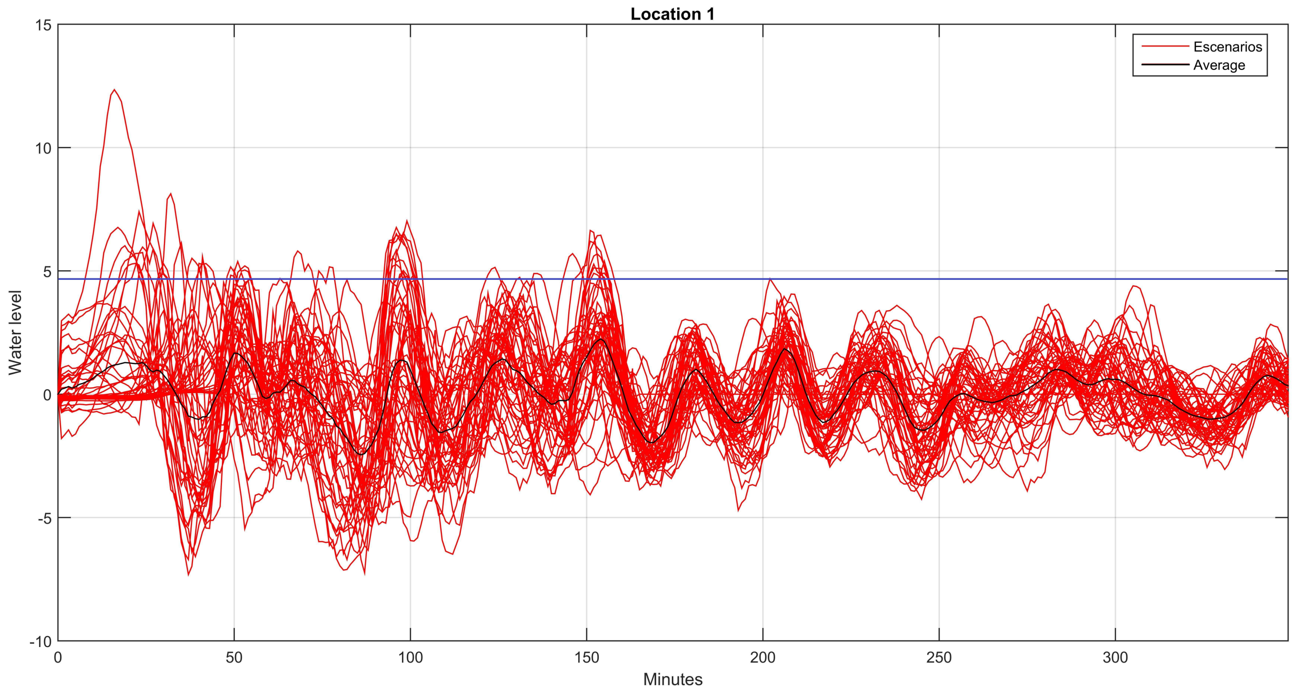


Figure L.3: Time vs Water level for location 1

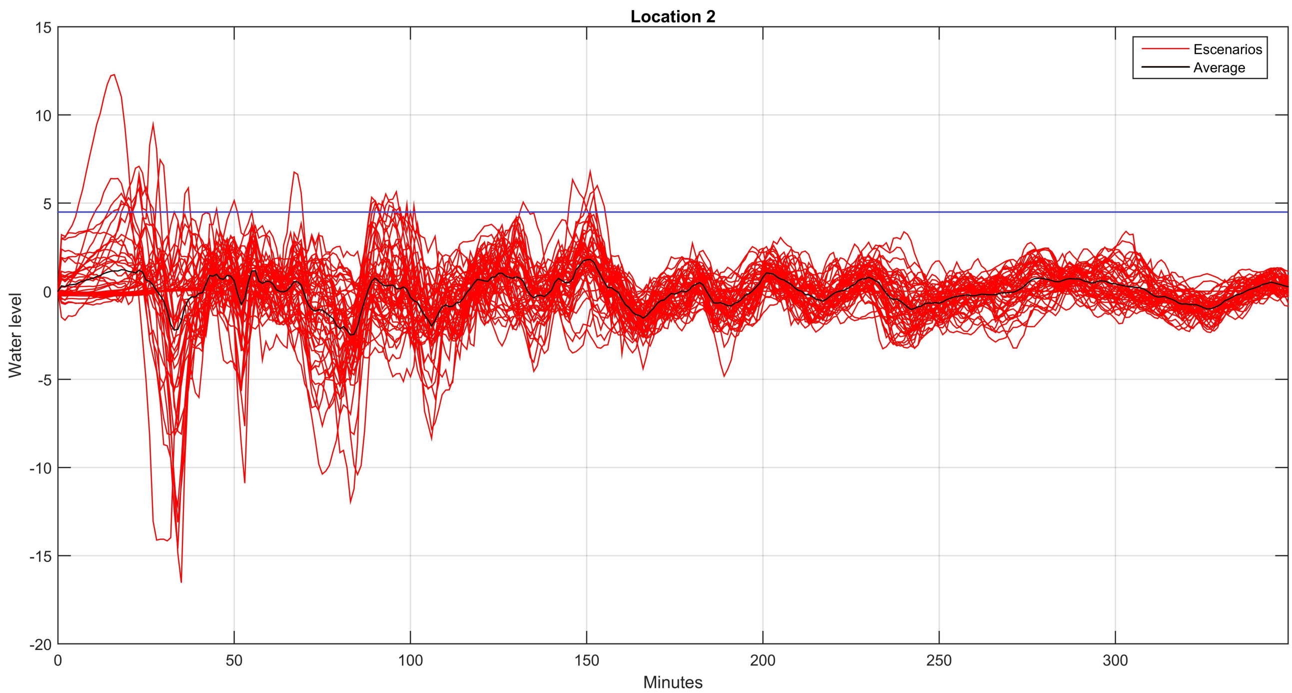


Figure L.4: Time vs Water level for location 2

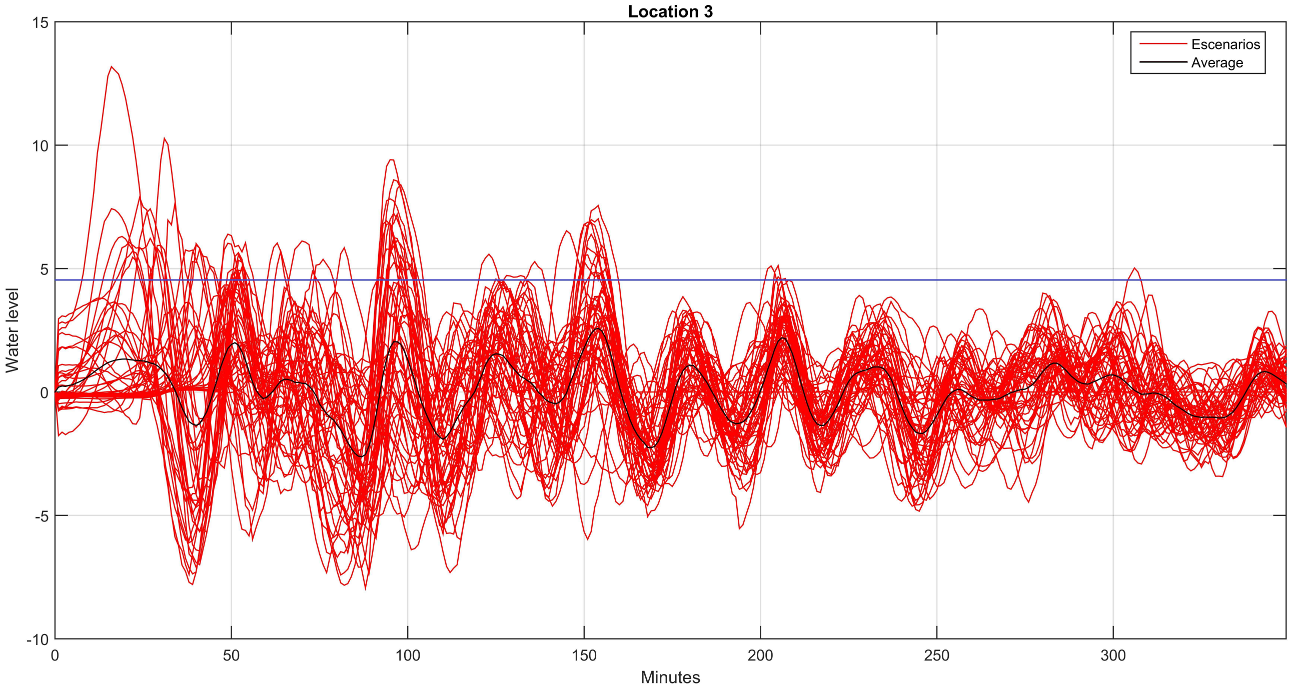


Figure L.5: Time vs Water level for location 3

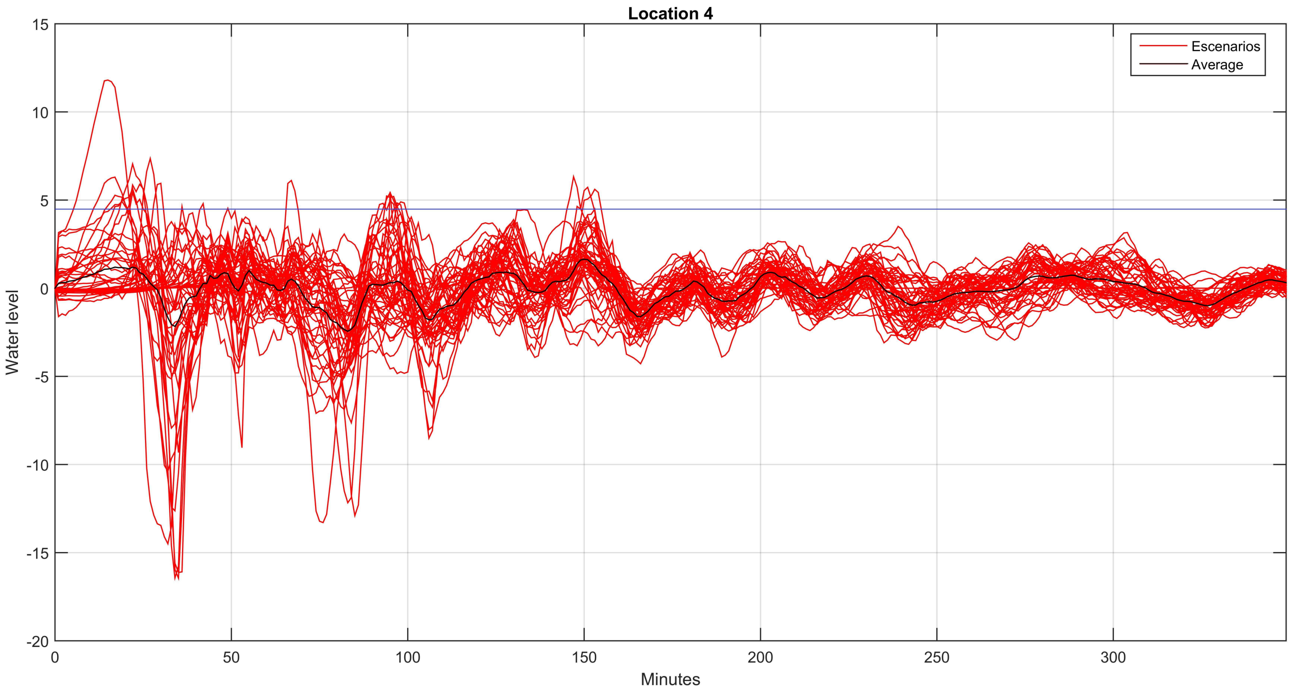


Figure L.6: Time vs Water level for location 4

Exceedance probability versus Water level

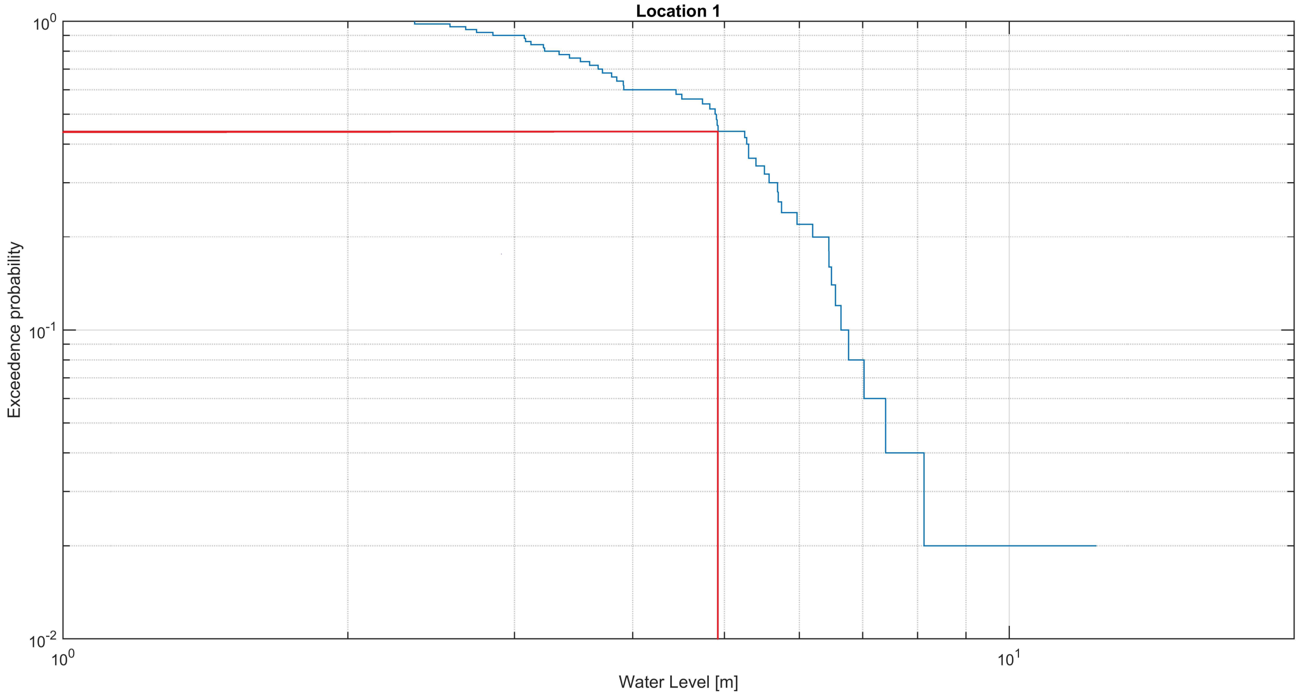


Figure L.7: Water level vs Exceedance probability for location 1

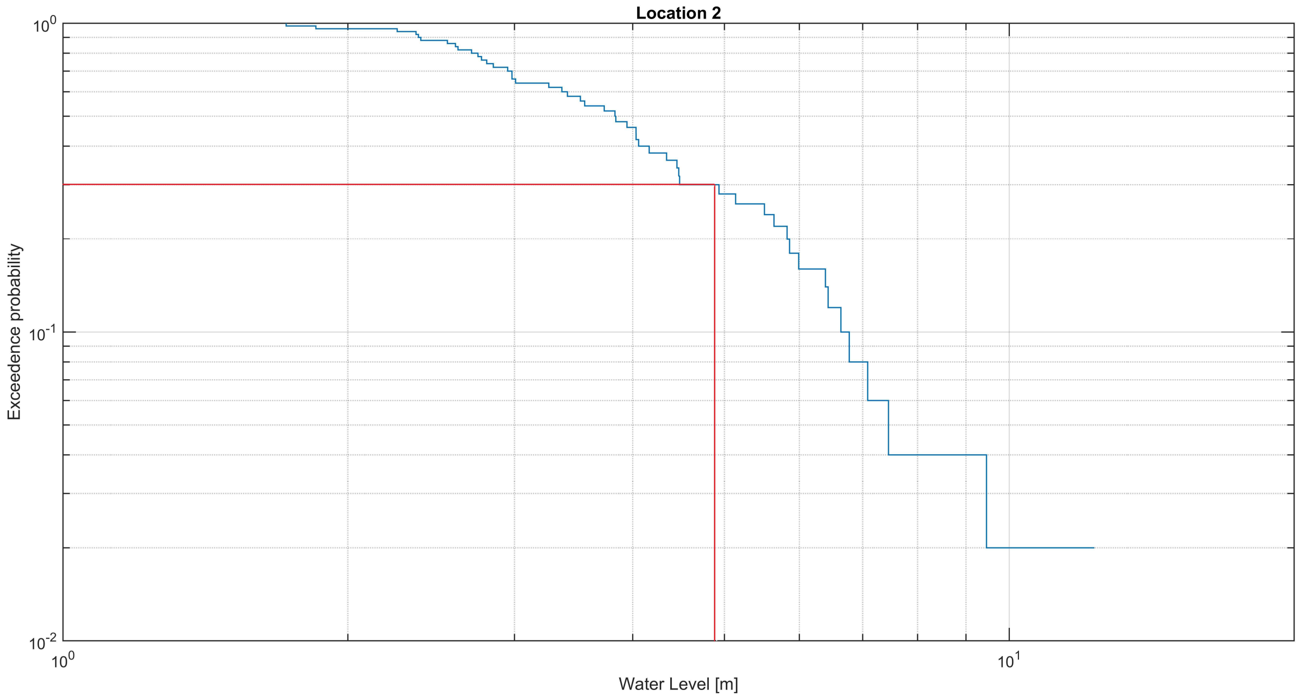


Figure L.8: Water level vs Exceedance probability for location 2

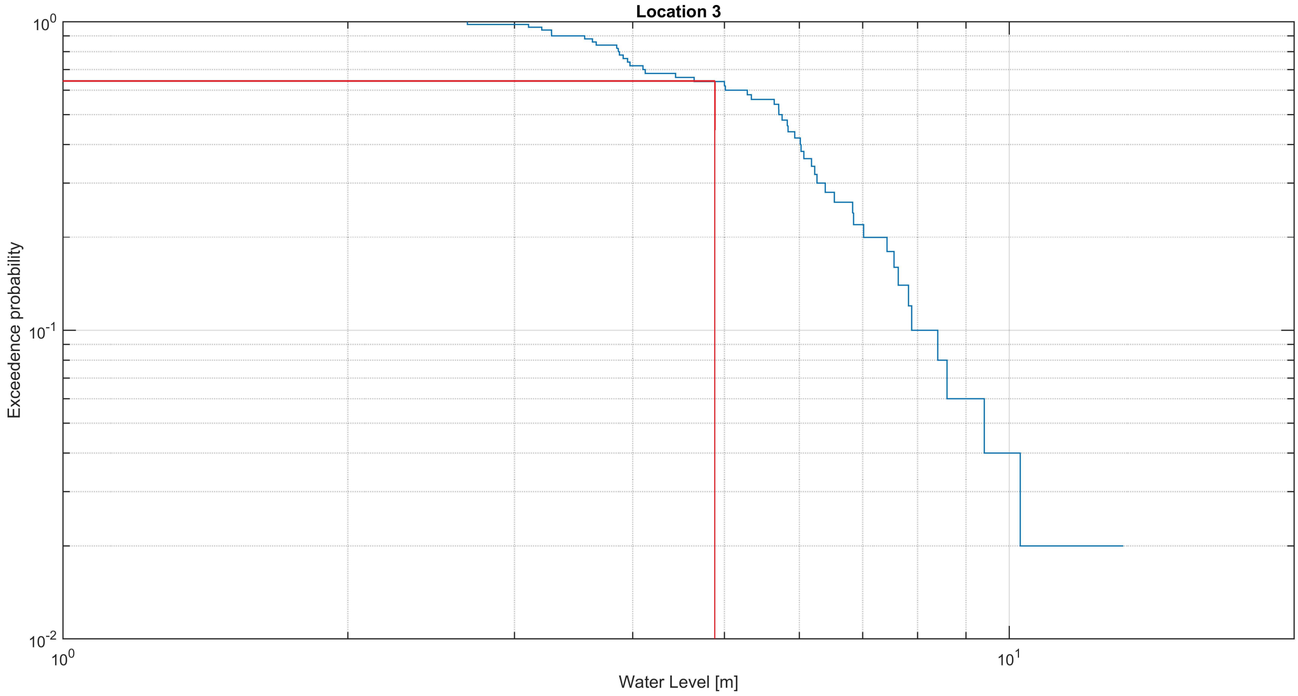


Figure L.9: Water level vs Exceedance probability for location 3

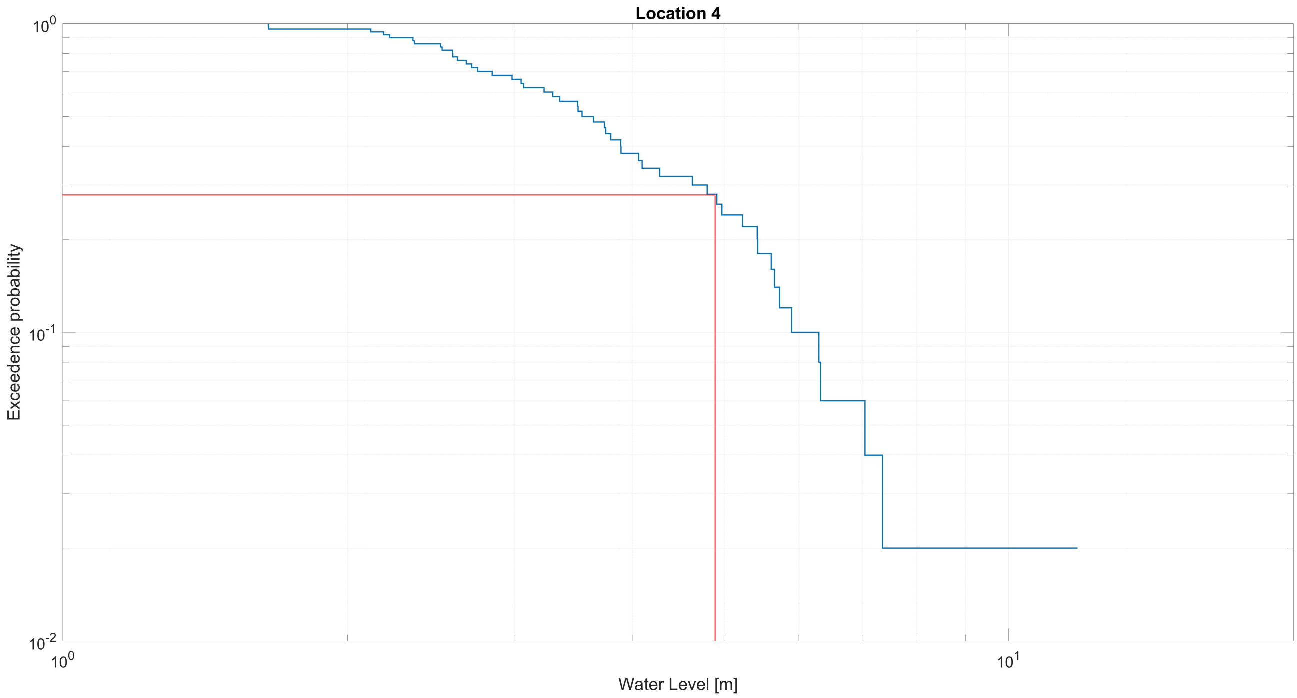


Figure L.10: Water level vs Exceedance probability for location 4

Water level versus Return period

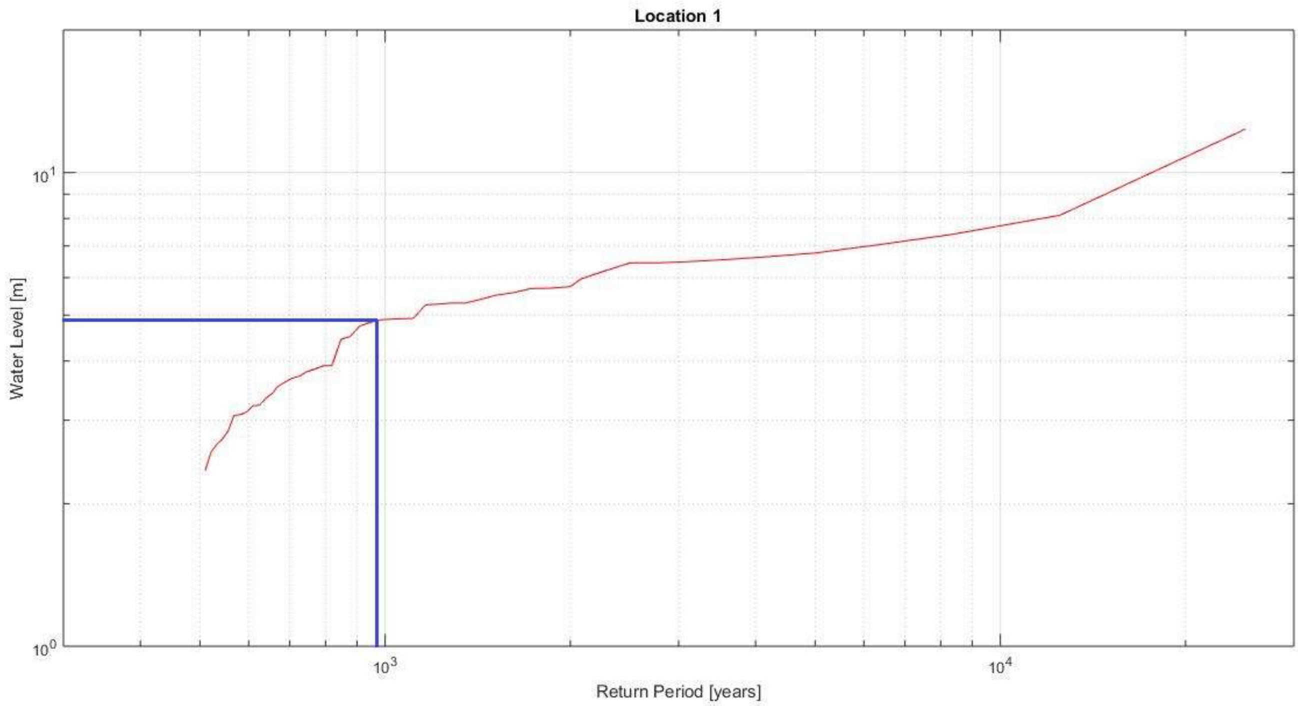


Figure L.11: Return period vs Water level for locations 1

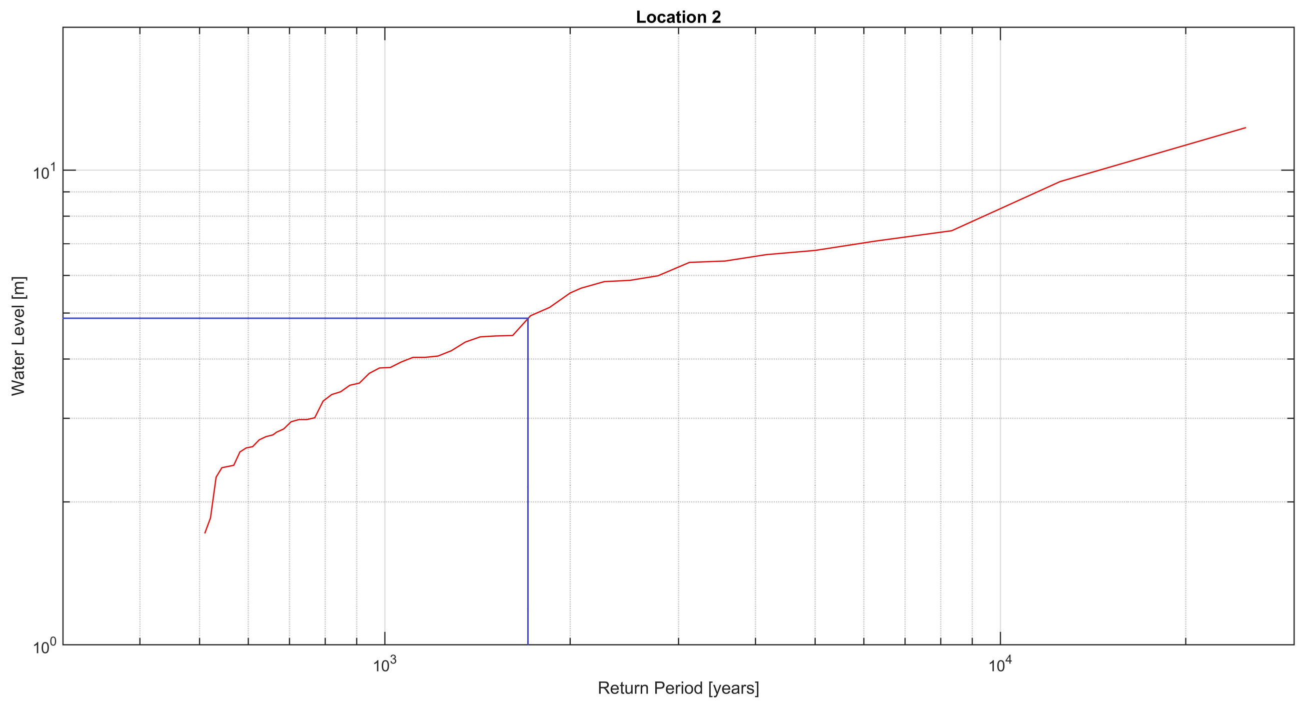


Figure L.12: Return period vs Water level for locations 2

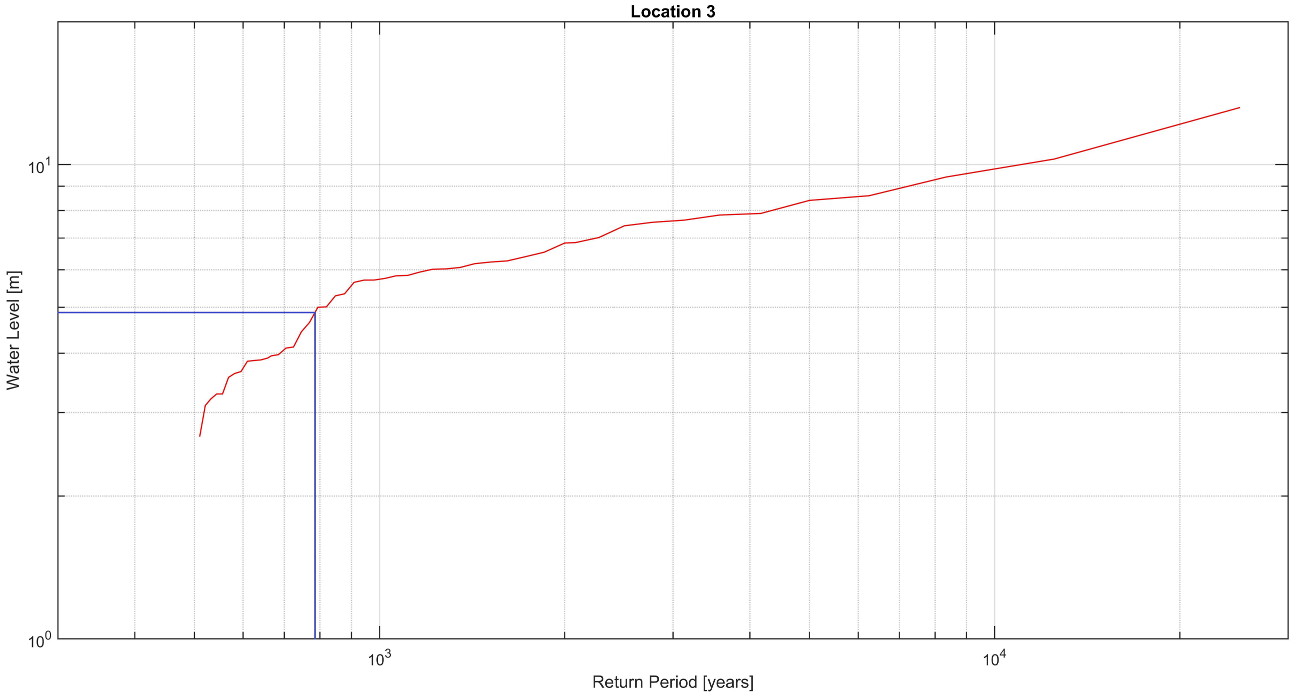


Figure L.13: Return period vs Water level for locations 3

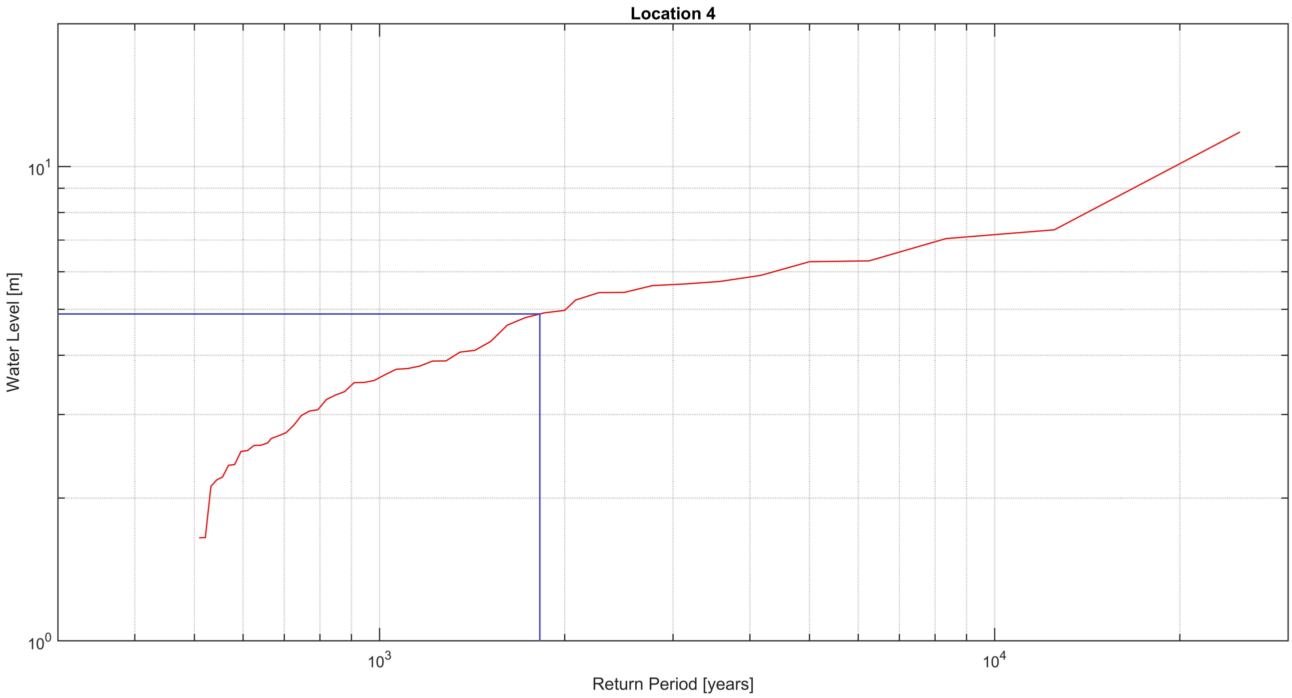


Figure L.14: Return period vs Water level for locations 4

L.3. Data Analysis

With the available data sets it is possible to research what the impact will be on the port of San Vicente when such a great earthquake occurs. In Table L.3 an overview is given of the data set for the known maximum allowable water level in the port (4.8m)

Location	Exceedance probability	Return period
Location 1	~ 45%	~ 975 years
Location 2	~ 30%	~ 1750 years
Location 3	~ 65%	~ 780 years
Location 4	~ 28%	~ 1750 years

Table L.3: Overview of data set for the known maximum allowable water level of 4.8 meter

As can be seen from Table L.3, locations 2 and 4 (near the breakwater and outside the bay) have a low probability of exceeding the 4.8 meters (~30% and ~28%) and therefore a very large return period (both ~1750 years). However, these locations are less relevant to the port compared to the other two, since these do not directly impact the port or its operations.

Locations 1 and 3 on the other hand are the most valuable to analyse for the port, since these are the locations closest to the quay. As can be seen noted from Table 6.3, the exceedance probability for locations 1 and 3 are respectively ~45%, ~65% and a corresponding return period of ~975 and ~780 years. From this it can be concluded that the risk of the port being flooded at such an event is still low, because it has a return period of roughly 800 years.

In case there is an earthquake that generates tsunami waves the port should be able to react accordingly. If it is possible (within the time frame of the tsunami arriving at the port) vessels should be navigated to open water out of the vicinity of the port. This in order to prevent or minimise collisions. From Figures L.3 to L.6 can be stated that the after roughly 25 minutes the first big tsunami waves generated by the earthquake will arrive at the port. For the port this time frame is extremely valuable. Given the fact that there is a vessel inside the harbour they need to decide whether it is achievable to navigate the vessel away or not. A vessel that is being unloaded will not be able to be moved in time. A vessel just arriving might still be navigated back to open water just in time.

Another aspect that should be considered is that after the first large wave a large drop will follow, as can be seen in Figures L.3 to L.6. This means the location for evacuation of the vessels should not be in too shallow water, to prevent the vessel from hitting the seabed. Although the water depths near the port of San Vicente increase rapidly, as can be seen in Figure F.11

Besides the emergency protocols for vessels, the protocol in the port should be familiar. All port employees should know what to do and where to evacuate to. Standard procedure states to evacuate to high grounds. Also the backup power and communication system should be available and tested. All these measures are meant to mitigate the risk and reduce the damage to the port and the number of casualties.