FINAL REPORT

Feasibility VLFS Manila Bay

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HOGESCHOOL ROTTERDAM

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Preface

The last phase of the Bachelor study civil engineering at the Rotterdam University of Applied Sciences is a thesis project. This thesis project tests the expertise of the graduation students weather they are ready for the business community. Besides, the graduation students have to satisfy to the given competences of the Rotterdam University of Applied Sciences.

The subject of this thesis is provided by Royal HaskoningDHV (RHDHV). This is a Dutch engineering company, acting all over the world in more than 100 countries. In over 135 years, RHDHV has grown to a professional and international operating company. Approximately 6000 people are working for Royal HaskoningDHV; they deliver consultancy and engineering services. Royal HaskoningDHV has approximately 100 offices divided over 35 countries presented all over the world. The company is specialized in Aviation, Buildings, Energy, Industry, Infrastructure, Maritime, Mining, Rural developments, Urban development and Water. The services contribute to a better and sustainable society, this resulted in their slogan; “Enhancing Society Together”.

In the period of February until June we, Sjaak Bijl and Victor van den Berg worked on this thesis project. We have experienced this graduation as interesting and educational. We have learned about the design of floating structures, hydrodynamic conditions, airports and land reclamation projects. Beginning this thesis project we had little knowledge regarding the aspects of the wave theory, which was a very important item during this graduation project. However, during the preparation- and feasibility phase we have learned a lot about this subject. The feasibility phase in particular was most challenging due to the limited expertise of the influences by a landing airplane and waves at a Very Large Floating Structure. We are satisfied with the results of our thesis and the knowledge we have gained.

We would especially like to thank our supervisor of Royal HaskoningDHV, Ronald Stive and our Rotterdam University of Applied Sciences supervisor; Harry Dommershuijzen, for their guidance and advices during this thesis project. Moreover, we would thank all colleagues within Royal HaskoningDHV who helped and guided us during the graduation process. In particular: Dirk-Jan Peters, Kasay Asmerom, Perry Groenewegen, Michiel Smits and Teodora Cristutiu. Last but not least we would like to thank the senior airport development advisor of NACO, Hein Baijer for his provided information about designing an airport and the review on documents.

Sjaak Bijl & Victor van den Berg

Rotterdam, 13-06-2017

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Summary

The last phase of the Bachelor Civil Engineering at the Rotterdam University of Applied Sciences is finished with a graduation assignment. The students Sjaak Bijl and Victor van den Berg investigated during this period the feasibility of a Very Large Floating Structure in Manila Bay. This VLFS has to serve as object within an airport layout. Using the assistance and knowledge of the graduation company Royal HaskoningDHV, this investigation has been defined and performed.

The current airport in metropole Manila is growing significantly; the predictions are a growth of 40 million passengers unto 2033. Since the extension of the airport in the density populated metropole is impossible an extension upon an artificial island is planned in Manila Bay. Within this research two designs are elaborated; a traditional land reclamation and an alternative design inclusive a floating runway construction.

Both designs are exposed to the environmental conditions that arise in Manila. Regularly passing typhoons, soft and weak layers in the seabed and the bathymetry of the seabed leads to high costs of both constructions. The sea defence construction is the most expensive part of the land reclamation. However the construction of a Very Large Floating Structure that reduces the dimensions of the traditional land reclamation will make the alternative solution economically attractive in case the local cost of sand reaches a cost level of around 30 USD per m^3.

The runway construction has the best possibilities to function as floating facility and it would be possible to build it as modular elastic deformable construction. The normative forces upon the floating runway are the Airbus A380 and post typhoon swell waves.

The design phase of this floating structure is split in 4 parts. Since the VLFS is composed out of several segments that are connected with each other a partition is made; the floating segments; the strength of these segments; the placement of these segments in a grid structure and the connection system between the segments.

The result of these phases are concrete casings placed in a herringbone grid structure, the height of the casings and the thickness of the floors give sufficient stiffness to withstand the normative bending moments that arises during post typhoon swell waves. The grid structure ensures a favourable collaboration between the segments and relieves the connection systems. Due to the placement in a herringbone grid the forces in the connection system remain limited. By the application of a fender combined with a hinge the construction is elastic deformable.

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Samenvatting

De laatste fase van de Bachelor opleiding Civiele techniek aan de hogeschool Rotterdam wordt afgesloten met een afstudeeropdracht. De afstudeerstudenten Victor van den Berg en Sjaak Bijl hebben gedurende deze periode onderzoek gedaan naar de haalbaarheid van een Very Large Floating Structure (hele grote drijvende constructie) in Manila Bay. De VLFS dient hierbij te fungeren als faciliteit binnen de plattegrond van een vliegveld. Met hulp en kennis van het afstudeerbedrijf, Royal HaskoningDHV, is het onderzoek gedefinieerd en ingevuld.

Het huidige vliegveld in de metropool Manila groeit significant; de voorspelling is een groei van 40 miljoen passagiers in 2033. Aangezien het vliegveld gelegen is in een dichtbevolkte metropool met weinig ruimte, is het onmogelijk om een uitbreiding op land te realiseren. Binnen dit afstudeeronderzoek worden hierbij de opties van een traditionele landaanwinning en een alternatief ontwerp, inclusief een drijvende landingsbaan overwogen.

Beide ontwerpen dienen hierbij bestand te zijn tegen de lokale omstandigheden van Manila. Regelmatige passerende cyclonen, de aanwezige zwakke ondergrond en de diepteligging van zeebodem leiden hierbij tot hoge kosten voor beide constructies. De zeewering binnen de landaanwinning kan gezien worden als de hoogste kostenpost. De constructie van een VLFS leidt tot kleinere afmetingen van de traditionele landaanwinning, hierbij wordt de alternatieve oplossing economisch aantrekkelijk indien de lokale zandprijs een waarde bereikt van 30 USD per m^3.

De landingsbaan kan het best als een drijvende faciliteit worden toegepast, het is mogelijk om dit op te bouwen als een modulair elastische vervormbare constructie. Maatgevende belastingen op de drijvende constructie zijn de Airbus A380 en de deining golven, veroorzaakt vanuit een cycloon.

Het ontwerpproces van de VLFS is opgedeeld in 4 gedeeltes. Aangezien de VLFS is opgedeeld in verscheidene segmenten, die allemaal gekoppeld aan elkaar worden, is er een onderverdeling gemaakt; grootte van de segmenten, sterkte van de segmenten, plaatsing segmenten in een bepaald raster en het type verbindingssysteem.

Het resultaat van deze fases is dat de betonnen kokers in een visgraat raster structuur worden toegepast. De hoogte van de betonnen kokers en de dikte van de vloeren geven voldoende stijfheid om de maatgevende buigende momenten door deining golven (veroorzaakt uit een cycloon) te kunnen opnemen. De rasterstructuur zorgt voor een gunstige samenwerking tussen de segmenten en verlichten de tussenliggende verbindingen. Vanwege de plaatsing in een visgraat structuur, blijven krachten in de verbindingen blijven beperkt. Bij het toepassen van een fender gecombineerd met een scharnier, reageert de constructie elastisch vervormbaar.

Contents

Appendices

Separately provided reports

In addition to the final thesis report, the following interim deliverables and documents for the University of Rotterdam are separately provided.

Interim deliverables:

A. Basis of Design
B. Study Very Large Floating structures
C. Airport Design
D. Traditional land reclamation and costs
E. Structural Analysis
F. Concept design floating segment
G. Concept design grid structure
H. Connection system
I. Concrete casing
J. Cost comparison

1 Introduction

1.1 Project Definition

Manila is the capital of the Philippines and its population is growing significantly. The coming years there is an urgent need to extend the airport capacity. Due to limited space on existing land, the option of land reclamation or floating should be considered.

In 2015 Ninoy Aquino International Airport (also named Manila International Airport) located in the Philippines (Figure 1), has broken their record of handling a total of more than 38 million passengers. Aquino airport is at the limit of its grow potential and therefore restricted in their capacity potential in the near future. An expansion on land in this area is hard to realize, because of the limited space, therefore extension into the sea needs to be considered.

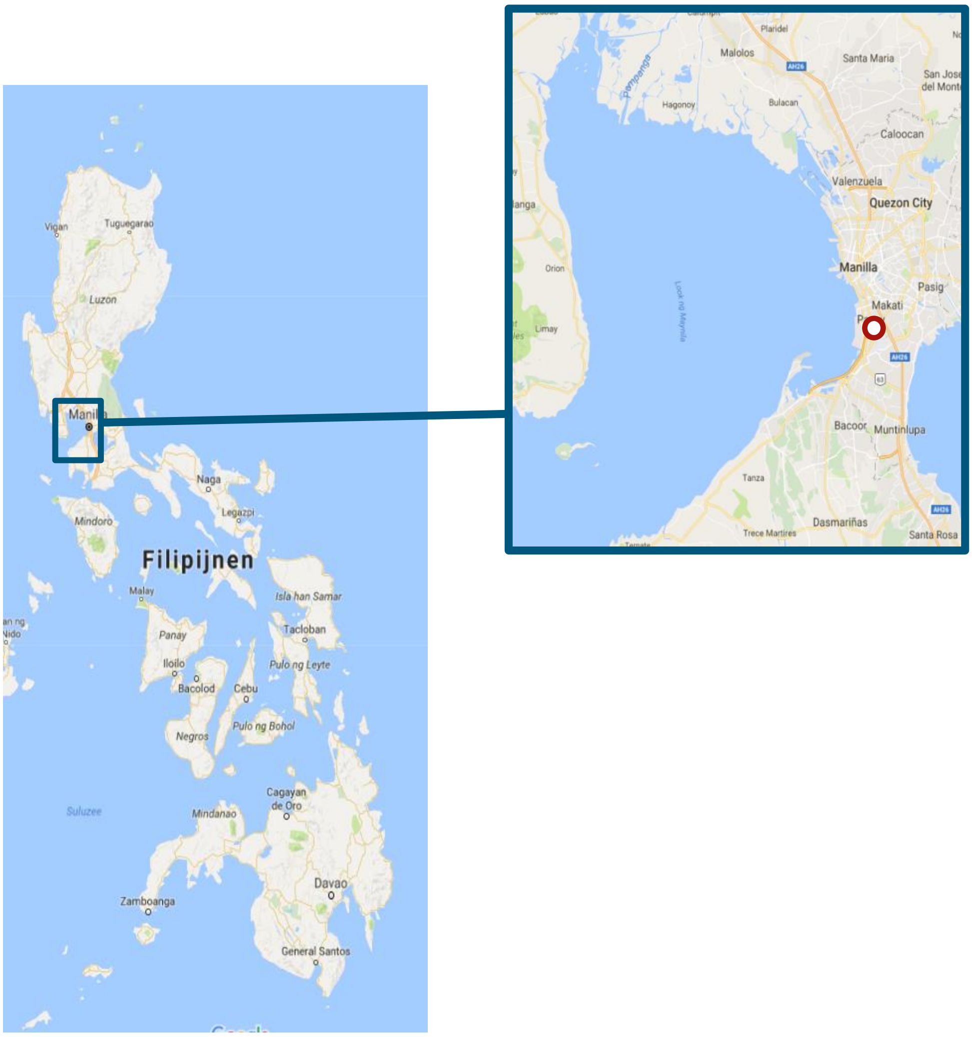

Figure 1 Project location Manila Bay (Google maps)

The question that arises is;

<u>Is it possible to design an element within an airport layout as very large floating structure (VLFS)? And will it result in costs savings compared to the total airport placed on land reclamation?</u>

1.2 Project goal

A standard solution is to execute Manila International Airport fully as an artificial island. However the purpose of this thesis is to investigate the technical and economic feasibility of a Very Large Floating Structure within an airport layout. A part of an artificial island shall be disconnected from the island and realised as a Very Large Floating Structure. The VLFS shall be a part of the aerodrome extension and would serve as an airport facility. In consequence the surface of the artificial island decreases. Figure 2 shows how the hybrid alternative design (apply of VLFS) is derived from the traditional land reclamation solution.

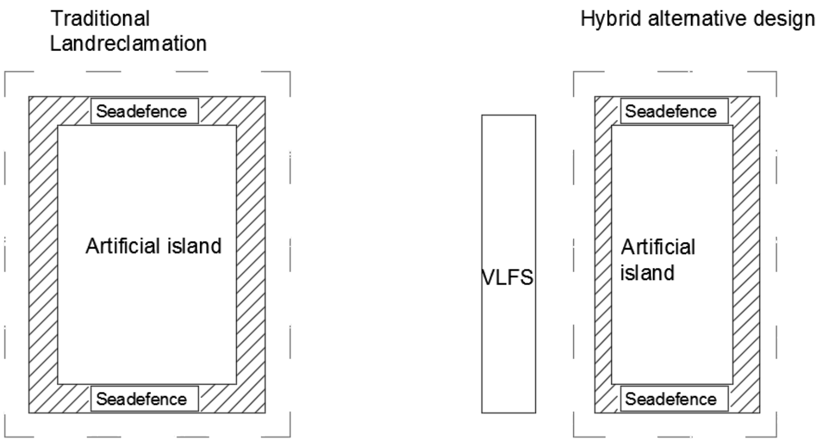

Figure 2 Goal of the thesis

The feasibility is especially aimed at costs. Namely; the costs of a traditional land reclamation increases rapidly with increasing water depths. This ultimately leads to an increasing amount of sand, which is the main material in land reclamation projects.

Another important construction part of an artificial island is the sea defence that surrounds the island. A sea defence is a construction mainly composed of rock and concrete; both expansive materials. The depth and hydraulic conditions at site are decisive in the design of the sea defence. However in the hybrid alternative design, the floating structure also has an influence at the sea defence. Namely in front of the artificial island the sea defence is less exposed by the waves; indicated in Figure 2**.**

1.3 Project approach

In order to reach the project goal and answer the main question this graduation research is split in several phases (Figure 3). Within each phase different documents are completed and sub questions are answered. The first phase was to summarize the local conditions at the project location Manila Bay. Parallel to this, existing Very Large Floating Structures are investigated.

Following the preparation phase the design phase is started. An airport layout that is capable of adopting the growth of Ninoy Aquino International Airport is designed within Deliverable C. All facilities within this Airport Design are constructed initially on an artificial island in Manila Bay. This land reclamation is elaborated and a rough price calculation is made.

The third step is a feasibility research to the application of a VLFS in Manila Bay. The sub question in this deliverable was; *Wat are the consequences of a typhoon wave and an Airbus A380 on the floating runway construction?* This Structural Analysis leads to the design of floating segments and a connection system between these segments.

Finally the cost comparison is made to answer the main question. The costs of the hybrid alternative design are compared with costs of the traditional land reclamation in Manila Bay. With this comparison can be concluded if a floating structure in Manila Bay results in an economical cost saving.

Figure 3 indicates the division of tasks (deliverables) during the graduation process wherein some deliverables also elaborated together.

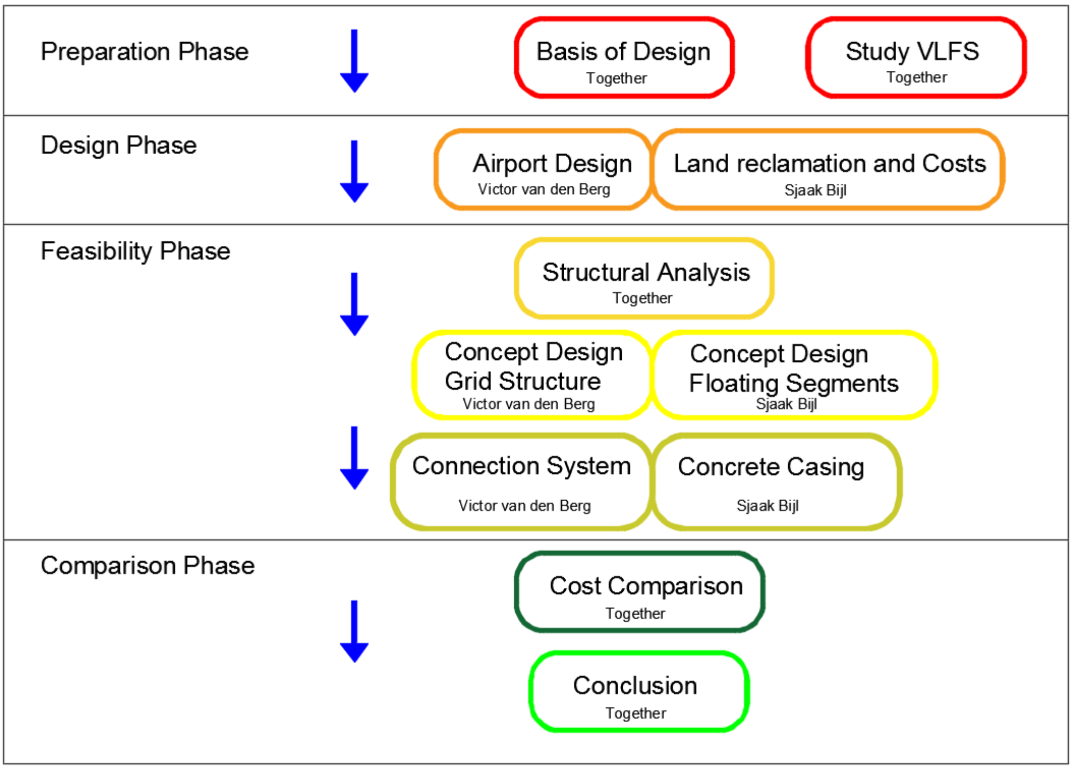

Figure 3 Graduation process

2 Literature Study

Due to a growing world population space in and around several metropoles is limited; the construction of artificial islands is widely applied to create usable areas. Also floating constructions can serve as extension of land to facilitate activities like housing, storage and recreation. Within this preparation phase several constructions/projects were found that are built on artificial island, however extension of land by means of Very Large Floating Structures is not much applied so far.

Examples of artificial islands are Macau International Airport (China); Kansai International Airport (Japan, Figure 4) and Chubu International Airport (Japan). All these artificial islands are constructed to facilitate an airport upon new land. An important advantage is a free access route above water and limited noise disturbance.

The construction of Very Large Floating Structures nowadays is rare. The biggest floating construction ever build is a floating runway in Japan; Yokosuka Floating Airport. Figure 5 shows the floating runway in Japan. The length of this construction was 1000 meter and the width 121 meter; the floating structure is mainly build out of steel. The construction served as runway for small aircrafts. The runway is demolished after 6 years; the reason of this short life span is unknown. Probably the reason is the etching trough salty water and material fatigue.

Another example is a floating pavilion in Rotterdam. This project is summarized in Deliverable B Study VLFS. This floating structure is made of expanded polystyrene foam; a light weight material.

A concept design by Thijs de Rijcken is a modular system for a floating residential area. This modular system is constructed with concrete combined with EPS. A concrete skeleton gives strength and the EPS delivers volume and buoyancy properties.

Figure 4 Kansai International Airport (Google maps)

Figure 5 Yokosuka Airport (Wang, 2010)

3 Statement of Requirements

3.1 Stakeholders

The stakeholders within this thesis are depicted in Figure 6. Since it is a feasibility study wherein the conclusion can be used everywhere in the world the stakeholders are briefly mentioned.

Figure 6 Main stakeholders

3.2 Requirements

The extension requirements of Ninoy Aquino International Airport are mainly regarding to the capacity of the new airport.

The current airport in metropole Manila handled 38 million passengers and 480.000 metric tons cargo in 2015. The predictions are a growth up to 80 million passengers unto 2033. As a result the airport extension must have a capacity of approximately 40 million passengers and must be capable to receive an Airbus A380. The Airbus A380 is currently the biggest plane that transports passengers; the specifications of this plane are summarized in Table 1.

In order to be able to handle 40 million passengers a year a total of two runways are required. Both runways should be capable to facilitate 30 plane movements each hour. This can either be landing or taking off.

During this thesis the new airport is named as Manila Bay International Airport.

Table 1 Specifications A380 (Aviationinfo)

Airbus A380	
Length:	73 m
Wing Span:	80 m
Total passengers:	853
Max. take of weight:	569 metric ton
Max. landing weight:	394 metric ton

A second important requirement is that wave overtopping upon the VLFS must be excluded during daily wave conditions.

4 Local conditions

4.1 Introduction

This project is appointed to Manila Bay; there are plans to build three artificial island North-West of Cavite City. The most norther island is planned as airport. For this location the local condition are collected and summarized in Deliverable A; the Basis of Design.

Figure 7 depicts the schematized project location of the airport. Each side of the island shall experience different hydraulic conditions; this result in differences in the design of a sea defence construction. The final dimensions arise from the design phase and are elaborated later in this thesis.

The Basis of Design is mainly derived on the RHDHV reports of Pasay and Paranaque Reclamation Development (RoyalHaskoningDHV, 2017) and Philippine Global Gateway (Stive, Confidential Report , 2015). Some of the hydraulic conditions are determined in consultation with the supervisor of RHDHV (Stive, 2017).

Figure 7 Project location Manila Bay International Airport

4.2 Environmental conditions

4.2.1 Chart datum

Chart datum is a reference level that is common to use in maritime engineering projects. Within this project Mean Lowest Low Water (MLLW) is set as chart datum. Reason is the draft of vessels around the construction. At Mean Lowest Low Water it is important that sailing around the land reclamation is possible; the depth around the island and the VLFS have to be measured from Chart datum.

Chart Datum	**=**	**Mean Lowest Low Water**	**(MLLW)**
Mean Lowest Low Water	**=**	**0.47 meter minus Mean Sea Level**	
Mean Sea Level	**=**	**Chart Datum + 0.47 meter**	
Mean Lowest Low Water	**=**	**Chart Datum + 0.0**	

4.2.2 Climate

Manila has a tropical monsoon climate. Tropical monsoon climates typifies to monthly mean temperatures above 18°C every month of the year. Every year contains a wet and a dry season but also a winter and a summer monsoon.

The west region of the Philippines is known for regularly passing typhoons. These typhoons cause high wind speeds. Contrary to this the daily wind conditions are mild. Figure 8 shows that the wind during a summer monsoon only reaches unto 10 m/sec out of the direction south west.

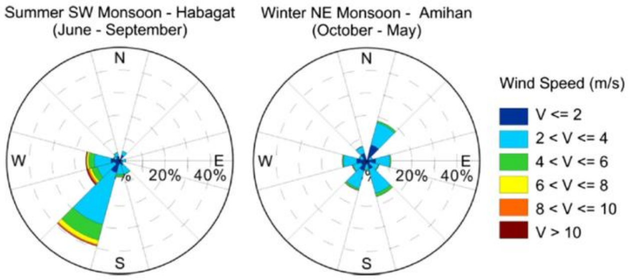

Figure 8 Daily wind conditions over a year (Stive, Confidential Report , 2015)

The typhoon conditions in Manila Bay are considered to be survival conditions and are summarized in chapter 4.4.

4.2.3 Bathymetry

The bathymetry of Manila Bay has an effect on the hydraulic conditions around the land reclamation and the floating structure. Likewise the depth of the seabed is one of the key points that lead to high cost of a land reclamation project.

The depth of Manila Bay varies among 4 meter close to the shore up till 28 meters in the middle of the bay. Figure 9 indicates the bathymetry at the location of Manila Bay International Airport. The bathymetry over cross section A-A starts at a water depth of – 4 m and rises until - 18.5 m below Mean Sea Level (MSL). Appendix A1 shows this bathymetry more detailed.

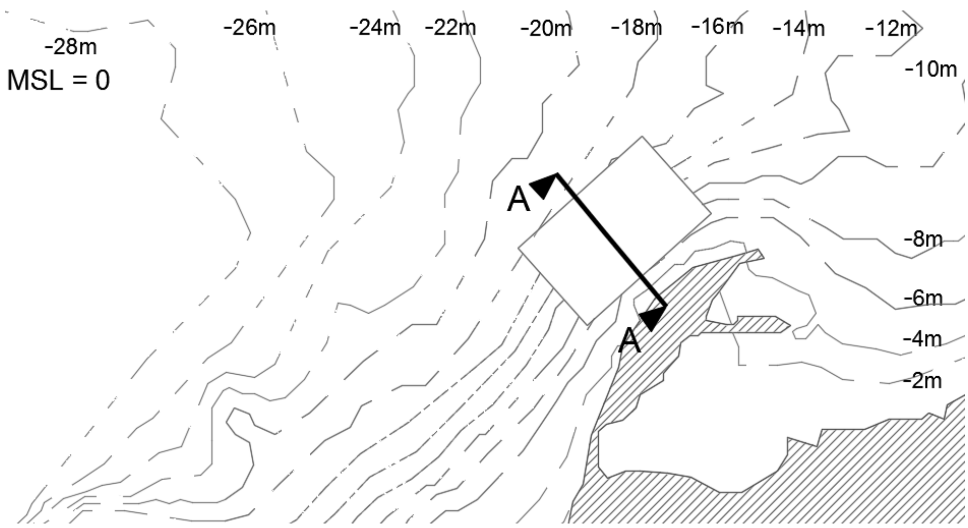

Figure 9 Bathymetry around Manila Bay International Airport

4.3 Geotechnical conditions

4.3.1 Soil profile

The seabed of Manila Bay consists out of different soil layers; the information about these layers is obtained from a Standard Penetration Test. It has been adopted that the output of this test applies over the total length of the island. Appendix A2 shows these layers over cross section A-A. It is called the “typical cross section” and is regularly used during the design of the land reclamation.

The uppermost layers consist of soft silty clay and medium dense silty sand. The SPT gives N-values that vary between the 0-10 blows. The underlying layers are very stiff clay and dense sand-hard clay with N values unto 50 blows. These layers are considered suitable for foundation of the land reclamation.

4.3.2 Seismic activity

Manila is located in an earthquake prone area. Earthquakes in this area are caused by the sliding of the plates from which the earth’s crust consists of. These plates are constantly moving and causing vibrations. Earthquakes influence the land reclamation design enormously. In consultation with the supervisor of RHDHV (Stive, 2017) is decided to disregard seismic activity in this thesis.

4.4 Hydraulic conditions

The most extreme hydraulic conditions at the project location occur throughout typhoons. By using outputs of several models the conditions that occur around the project site are established. Within this feasibility study the conditions are simplified in 3 load cases. Namely:

- Daily conditions
- Typhoon conditions
- Post typhoon swell conditions

The hydraulic conditions that occur are waves with different length, heights and periods; currents, surges and design water levels. Within this there is a distinction in different return periods; the most used return period is 1 per 100 years. An overview of the hydraulic conditions is predicted in Table 2.

Table 2 Summary of Hydraulic conditions

Load cases	Significant wave height H_s [m]	Wave period T [sec]	Direction [^{0}]	Design Water Level [m CD]	Corresponding tide level	Surge height [m]
Daily - operational conditions	1	3-12	225	1.04	MHHW	-
Survival - typhoon conditions	7	9	270	1.92	-	0.8
Post typhoon swell conditions	1.5	14	225	1.04	MHHW	-

5 Traditional land reclamation

5.1 Footprint land reclamation

This chapter contains a summary of Deliverable D “Land reclamation and costs”; this part of this research is conducted by Sjaak Bijl. The most important conclusion in this investigation is to set the total costs if the entire airport is executed as a traditional artificial island. Finally the cost indication is used to make a comparison between the traditional land reclamation with the hybrid alternative design. In chapter 12 is set this comparison.

The total land reclamation area is divided in two different areas; airport layout and the surrounded sea defence. Figure 10 depicts a schematized footprint of these areas within the footprint.

A total price is established according to the output of Deliverable C “Airport design’’. The dimensions of the airport layout part are set on 4600 meter long by 3150 meter wide. In chapter 6 is further described how these dimensions are achieved.

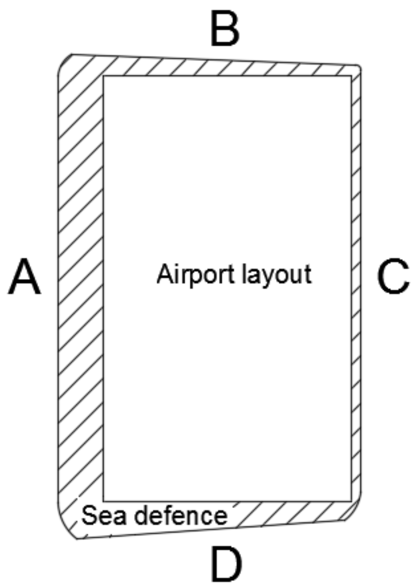

Figure 10 Footprint traditional land reclamation

5.2 Activities

Ground level of the airport upon the artificial island is set on 4.5 meter above Mean Sea Level. The main purpose of this height is to protect the inside area to flooding and minimalizes wave overtopping.

The main costs items to execute the entire airport on traditional land reclamation are as follows:

- Dredging
- Sea defence
- Sand fill

5.2.1 Dredging

To start the sand filling on strong layers; soft layers should be removed. According to the Basis of Design the uppermost layers are not strong enough to serve as a foundation for the sea defence and sand fill in Manila Bay. Appendix A2 “Typical cross section seabed” indicates to dredge the silty clay and medium dense silty sand. In total 13.8 million cubic meters of soft layers is dredged.

5.2.2 Sea defence

The highest cost item of the land reclamation is the surrounded sea defence construction. It includes different types of sea defence constructions. The application variations arise through the following points:

- The water depth
- The wave conditions (Figure 11, shows types of wave expose by the different sides)
- Function of land behind the sea defence

The result on the fully exposed side (hardest exposed side) is a rubbly mound construction with on top a concrete seawall construction to prevent wave overtopping. Further the sea defence is covered by using Accropode units.

Based on extend of exposure the price of the other three sea defence sides is assessed. Table 3 depicts the price differences per meter sea defences of all the sides.

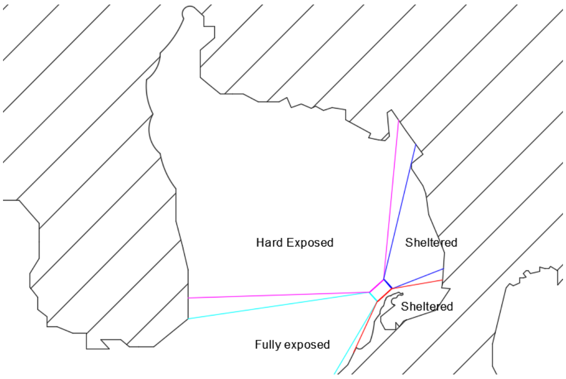

Figure 11 Extend of expose different sides

Table 3 Price difference between sea defences

Sea defence	Extend of exposure	Price per meter (USD)
A	Hard exposed	160,000
B	Sheltered	106,000
C	Sheltered	45,000
D	Fully exposed	234,000

5.2.3 Sand fill

Sand fill is necessary to create an artificial island inside the entire surrounded sea defence construction. A height of 4.5 meter above Mean Sea Level is required. To determinate the costs of this activity, the airport layout dimensions in Figure 12 are applied. By using the knowledge and experience of RHDHV colleague (Smits, 2017) a cubic meter price is established of 9 USD. Based on Figure 12 the total amount of cubic meters sand is set on 256.9 million m^3.

A Very Large Floating structure would decrease the dimensions of the sand fill. Sand fill by the traditional land reclamation solution should be applied to a depth of 18.5 meter below MSL.

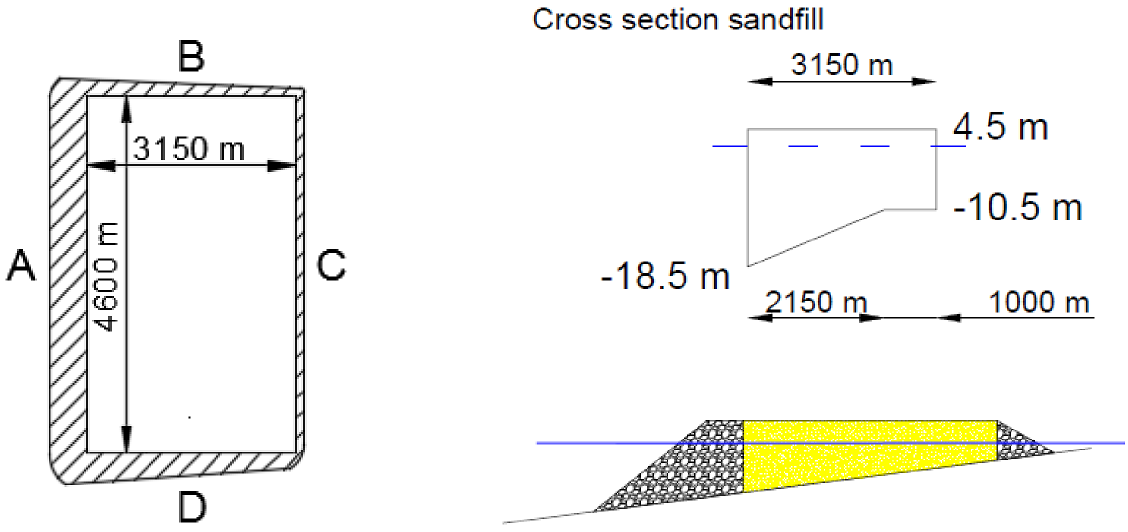

Figure 12 Sand fill dimensions

However according to the supervisor of RHDHV (Stive, 2017) it is not clear weather sufficient sand is available at the project site. Because of the enormous land reclamation plans nearby Manila sand become scarce. It would be possible the price of 9 USD per cubic meter raises to 25 USD per cubic meter or even more.

5.3 Total costs

The total price over the 3 main activities during the construction of the artificial island is depicted in Table 4. The three main activities are summed up and give a cumulative price of 4.442 billion US Dollars.

As described in paragraph 5.2.3 the unit price of sand varies widely. Since the total price has a big influence on the total cost of the land reclamation, this will be included in the cost comparison.

Table 4 Costs of entire traditional land reclamation

Total Costs	
Description	**Amount [$]**
Dredging	114.1 million
Sea defence	2,021 million
Sand fill	2,312 million
Total	**4,442 million**

6 Airport design

6.1 Floating facilities

To understand if a Very Large Floating structure can be implemented in the future airport, a study to the airport and runway facilities of Manila Bay International Airport is required. This investigation results in a reference design of Manila Bay International Airport, where all required facilities included. During this research there has been contact with the company NACO Airport Consultancy and Engineering, which is a company of Royal Haskoning DHV.

Earlier mentioned Manila Bay International Airport serves a capacity of 40 million passengers a year wherein a dual runway is applied. Based on the predominant wind direction of southeast, it results both runways are located to WSW (west southwest) and ENE (east northeast). On basis of a RHDHV study about Manila Bay International Airport (HNM / FBK, 2014), the main parts of the airport layout are:

- Northern runway
- Other facilities (terminal, apron, hangar, cargo, taxiways)
- Southern runway

Table 5 Determination floating facilities

Facility	Main variable average load (N/m^2)	Safely executed as floating
Terminal	Unknown	No
Apron	322	?
Northern runway (only landing)	2.2	Yes
Southern runway (only take-off)	3.2	Yes
Taxiway	3.2	Yes
Hangar	>207	?
Cargo	207-322	?

To understand which facility has the possibility to be executed as floating, is established which main variable average loads are presented at each facility. Normative loads at this airport are the airplanes (Airbus A380) or smaller. This results in Table 5, where is concluded that both runways and taxiways have the possibility to be safely executed as floating structure as the variable loads will cause minimum impact on the buoyancy.

Only one of the runways is executed as a floating structure. Figure 13 shows that the northern runway in the traditional airport layout is located at a much larger water depth than the other runway; therefore it is more cost effective to execute this one as an entire floating structure. In addition the load per square meter at the northern runway is somewhat lower due to accommodate only landing airplanes.

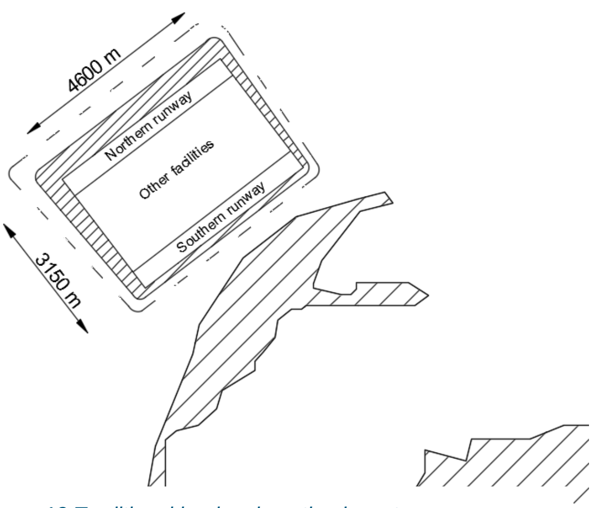

Figure 13 Traditional land reclamation layout

Derived from Appendix C2 are set the total airport dimensions of 4600 meter long and 3150 meter wide.

6.2 Other facilities

All the other facilities of Manila Bay International airport have executed as an artificial island. Buildings (terminal, hangar and cargo terminal) and aprons are positioned logically using the guideline for designing an airport (International Civil Aviation Organization, 2013). Thereby in this hybrid alternative design the southern runway is also located on the artificial island. Appendix C2 indicates how both the hybrid alternative design as the traditional land reclamation is classified.

6.3 Floating northern runway

6.3.1 Build-up

The Very Large Floating Structure functions for landing airplanes at Manila Bay International Airport. On the floating structure a runway is required of 3600 meter long and 80 meter wide. Since it is necessary airplanes can leave the airstrip as quickest as possible, a parallel taxiway is applied on the floating structure. To settle the air traffic, five connections are required between runway and taxiway. Based on the design requirements of the book (International Civil Aviation Organization, 2013), the total floating construction is 3900 meter long by 450 meter width. According to Appendix C2 is set that the VLFS is located at a water depth that that varies from 16 meter below MSL to 18 meter below MSL.

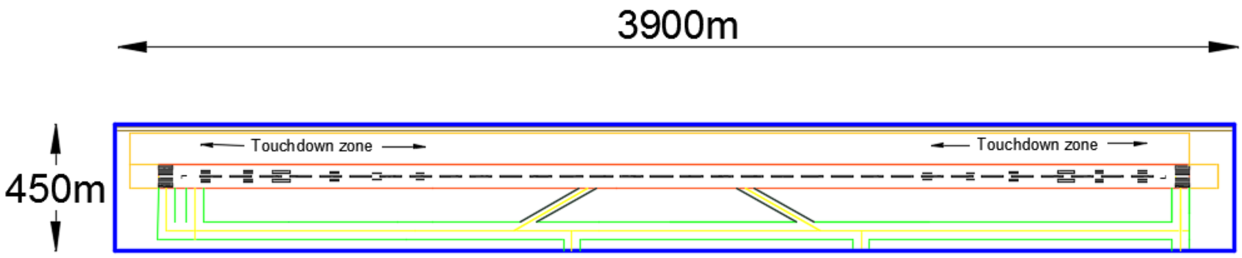

Figure 14 Build-up Northern runway

Two important instruments at the runway have influence on the total length of the VLFS. These are the localizer and glideslope transmitter. Both devices provide the pilot information about the location of the plane referred to the centre axis of the runway and height to the runway during landing. Since these devices are situated approximately 350 meter at the end of the runway, is decided for cost considerations not to place this on the VLFS. The systems are mounted separately on mooring piles. In consequence the total length of the VLFS in the alternative hybrid design decreases from 4600 meter to 3900 meter. Figure 14 indicates the build-up of the VLFS, which is based on guideline for designing an airport. (International Civil Aviation Organization, 2013)

6.3.2 Connection artificial island

The floating runway construction must be connected to the artificial island. A bridge connection which functions as taxiway is therefore necessary for airplanes to reach the vertically “fixed’’ part of the aerodrome. Based on the maximal longitudinal slope at the taxiway, a length of 250 meter is required. It is essential to minimize the connections because the costs are high and the construction is very complicated.

Three connections are applied between the floating and fixed part of the airport. In consultation with senior airport development advisor of NACO (Baijer, 2017) three connections can generally settled the air traffic. In Appendix C3 is depicted the bridge connection in the normative situation between the floating structure to the fixed airport. The level of the floating structure is based on the LAT (lowest astronomical tide, -1.04m MSL) with a freeboard of 2.0 meter. This value is set in consultation with the supervisor of RHDHV. (Stive, 2017)

First it consists of a part of 236 meter, which moves on the floating structure by the water level and on the other side is mounted on a concrete pole. The last 14 meter is a safety distance which leads to the fixed airport. On the fixed airport the connection connects at a height of MSL +4.50 meter. Important to mention is that this connection is not elaborated further in this thesis.

Figure 15 shows the taxiway connection between the VLFS and the vertically fixed airport.

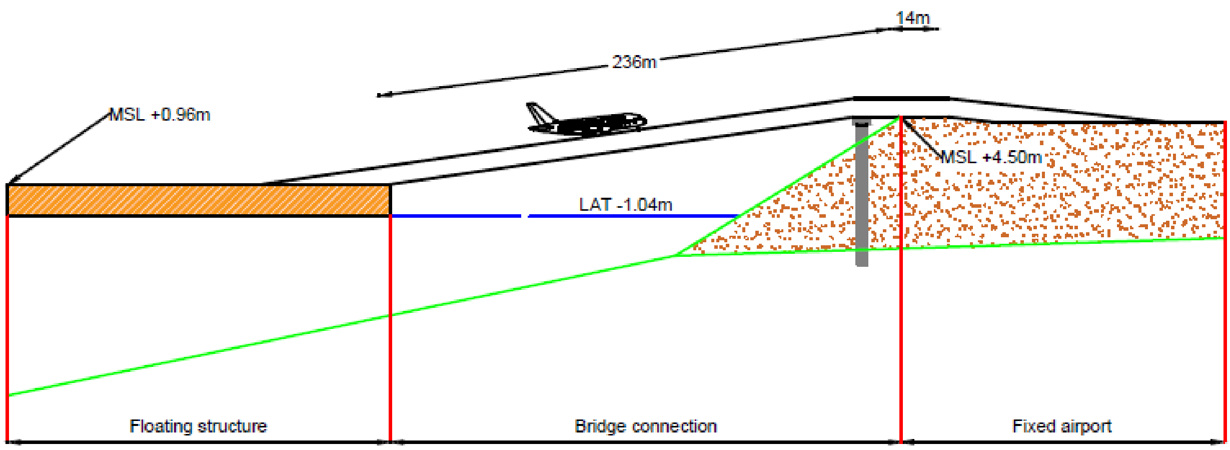

Figure 15 Taxiway connection

6.4 Layout hybrid alternative design

By the application of a VLFS the traditional land reclamation solution changes in the hybrid alternative design; depicted in Figure 16. The floating runway is parallel located to the artificial island and has a length of 3900 meter. Three taxiway connections of 250 meter long are applied to connect the northern runway with the other facilities. Relative seen to the traditional land reclamation the width of the airport decreases from 3150 meter to 2700 meter.

Earlier described is that the length of the northern runway is reduced in this hybrid alternative design relative to the traditional land reclamation layout.

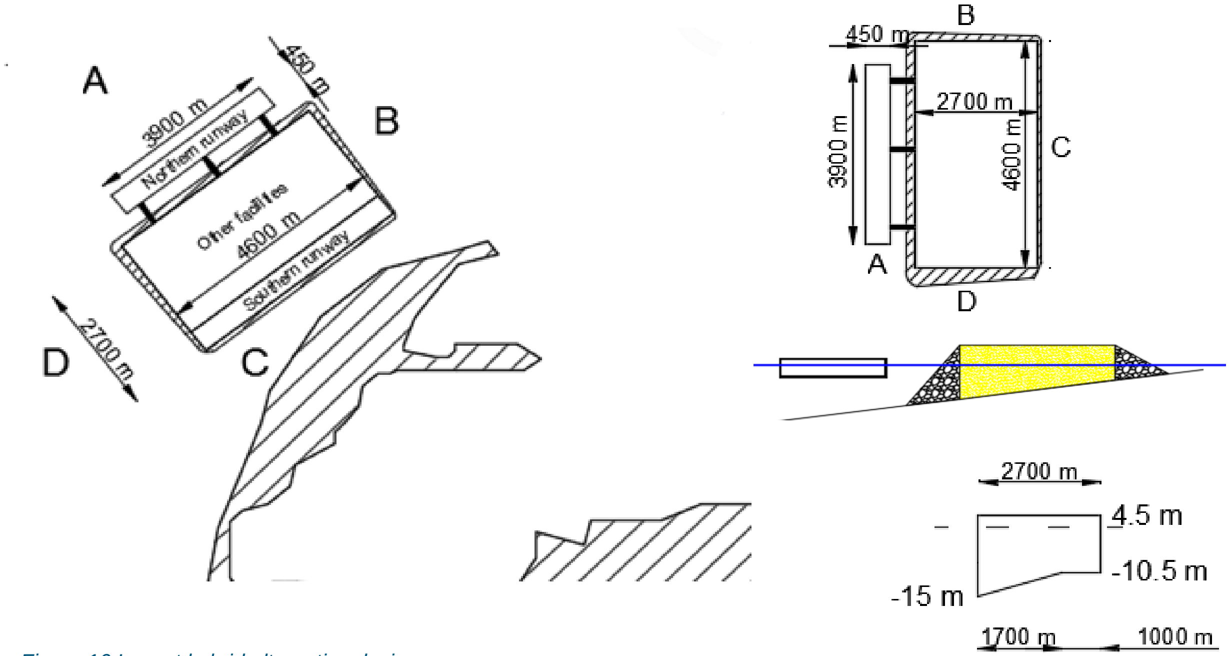

Figure 16 Layout hybrid alternative design

The change of the traditional land reclamation to the hybrid alternative design does have two important economic advantages:

- <u>Sea defence A can be executed smaller and cheaper</u>

By positioning VLFS as depicted in Figure 16, it can functions also as breakwater for sea defence A. Since this side is defined as the hard exposed side, this can lead to significant cost savings.

- <u>Amount of sand in the artificial island decreases</u>

The amount of sand decreases by applying a VLFS based on the cross sections of Figure 16. Since sand fill will only be applied to a depth of 15 meter below MSL instead of the 18.5 meter below MSL.

7 Structural Analysis

7.1 Elastic deformable construction

A vessel or construction in waves is exposed to different waves with different lengths and heights. Several movements occur; these movements were indicated as roll, pitch and yaw. During these movements a construction experiences huge bending moments.

A Japanese professor (Wang, 2010) derived Figure 17 of a study to very large floating constructions. By using two ratios the graphics shows the reaction of the structure in the wave conditions. A vessel moves in the waves; the bending moments that arise due to this are adopted in the total height of the vessel. However it is impossible to build a relatively flat runway with sufficient stiffness.

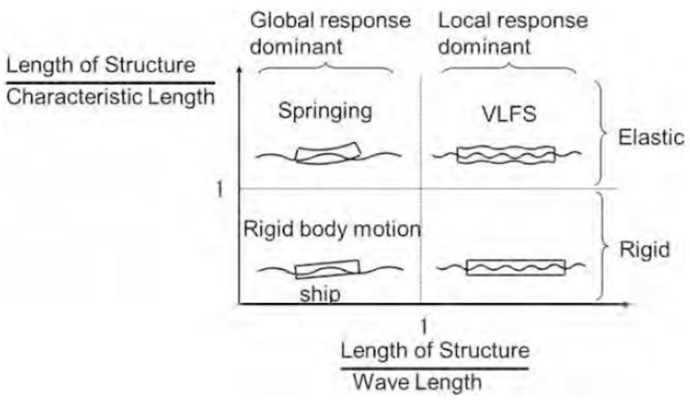

Figure 17 Graphic about reaction floating body by waves

The characteristic length is the outcome of a formula that belongs to the graphic; the formula is applied in Deliverable E. The big length of the floating runway and the wave length result is a local and elastic response of the structure due to waves. This proves that it would not be impossible to build a total rigid construction that has the dimension of the runway. The floating runway shall be a modular compiled construction by means of a hinge connection system

Figure 18 shows a modular cross section, planes cause a distortion downwards and waves cause a distortion up- and downwards. Rigid elements connected with a system that allows small rotation can serve as floating runway; a load would cause distortion over a small area.

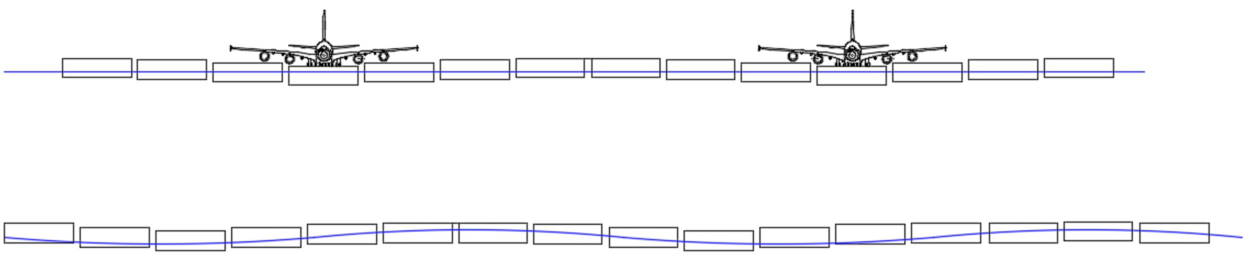

Figure 18 Local deformation of the runway construction

7.2 Load combinations

During the design phase the three hydraulic conditions are converted to load combinations.

During this design phase three load combinations are used regularly:

- Daily conditions – Operational conditions
- Typhoon conditions – Survival conditions
- Post typhoon swell conditions – Survival conditions

Figure 19 shows these load combinations, within this feasibility study is assumed that the floating runway is out of use during typhoon conditions and post typhoon swell conditions since the movements in the structure become too high. At daily conditions the waves in Manila Bay are small; these circumstances dominate approximately 90% of the year. During this time the construction can be used for landing and thereby several planes can stand upon the floating object.

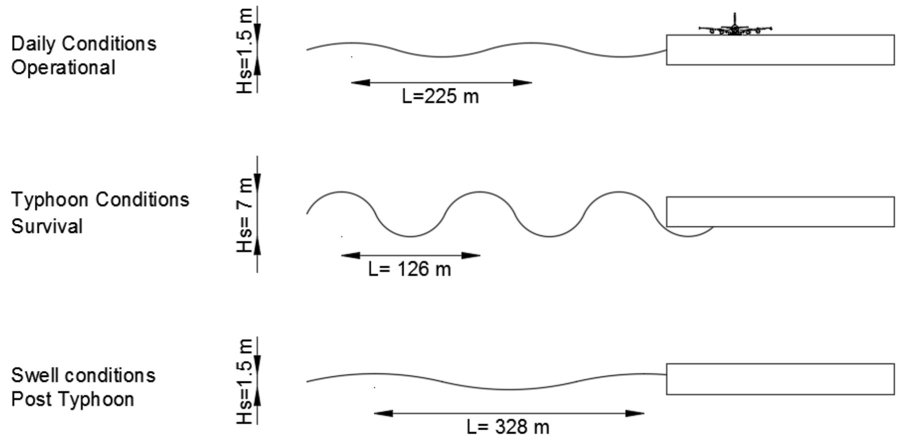

Figure 19 Load combinations

7.2.1 Waves

The load out of waves is complicated and can be split in several different forces unto the construction. Figure 20 shows wave attack, wave overtopping and waves underneath the structure.

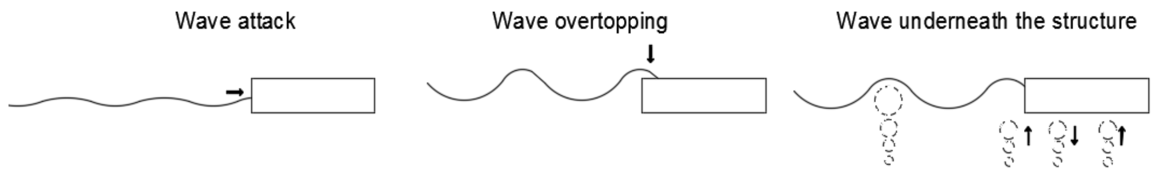

Figure 20 Different forces throughout waves

The waves underneath the structure are considered as normative, since the wave attack and wave overtopping loads only occur along the sides of the floating runway. The feasibility of this VLFS mainly depends on the size of the bending moments as result of the orbital movement underneath the structure.

The wave motion underneath the structure causes overpressure and negative pressures that move along the total construction. These opposite vertical forces results in bending moments inside the construction. Figure 21 depicts the bending moments inside the floating construction. The forces that occur are calculated in Deliverable E the Structural Analysis.

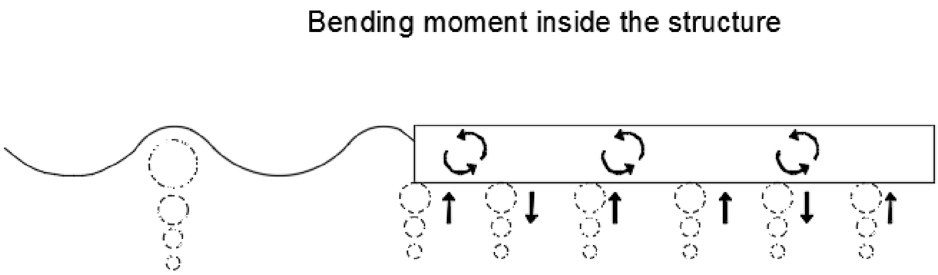

Figure 21 Bending moments inside floating construction

Equation 1 is used for the calculation of the bending moments; the biggest value arise throughout long waves; the post typhoon swell waves. Table 6 shows the different values of the three wave conditions.

Maximum bending moment:

$$M = \frac{1}{\pi^2} * P * (0.5L)^2 \qquad \text{Equation 1}$$

M	bending moment inside construction	kNm
P	mean pressure inside a wave	kN/m²
L	wave length	m

Table 6 Values bending moments inside structure

Conditions	Bending moment inside construction [kNm]
Typhoon conditions	2685
Daily conditions	1916
Post typhoon swell conditions	4293

The amplitude of a wave is a parameter that is used to calculate the mean pressure inside a wave; within this calculation the amplitude is reduced with a transmission coefficient (tc). Reason for this is that the movement of the wave under the large floating structure can not to be considered as a free wave. The wave is strongly influenced the construction due to this and by the length of the structure, the transmission of the orbital movement decreases. This transmission coefficient is set on **0.2** (according to (Peters, 2017)).

7.2.2 Airplane

To ensure an airplane can be adopted in a rigid floating element, the runway should be modularly constructed. A plane causes a displacement of water over a certain area and thereby a deeper draft. The water underneath the construction gives resistance to the downward movement. An airplane upon the floating structure can be compared with a person on a trampoline.

A rigid segment can be obtained by designing the element sufficient high. The desired result is that deflection of the segment is minimized. An airplane causes bending moments in the segments and shear forces in the connection system. Concluded of Deliverable E “Structural Analyses’’ is set that the bending moment throughout an Airbus A380 is smaller than the bending moment that arises throughout the post typhoon swell waves.

Based on Table 6 is concluded the normative load that arises in the elements is 4293kNm.

7.3 Schematization structure

The dimensions of the floating runway are set at 450 meter width and 3900 meter length.

Vertical movements of the total structure will arise throughout astronomical tide fluctuations and variable loads throughout planes.

Several mooring systems along the structure allows these vertical movements, however prevent movements in horizontal direction.

Figure 22 shows the schematization of the total floating runway construction.

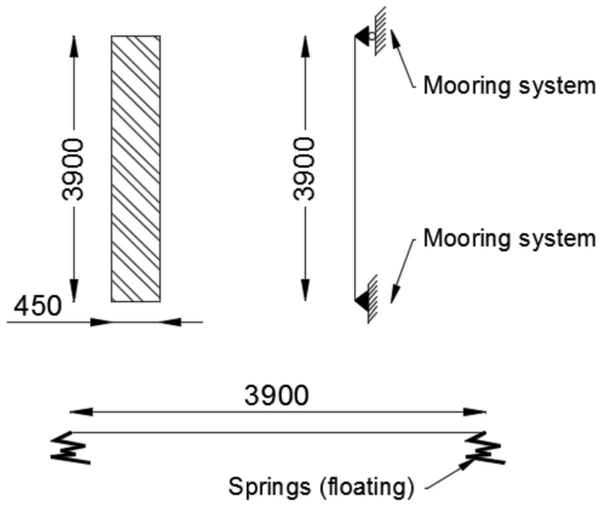

Figure 22 Schematization floating runway

8 Design floating segments

8.1 Cross section shape

This chapter contains a summary of Deliverable F “Concept design floating segment”; this part of this research is conducted by Sjaak Bijl. The design of the floating runway consists of several building segments. Subsequently different shapes of building blocks in the cross section are possible. A cross section shape has to provide a surface to attach the connection system between the segments.

Derived from Deliverable F “Concept design floating segment” a barge shape is set as building block. Figure 23 schematics the box shape; all walls of this shape are flat. Main reason to choose for this shape is that is simple to build it in concrete or steel. In general the costs of this simple barge shape are relative low.

Figure 23 Barge shape

A barge structure has a relative small draft and high freeboard. Likewise these shapes are previous applied in big floating constructions that are exposed to heavy loads. Disadvantages of this segment are the relative high wave impact and the vertical forces at the bottom of the structure are more complicated.

It is concluded that the barge structure gives the best possibilities to build simple, big and rigid segments and that is possible to attach a strong connection system.

8.2 Material

Another important consideration is the material of the building segment itself. Most common materials for floating segments are steel and concrete. In smaller and light constructions EPS and composite are good alternatives. Derived from Table 7 EPS cannot deliver sufficient strength to the construction and the resistance in salty conditions is bad. Very big floating structures in heavy wave conditions are never realised in composite; therefore this material is not considerate. A combination of steel and concrete is result in a material where the best properties are applied; reinforced concrete.

Main reasons to choose for the concrete casing are the simple process ability and the costs. Besides the earlier described runway in Japan (Yokosuka Floating Airport) consist of steel and is demolished probably due to the salty conditions. Because of this past it is better to choose the material concrete as casing.

Table 7 Material properties ((Blok, 2012) (Stybenex) (Vonk, 2015))

	Concrete C35/45	Steel S235	Composite	EPS
Weight	24 kN/m^3	78 kN/m^3	1.8 kN/m^3	0.4 kN/m^3
Young modules	Varies; 3.3*10^4 N/mm^2	2.1 *10^5 N/mm^2	1.6*10^5 N/mm^2	8 N/mm^2
Compressive strength	27 N/mm^2	235 N/mm^2	150 N/mm^2	0.15 N/mm^2
Tensile strength	1.65 N/mm^2	360 N/mm^2	300 N/mm^2	0.2 N/mm^2

9 Grid structure

9.1 Placement segments

Before determining the size of the segment and type of connections, it is essential to understand how the grid structure of all the floating elements is formed. A grid structure gives in the top view the pattern wherein all the segments are placed to ultimately form the entire runway construction. The shape of the segment in top view is earlier set as a box shape. However seen in the top view different patterns are also possible. Due to the waves in Manila Bay all the segments must be laid in an optimized grid structure.

9.2 Explanation principle grid

When a wave field reaches a specific grid structure, it is required that forces and bending moments can be absorbed by the segments. Most important principle is that segments should be able to absorb as many waves as possible from different directions. When a wave reaches a separate segment, it rolls underneath the structure; this is depicted in Figure 24. A bending moment arises inside the floating segment which must be absorbed by the element itself.

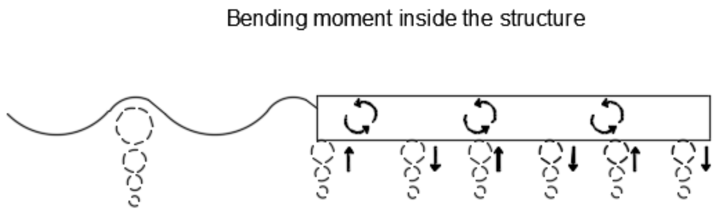

Figure 24 Occurring bending moment by waves (one segment)

If a situation with two connected segments is considered, see Figure 25, a wave rolls also underneath the elements and causes bending moments inside both structures. Earlier mentioned is that a hinge connection system is applied and allows rotations. When a wave rolls underneath both connected segments, a rotation arises between the floating structures. This rotation is caused by overpressure and negative pressures of waves that move along the total construction. If the wave length is longer, the rotation between the floating structures will increase.

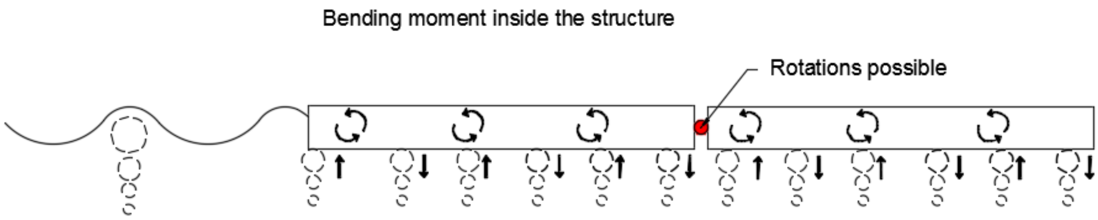

Figure 25 Occurring bending moment by waves (two connected segments)

The purpose is to set a favourable grid structure which divide the rotations between elements as best as possible across all the elements and distributing the forces as well as possible. Consequence is that a grid structure is required that has high strength properties in all directions.

9.3 Requisite pattern

9.3.1 Grid structure

To understand when a grid structure has high strength properties against the presented waves is set a comparison between the half-stone pattern and herringbone structure. Both structures are implemented as the floating runway construction in Manila Bay.

Figure 26 shows the occurring bending moments inside the grid structure by an extreme situation. It can be concluded the herringbone grid is much stronger in this direction. Rotations and forces within this pattern will be distributed over all the segments by different wave directions. In the half-stone band rotations in this figure rotations will not be distribute, this is very disadvantageous. Therefore a herringbone pattern has high strength properties against presented waves.

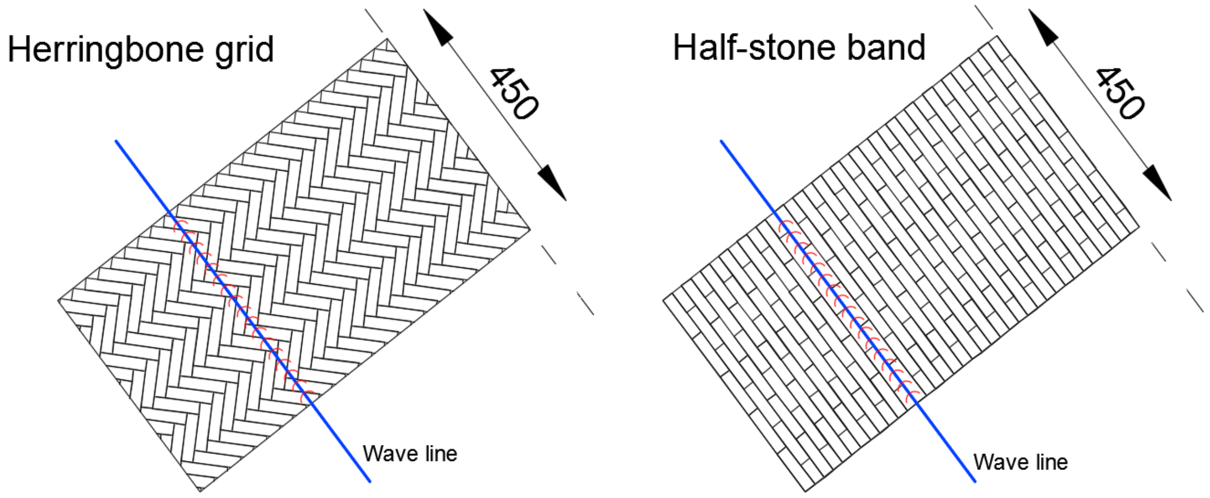

Figure 26 Occurring bending moments inside grid

Earlier mentioned is that the connection is a hinge system and therefore allows rotation. In Figure 27 is displayed the cross section of two connected floating elements. A huge rotation arises because of the opening between the elements. This extreme situation occurs only if the wave line is parallel located with connection system. In the herringbone grid structure this situation never arises, since the wave line intersects several segments that can adopt forces throughout waves. The concrete casings are designed by means of the stiffness to withstand the forces caused by post typhoon swell waves.

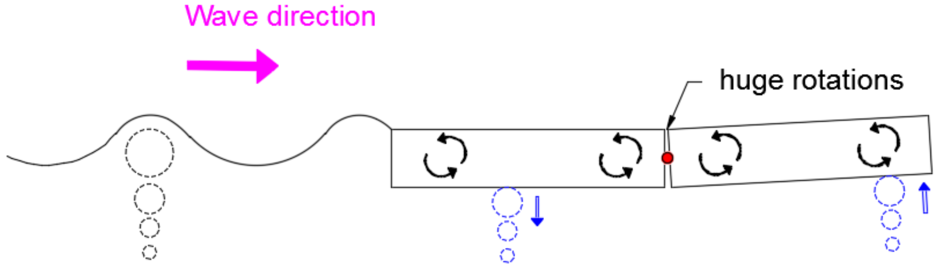

Figure 27 Cross section half-stone band structure

9.3.2 Connections

Several different grid structures are assessed and rated with a percentage. Thereby within a certain grid different width-length ratios are possible. Different sizes of ratios are investigated; these are 1:2, 1:3 and 1:4. Higher ratios are disregarded, since these are detrimental to the workability and strength of the elements.

Figure 28 shows the herringbone grid structure with the different width length ratios. One wave direction is displayed by each structure and the shaded segments can adopt forces throughout waves. Concluded can be set that in one pattern a ratio of 1:4, the quantity of concrete cases (in percentage) as absorb bending moments is the highest. Therefore this is the grid structure with the best strength properties.

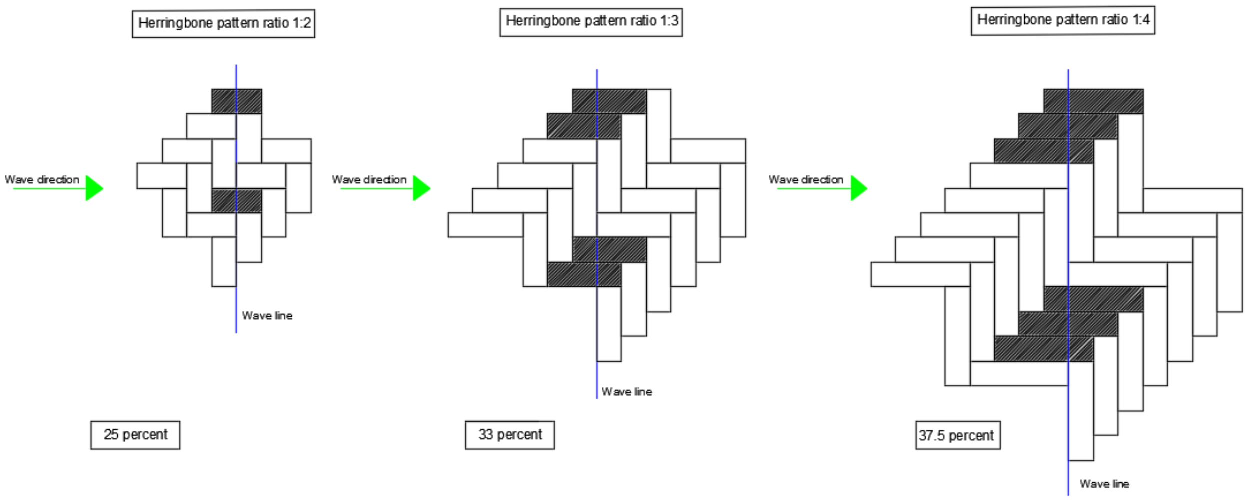

Figure 28 Different width length ratios herringbone grid structure

To establish the connection system, first is essential to position all the connections within the grid structure. In other words it means the quantity of required connections within the gird structure is established. Earlier mentioned is that a herringbone structure (ratio 1:4) is applied, wherein a hinged connection system is used. Since all the concrete casings have a rectangular shape in the top view, it is possible to add connections along the long or short sides of the elements. The total dimensions of a concrete casing are 90 meter long, 22.5 meter wide and 6.5 meter high. How these dimensions are achieved is explained in the next chapter of the concrete casing.

Connections along the long side result in a torque which functions to distribute rotations and forces over all the elements, depicted in Figure 29. By a relative higher arm at a certain bending moment, a relative smaller force can be adopted in the connection. Concluded concrete casings which are connected along the long side have to absorb lower (shear) forces and can be dimensioned less heavily.

In Figure 29 the wave line is parallel located to the connection system. Following to the green line, the occurring bending moment will distribute. Two of the red connections reinforce each other; at a greater intermediate distance, it increases the torque that can be adopted. In these hinged connections shear forces has to be adopted.

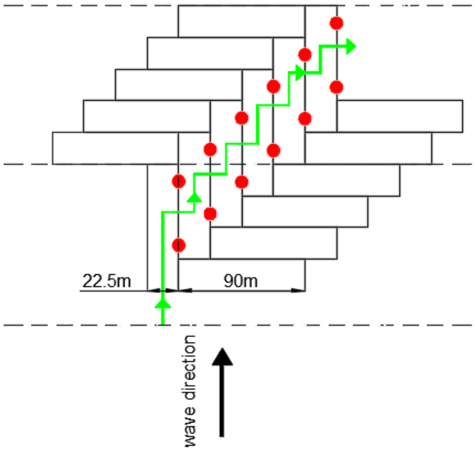

Figure 29 Principle connections long side

9.4 Chosen herringbone structure

Different grid structures are drawn up in a longlist. In this stocktaking different patterns and shapes are used. Main goal is to set a grid structure which can divide the rotations between the segments and distributing the forces as well. However in view of the project goal, it is also required to minimize the costs. It means manufacturability and experience in the execution are important requirements for the grid structure. The three strongest grid structures to absorb waves are displayed in Figure 30.

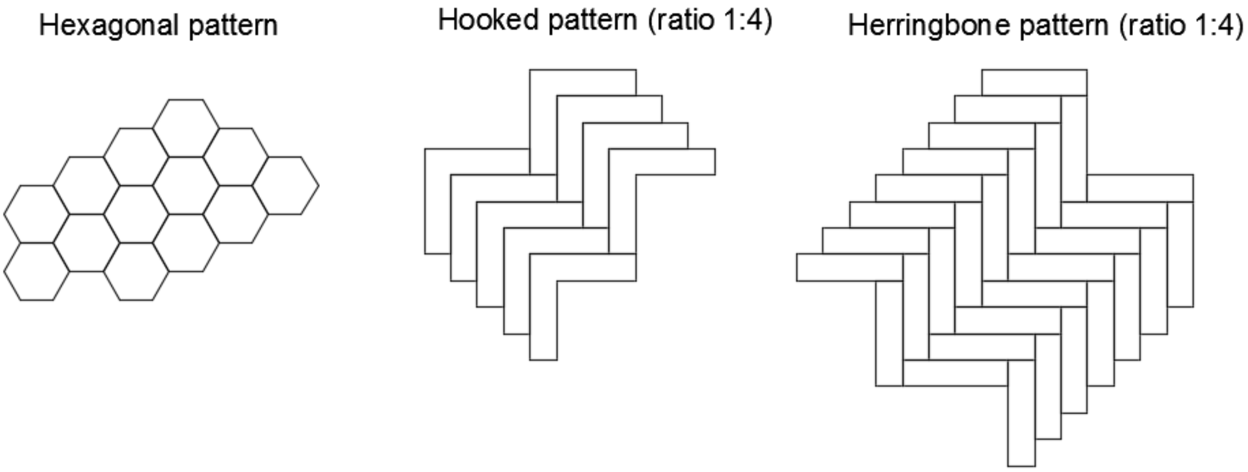

Figure 30 Strongest grid structures

Derived of the literature study (Deliverable B “Study VLFS’)’ the hexagonal shape is the first option; main advantage is the strength of the structure in all directions. This segment shape can be considered as a hexagonal platform. However relative to the other two structures the shape is very complicated. Formwork and connections to other segments must be designed very accurately. Consequence is that the manufacturability and the operation to place the segments are time-consuming and the costs of the entire runway increases enormously. There is little experience with hexagonal segment shapes; consequence this will make the investigation far too complicated.

Main advantage of hooked pattern (width-length ratio 1:4) is that operation of the segments is relative seen the easiest. The hooked segments squeeze as it were on each other and form the total grid. But also this segment shape is more complicated than the herringbone structure.

At least the herringbone pattern (width-length ratio 1:4) has the main advantage of relative simple rectangular shape. Also the shape of the element can be compared with the barge or an immersed tunnel segments; it means experience in the field of connecting the segments is present. Downside is that all the segments must be connected exactly as a herringbone width length ratio of 1:4.

By comparing the three different grid structures is chosen to apply the herringbone pattern. The main arguments to apply this grid structure are:

- easiest to manufacture;
- bending moments by waves are always adopted from the predominant wave direction;
- grid structure itself has in general the most experience to realise.

Based on the Basis of Design the main wave direction of the normative swell waves varies between 225^0 and 270^0. The orientation of the grid structure is established that from the predominant wave direction almost all occurring bending moments are adopted by the segments. This statement is further explained in paragraph 6.3. It results a herringbone pattern with a width length ratio of 1:4 is the best grid to apply. Over the herringbone grid structure the biggest part of the bending throughout waves are adopted in the concrete segments. Consequence is that the loads in the connections are minimized.
Figure 31 depicts the placement of all the segments in the grid structure.

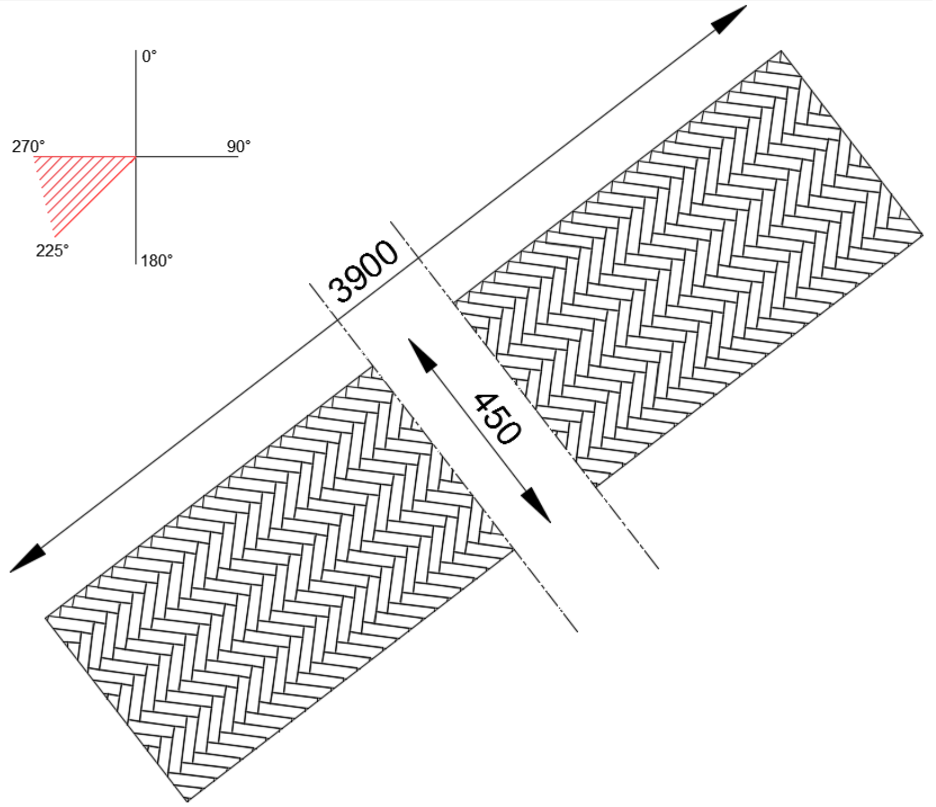

Figure 31 Placements segments in grid

Over an intermediate distance of 60 meters two connections makes it possible to adopt high bending moments. However connections along the short side are indispensable to keep all the concrete casings together. Only these connections have to withstand the occurring shear forces when one segment moves downwards. In Figure 32 the required connection points of one segment are shown. A total of 3428 connection systems are needed for the floating runway construction.

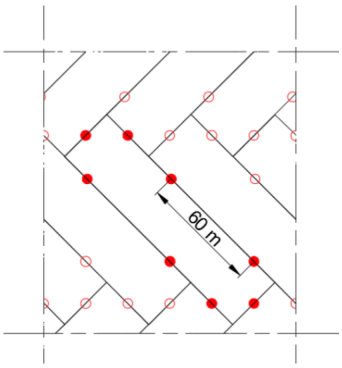

Figure 32 Intermediate distance

10 Connection system

10.1 Longlist

10.1.1 Boundary conditions

Within this feasibility study the hinge connection system is one of the most critical points. This system has to withstand the normative shear forces of an Airbus A380 and post typhoon swell waves. Besides it means the hinge system has to rotate in upwards (airplane + waves) and in the downwards (waves) direction. Reason is to ensure the floating runway construction response elastically and deformed local.

Another important boundary condition is that the maximum required distance between the elements is determined. Since it should never occur that an airplane can come with their wheels in the seam between the floating elements. Consequence is that the presented airplane with the smallest wheels at Manila Bay International Airport is determined. It requires that the maximum intermediate distance between the segments is not higher than 20 centimetres.

10.1.2 Alternatives

An alternative system is to put a steel cable throughout the segments and tensioning the cables. It creates a strong connection and limited rotation is possible. However it is really hard to realise this for all the connections over the total runway construction. Next a hinge combined with a spring is an alternative where two connection elements work together. The hinge allows rotation and the spring can be pressed or depressed. Downside is that there is hardly any experience to apply this system.

A connected fender system with bolts is also a serious option. Fenders consist mainly of rubber, which is a very elastic material. This material is also good resistant against salt water. Another alternative is to customize both ends of the segments, In this case, segments fall into each other like puzzles, whereby also a thin layer of rubber or synthetic material is applied. As last a pin connection is potential solution, whereby one segment has a sort of steel pin, which can interlocked with the other floating element. Main advantage is the easy execution; however a downside is that corrosion problems can occur. In Appendix H1 all the connection systems are schematically depicted

10.1.3 Chosen final system

A longlist is set for all the alternative connection systems. To determine the final system selection criteria are used to rate the alternatives. One of the most important requirements in relation to the project goal is that it is technically possible to apply the system for in total 3428 connections. It means the connection should be easy to manufactural and to execute. But the system must be able to function in the heavy wave conditions of Manila Bay and withstand the impact of an airplane.

Another important requirement is that the costs should be limited. It means a simple, sufficient strong connection is attractive. Therefore the connection should be consisting of limited, easy obtainable components.

Other less important criteria are durability and maintainability. The lifespan of the connection system should be certainly decades. Components inside a connection which are constantly exposed to the sea water are salt-resistant materials. Maintenance should also be considered; therefore the connected segments should have the possibility to disconnect. It must be possible to unlock a segment in the final grid structure for maintenance or even replacement.

By comparing the all the alternative connection systems, the hinge combined with a spring and the fender solution are the most feasible. The main arguments to apply a hinge combined with a spring are:

- best technical possible to apply it for the huge quantity of connections within the grid structure;
- connection system deliver high strength properties;
- relative simple build-up, therefore the costs are relatively not very high;
- possibilities to unlock the segment for maintenance.

Reasons to choose for the fender solution are:

- technical possible to apply it for the huge quantity of connections within the grid structure;
- connection system deliver high strength properties;
- the rubber of fenders is a salt-resistant material.

In consultation with a RHDHV expert (Peters, 2017) about the most feasible connection system, is concluded to combine the hinge (located upside in the cross section) with a fender block. Thereby the fender block (mounted in depressed state) functions as the compression spring at the bottom side in the cross section. A combination of steel hinge and the salty resistant fender result in a system which consists to favourable properties.

Movements

When an airplane moves over two connected segments (named as the downward situation), a rotation occurs upwards in the hinge. Resulting to the rotation and deflection a compression force arises in the hinge. The fender block is mounted in compressed state; it leads in this situation to a reduction of the compression. A downward situation can also arise when two wave tops are located underneath both segments. When the wave top is located underneath the connection, it creates an upward situation. The rotation in the hinge is downwards and causes a tensile force. At the bottom side the fender will be pressed by the compression force. Due to this depression, the rotation on the upper side will be damped. In Figure 33 is shown the behaviour in the downward and upwards situation.

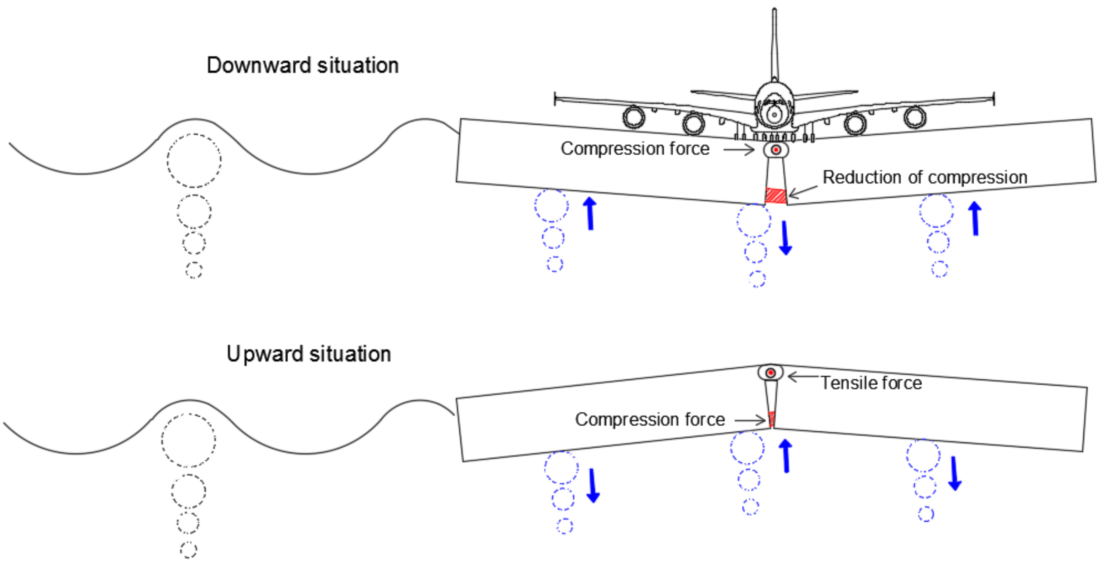

Figure 33 Behaviour connection system[1]

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[1] Note: The rotation displayed in this figure is roughly schematized; however in the realistic situation this rotation will never so high.

10.2 Final connection system

10.2.1 Cross section

Earlier set is that a hinge is placed upwards to ensure the rotation between the segments due to the loads is minimized. To place a hinge connection upside, consequence is that the concrete casing consists of notches at the location of the connections. Figure 34 indicates all the notches by one segment in the top view. At all the 8 notches at this segment the same connection system is applied.

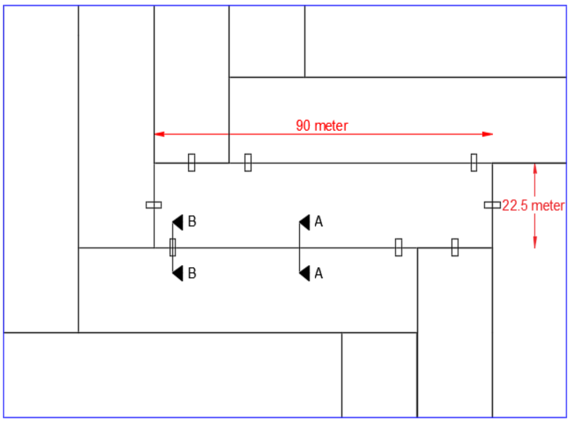


Figure 34 Top view connections segment

In Figure 35 is depicted the cross section over B-B in the above view. At the upside a hinge connection is created by through a pen into two steel eye plates. Rotation is possible over a pen of steel. It is noted that the hinges will also have to accommodate very small rotations in other directions than the main hinge direction. These rotations are assessed to be balanced by material deformations within the hinges.

Since huge shear forces arise in the construction of steel; a heavy steel beam profile is attached on the concrete floor. An intermediate distance of 100mm between the casings is applied. Main reason is that this distance provides sufficient drainage can take place.

Above both steel beams in Figure 34 a demountable cover plate is mounted. This cover plate ensures that no “thresholds’’ are presented at the runway construction. Earlier mentioned is that the fender block at the bottom side functions to reduce the rotation inside the connection.

The following section discusses the details of both the hinge connection (detail 1) and the fender block (detail 2). For cross section A-A of Figure 34 is referred to Appendix H2.

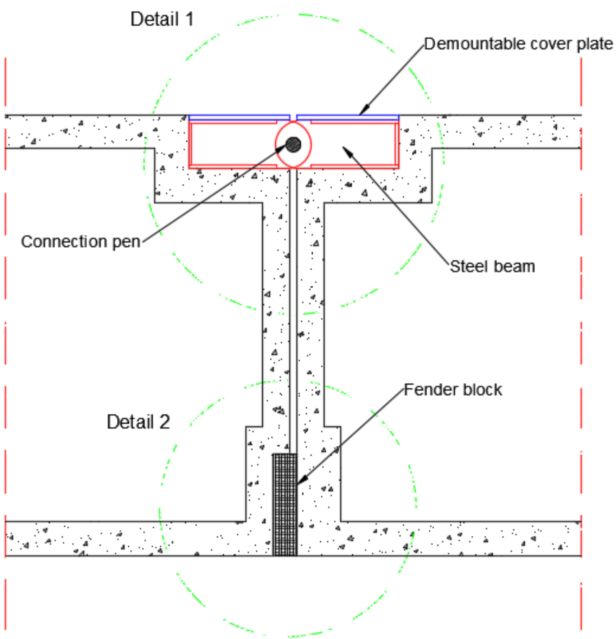


Figure 35 Cross section B-B

10.2.2 Details

Figure 36 indicates the details of the hinge system. The steel beam can be seen as a very strong profile with thick flanges of 50mm. These thick flanges are required to ensure shear forces can be adopted inside the connection. Through the steel flanges the biggest presented bolts are applied, M48 sizes, to create a connection with high strength. Demountable cover plates of 80mm are laid on the top of the steel beam. In Appendix H2 is included a detail top view of the hinge connection.

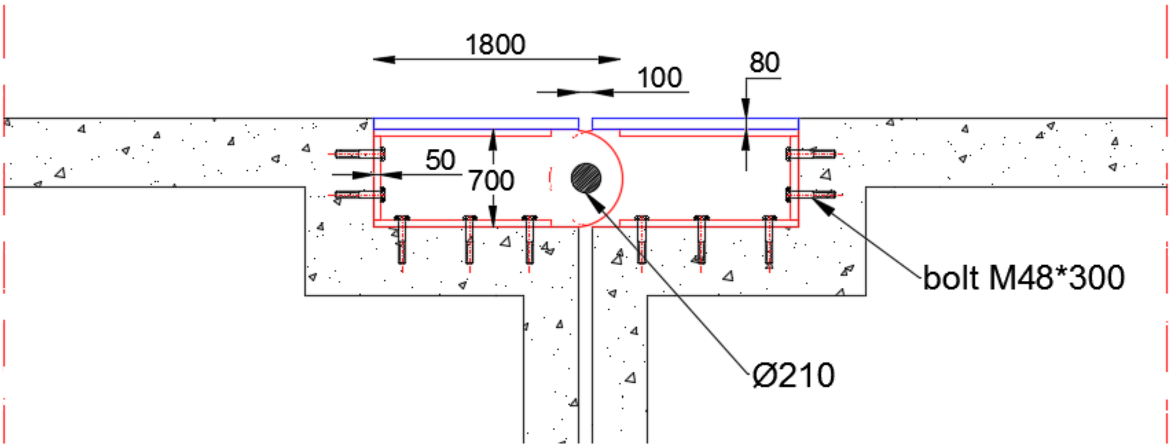


Figure 36 Detail 1 Hinge system (dimensions in millimetres)

In Figure 37 is depicted the details of the fender system. A rectangular fender (mounted in compressed state) is applied which contains of connection holes (green shaded area). Through this 1.5 meter high fender also strong anchor bolts of M48 are used. These are placed so that the fender is very tightly connected to a concrete casing.

In general the dimensions and bolt sizes inside this connection are assumed by means of the presented loads inside this connection. A critical part in this connection is the steel pen. Since the steel pen has to adopt the shear forces caused by the post typhoon swell waves, a diameter of 210mm is required.

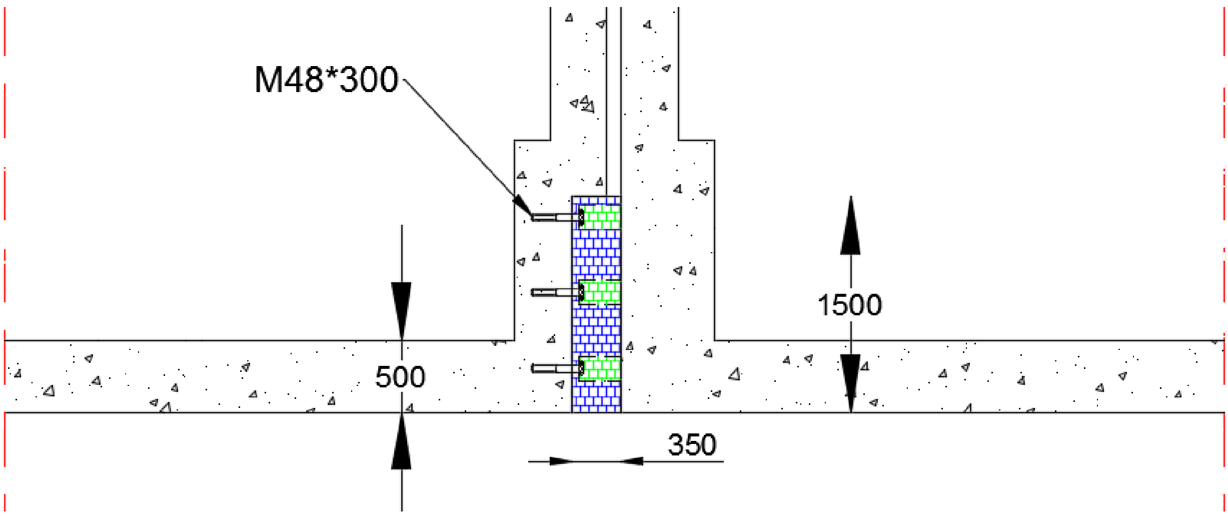


Figure 37 Detail 2 Fender system (dimensions in millimetres)

Royal HaskoningDHV

11 Concrete casing

11.1 Build-up segments

This chapter contains a summary of Deliverable I “Concrete Casings”; this part of this research is conducted by Sjaak Bijl. Main goal of this study is to set the dimensions of the concrete casings whereby these segments barely deformed by the normative post typhoon swell waves.

To ensure the segments are sufficient strong, a strength class has been chosen. All concrete casings are located in Manila Bay; therefore the environmental concrete class can be named as XS. Within this class it demands a strength class of C35/C45. A concrete casing consists out of an above and bottom floor. Between these floors walls are placed. A freeboard of 2 meter is required for the floating segments.

Since an airplane causes a huge bending moment in the above floor of a concrete casing, intermediate walls are placed. Walls inside the casing adopt the shear forces. Consequence is that bending moment inside the floor is lower; however intermediate walls are quite expansive.

Inside the casing walls are places over 15 meters in the length direction and 5 meter in width direction. Derived from these distances is set that the concrete casings have total dimensions of 22.5 meter width and 90 meter long. This width length ratio correspondent to the herringbone grid structure, ratio 1:4.

11.2 Stiffness segments

To create a high stiffness of the concrete casing, it should have a certain height. A bending moment throughout the post typhoons swell wave is normative. The value of 4293kNm per meter wave is used to set the required stiffness of the casings.

However due to the concrete casings inside the herringbone grid structure the stiffness is higher. Based on Figure 28 a shaded segment has to adopt the bending moment over one “standing’’ and one “lying’’ segment. Since the wave line is perpendicular located to the connections, it means the intermediate segments (not shaded) cannot adopt bending moments.

A permissible deflection is set on 0.009 meter (1/1000*total span). Consequence is that the segment is 6.5 meter high and bot floors have a thickness of 0.5 meter. With this height the segments have a freeboard of 2.34 meter. In Figure 38 is shown the cross section of the concrete casing. At the location of the notch the previously connection system is connected.

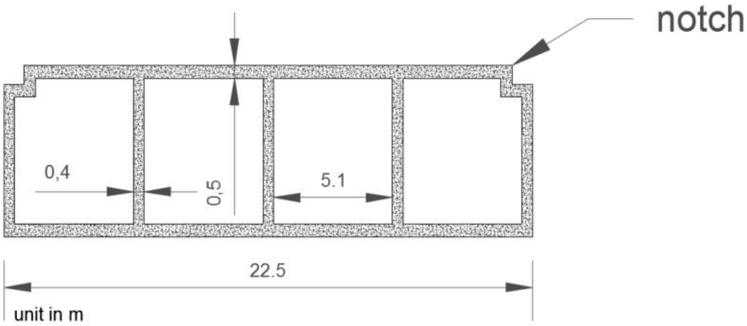


Figure 38 Cross section concrete casing

12 Total costs VLFS

Since the sizes of the concrete casing are known and the connection system it is possible to make a cost estimation of the Very Large Floating Structure. However additional elements such as the bridges and mooring systems have to be part of the VLFS.

In Table 8 is estimated that the total price of a 3900 meter long and 450 meter width VLFS is 2133.5 million USD. The concrete casings largely (more than 80 percent) influence the total price of the VLFS.

To estimate the price of the concrete casing is used the knowledge about the heavy conditions in Manila. Finally in consultation with (Peters, 2017) is decided to use a price of 600$/m^3$. An optimization of the concrete casing dimensions could result in a smaller amount of connection systems. However it would probably not lead to a considerable saving.

In Deliverable H “Connection system’’, Deliverable I “Concrete casing’’ and Deliverable J “Cost comparison’’ the total cost estimation of the VLFS is elaborated in more detail.

Table 8 Cost estimation VLFS

Cost estimation Very Large Floating Structure		
Compounds	**Quantity (num**	**Price in million USD**
Concrete casings	975	1795
Connection systems	3428	186.1
Bridges	3	150
Mooring system	12	2.44
Total price		**2133.5**

13 Cost comparison

Both the construction of an artificial island and the construction of a VLFS are expensive projects. All costs that are presented in the previous chapters are summarized in this chapter. This comparison is clarified with Figure 39; the so called traditional land reclamation versus the hybrid alternative design. A similar figure is shown at the start of this research. The new figure shows the outcome of this research.

- the width of the land reclamation decreased from 3150 meter to 2700 meter
- the floating runway also functions as a breakwater in front of the sea defence

The sand fill cross section over both artificial islands is previously depicted in Figure 12 and in Figure 16. Appendix J1 shows the top views and both cross sections.

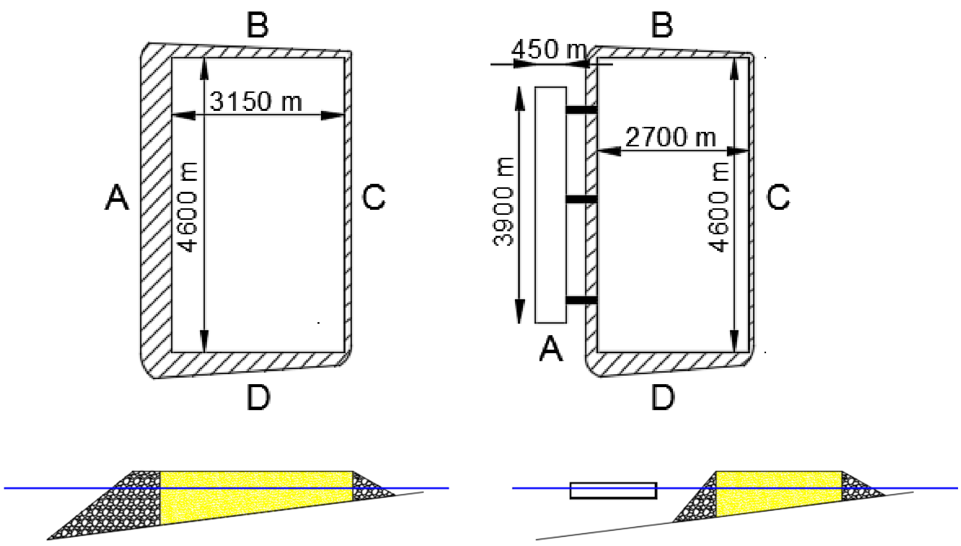


Figure 39 Traditional land reclamation and hybrid alternative design

In order to be able to compare both designs two tables are made. Table 9 indicates the total price of the traditional land reclamation; whereas Table 10 shows the total costs of the hybrid alternative design.

Table 9 Total costs traditional land reclamation

Traditional land reclamation (net surface: 14490000 m^2)				
Component	**Quantity**	**Unit price**	**Total price (million USD)**	**USD per net m^2**
Dredging	$16.3*10^6$ m^3	7 USD/m^3	114.1	
Sand fill	$256.9*10^6$ m^3	9 USD /m^3	2312	
Sea defence A	4600 m^1	160000 USD/m^1	736	
Sea defence B	3150 m^1	106000 USD/m^1	333.9	
Sea defence C	4600 m^1	45000 USD/m^1	207	
Sea defence D	3150 m^1	234000 USD/m^1	739	
Total price			4,442	310

The total price of the traditional land reclamation is 4,442 million USD. If there is sufficient sand available in the borrow pit San Nicolas Shoal (because sand price is based on that borrow area) the square meter price for this land reclamation in Manila Bay shall be approximately 310 USD / m^2.

The alternative design includes a very large floating runway construction. By the application of this VLFS the width of the land reclamation decreases to 2700 meter. The reduction in cross section (and thus of the sand fill) is located at the deepest part of the Bay. This considerable decreases the amount of sand in the reduced artificial island. Moreover the runway will function as breakwater in front of sea defence A. As a result the cost of this sea defence decreases due to the sheltered location. It has been assessed that the costs per running meter will reduce with at least 50%.

Table 10 Total price hybrid alternative design

Hybrid alternative design (net surface: 14175000 m^2)				
Component	**Quantity**	**Unit price**	**Total price (million USD)**	**USD per net m^2**
Dredging	$16.3*10^6$ m^3	7 USD/m^3	114.1	
Sand fill	$204*10^6$ m^3	9 USD /m^3	1836	
Sea defence A	4600 m^1	80000 USD/m^1	368	
Sea defence B	3150 m^1	106000 USD/m^1	333.9	
Sea defence C	4600 m^1	45000 USD/m^1	207	
Sea defence D	3150 m^1	234000 USD/m^1	739	
VLFS			2133.5	
Total price			5,617.4	396

The total cost of the alternative hybrid design is estimated on 5,617.4 million USD. It can be concluded that the application of this VLFS does not lead to an economization or cost saving. However, the price of sand in Manila fluctuates constantly in the time. If the price of sand increases in the future there could come a break-even point. This is calculated with the equations presented below:

Equation total costs Traditional land reclamation:

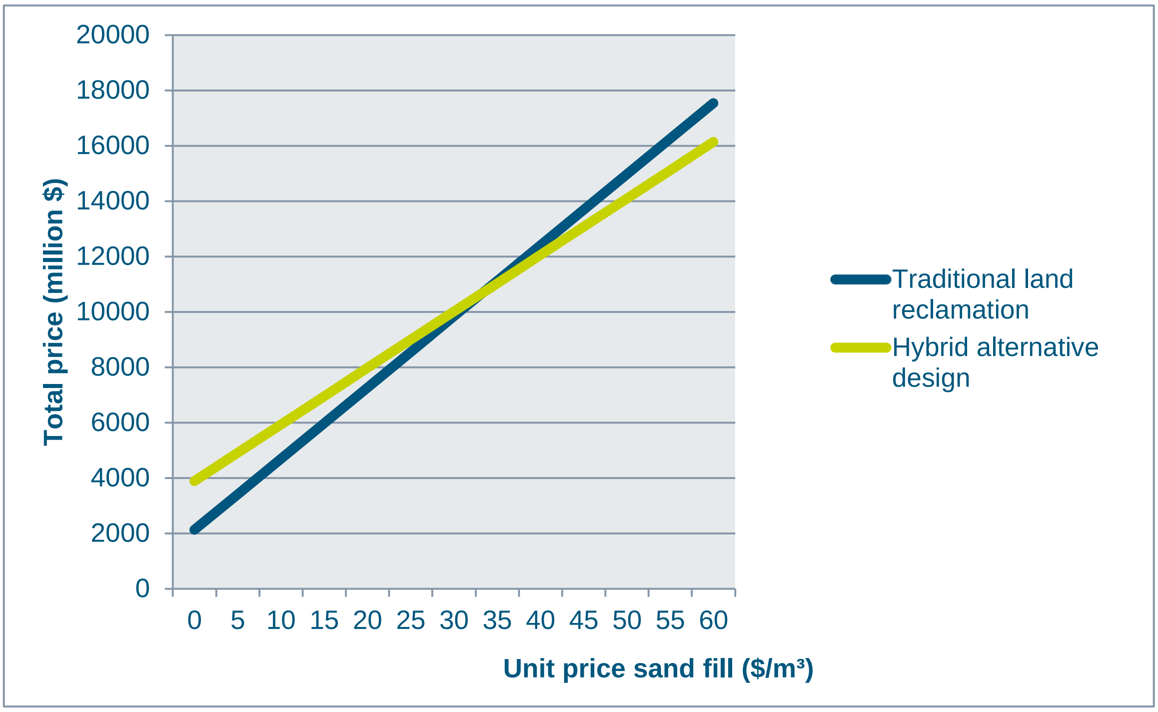
m^3 sand fill	*	Unit price sand	+	dredging	+	sea defences
256.9*10^6	*	X	+	114.9*10^6	+	2015*10^6

Equation total costs Hybrid alternative design:

m^3 sand fill	* Unit price	+	dredging	+	sea defences	+	VLFS
204*10^6	* X	+	114.9*10^6	+	1647.9*10^6	+	2133.5*10^6

Traditional land reclamation	**=**	**Hybrid alternative design**
(256.9*10^6 * X)` + 114.9*10^6 + 2015*10^6	=	(204*10^6 * X) + 114.9*10^6 + 1647.9*10^6 + 2133.5*10^6
(256.9*10^6 * X)` + 2130*10^6	=	(204*10^6 * X) + 3895*10^6
(52.9*10^6 * X)	=	1765.5*10^6
X	=	33.36 \$/m^3

The Global Gateway Philippines is a project that consist of 3 artificial islands in Manila; due to this and possibly due to other large scale reclamations to come in Manila Bay the sand could become scarce and the price would seriously increase. Graphic 1 shows this break-even point, i.e. around 33 USD/m3.



Graphic 1 Expend total costs in relation to unit price sand

14 Conclusion

The main question of this graduation research is as follows:

Is it possible to design an element within an airport layout as very large floating structure (VLFS)? And will it result in costs savings compared to the total airport placed on land reclamation?

Based on the work done as part of this thesis, it is overall concluded that:

Runway
It is possible to design a Very Large Floating Structure in Manila Bay that is part of the airport extension. The outcome is that the runway has the best possibilities to function as VLFS. Reason for this is the load that acts upon this structure; the weight of planes on the structure spreads out over a big surface. The load upon an apron/ramp area is higher since several planes are simultaneously placed upon a small area.

Additional benefit of the big dimension of a floating runway is that the construction can serve as floating breakwater that (partly) protects the reclamation behind it. This will lead to a smaller and less expensive sea defence construction.

Elastic deformable VLFS
The floating runway construction in Manila Bay should be compiled out of a large number of relatively small concrete casings that are closely connected with each other since it is impossible to build one rigid structure with the dimensions of 3900 m long and 450 meter wide. This elastic deformable construction can respond to the local wave conditions in Manila Bay and the planes landing upon the structure.

The wave conditions in Manila can be rather extreme because of frequently passing typhoons; this is the main reason for leading to relatively high construction costs. The floating segments have to withstand upward bending moments that reach 4,293 kNm per meter structure width. The placement of the individual segments in a herringbone grid structure, connected by a hinge system leads to a strong and flexible VLFS.

The concrete casings (building blocks) have a width-length ratio of 1:4. By placing two hinges at the long side and one hinge at the short side of each building block, and next to that apply a herringbone placement pattern for all blocks, it was found that the forces and rotations are best spread over the VLFS.

Costs
The construction cost of the VLFS becomes relatively high because of the big dimensions resulting from the extreme design wave loads. Also the bridge connections and the mooring system increase the price considerably. The order of magnitude of one floating square meter is assessed at 1200 USD gross (price level 2017).

The application of a VLFS reduces the amount of sand that is needed to construct the (reduced) island; a second saving arises since the sea defence at the lee side of the VLFS is relieved from extreme wave attack. However, for the assumed sand fill price of 9 USD/m3, these advantages do not lead to savings for the airport extension positioned in Manila Bay. The application of a VLFS as runway is presently estimated to increase the total project cost with approximately 25%, compared to a traditional land reclamation approach. If sand becomes scarce in the region of Manila this would lead to a higher price for sand. It was found that there is a break-even point at 33 USD/m^3.

15 Recommendations

15.1 Introduction

The floating runway construction that is theoretically designed in this report is an initial concept. No prototype has been build which was suitable for scale tests in a laboratory. The design of the floating runway construction in this report is used to make a comparison with traditional land reclamation in Manila Bay. However, the developed concept of this elastic deformable floating construction can be applied in almost every sea or lake around the world; likewise the floating “building ground” can be used for different activities.

Since the construction of VLFS nowadays is still very rare a continuation of this research is useful and required.

15.2 Design aspects

The following steps are recommended:

Tests with prototypes
The Rotterdam University of Applied Sciences has access to a wave simulator. By building a prototype at reduced scale, tests with this structure can be made in this wave simulator. It is recommended to start with 2 prototypes; one structure with elements placed in a half stone pattern and the second one in herringbone pattern ratio 1:4. In this way the reaction of both structures exposed to different waves can be studied.

Seismic activity
The basis of design describes the seismic activity in the region Manila. The land reclamation is exposed to the vibrations that arise through sliding plates of the earth crust. These movements can lead to damage on the sea defence construction; the seismic activity is not included in the considerations involved with the design of the sea defences around the artificial island. According to (Lem, 2017) a sea defence in earth quake prone area is very complex and expensive. In order to establish a more accurate price for the island the seismic activities have to be part of the full design.

Mooring System
The costs of the mooring system are roughly calculated in Deliverable J. The diameter of the pile is estimated; the forces and impacts out of waves and moving airplanes that reach the mooring system have not been studied in this thesis. Further in Deliverable F is concluded that the application of semi-submersible segments relieve the mooring systems since an open structure is less sensitive to waves. A more detailed research is needed to design the mooring system.

Bridge Connection
The bridge connections that are part of the alternative hybrid design are schematically elaborated in Deliverable C and the costs are roughly calculated in Deliverable J. Important to notice is that more detailed research is necessary weather it is possible to economically design and construct a bridge construction between a floating runway and an island that can serve as taxiway for airplanes.

15.3 Optimizations

Dimensions concrete casing

The dimensions of the concrete casing are based on the intermediate distance of 15 m between the internal support walls; 90 meter is a multiple of 15 meter. Probably it would be possible to build bigger segments; bigger segments can result in a reduction of the number of connections. This can lead to a significant cost saving of the total runway construction since the connection system is complex and expensive.

Connection system

The connection system that is elaborated in this report is an important element in the functioning and performance of the VLFS. In this thesis study a detailed analysis of the forces that arise inside this system was not carried out. The dimensions of the hinge system and the fender which are similar for each connection are roughly estimated based on engineering knowledge. More design work will be required in order to come up with an efficient and reliable connection system.

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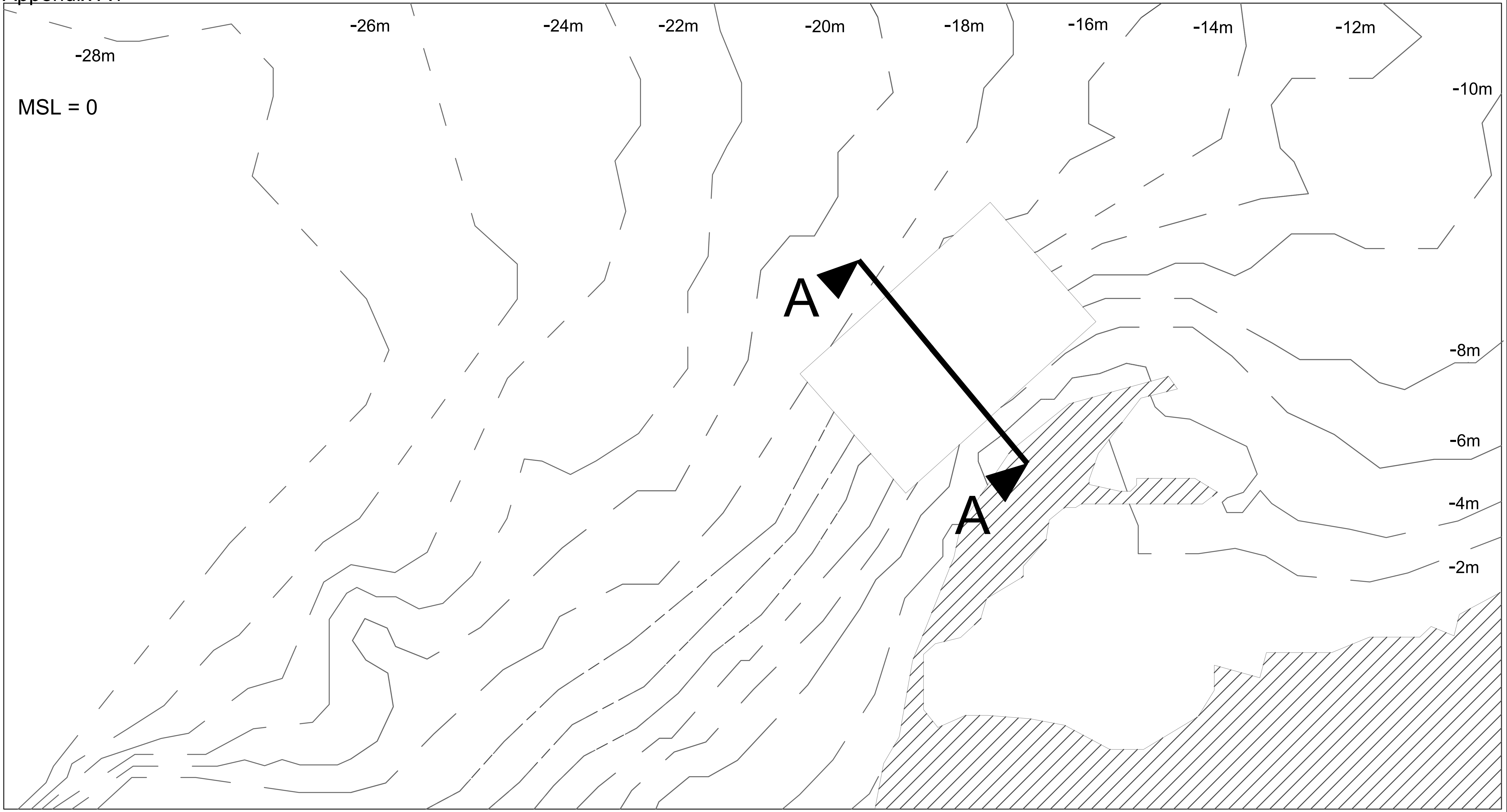
Appendices

Appendix A1	**Bathymetry Project Site**
Appendix A2	**Typical cross section seabed**
Appendix C2	**Reference design of Manila Bay International Airport**
Appendix C3	**Floating structure**
Appendix H1	**Longlist Connection Systems**
Appendix H2	**Final Design Connection System**
Appendix J1	**Cross section Traditional land reclamation + Hybrid alternative design**

Appendix A1



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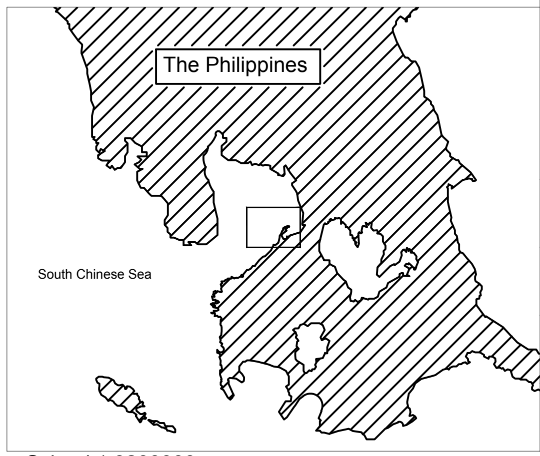

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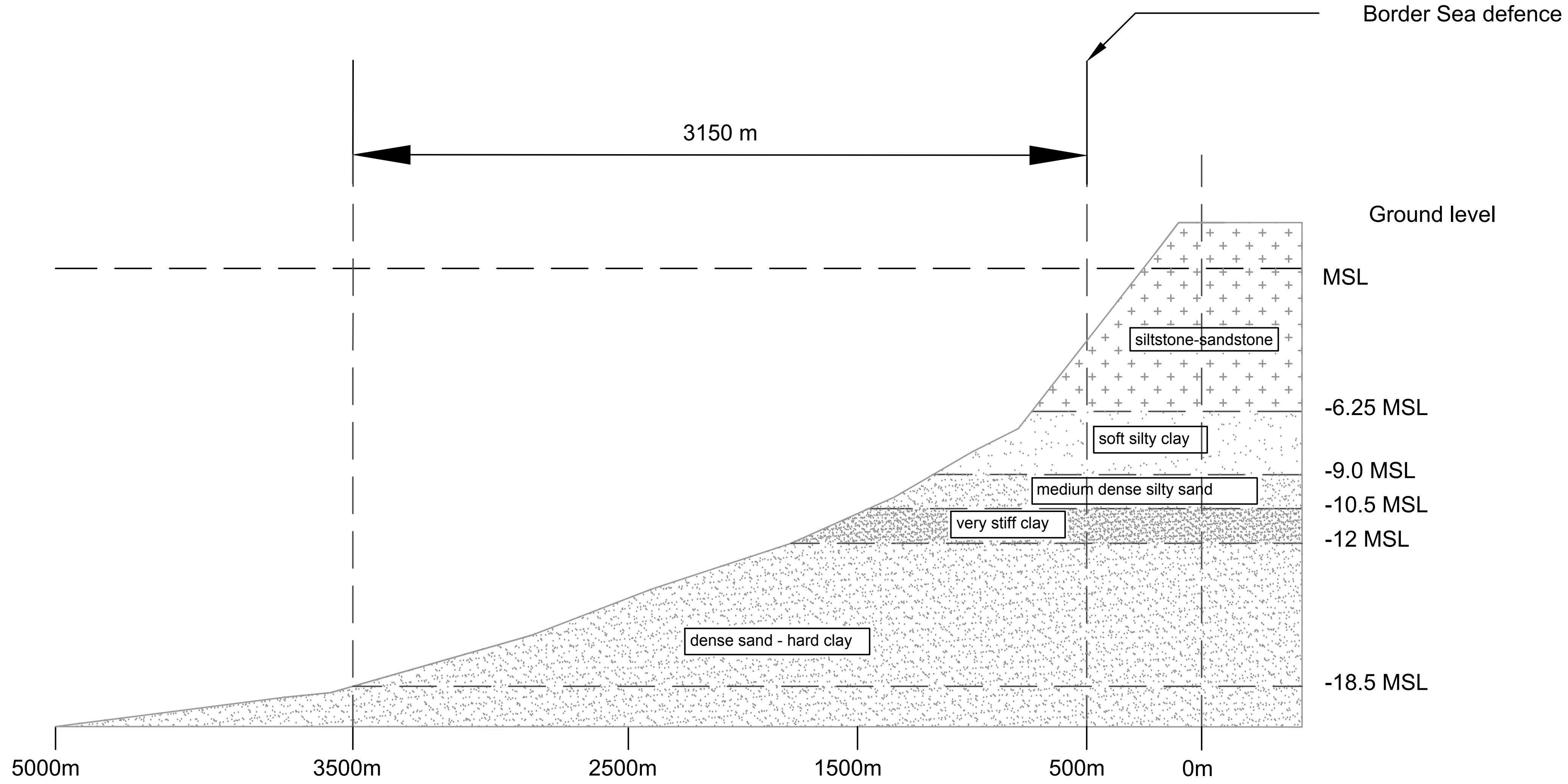
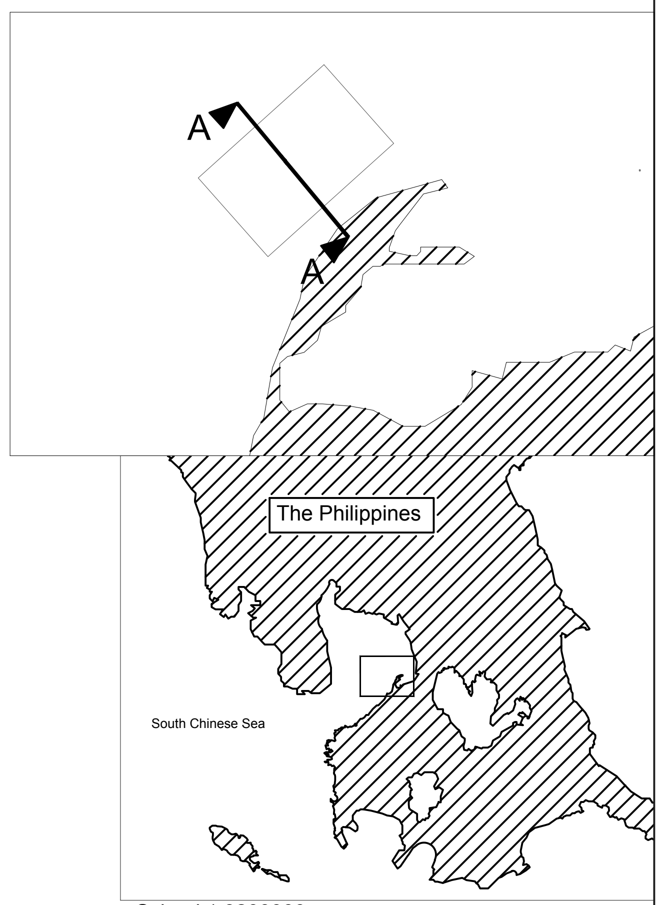
Rotterdam University of Applied Sciences

Project: Feasibility VLFS Manila Bay				
Course code: CIVAFST	Group: 01	Client: Ronald Stive	Section: Bathymetry	
Draftsman: Sjaak Bijl				
Check: Paraaf	Schale: 1:333	Page Number:	Draft Number: 01	

Appendix A2
Cross section A-A





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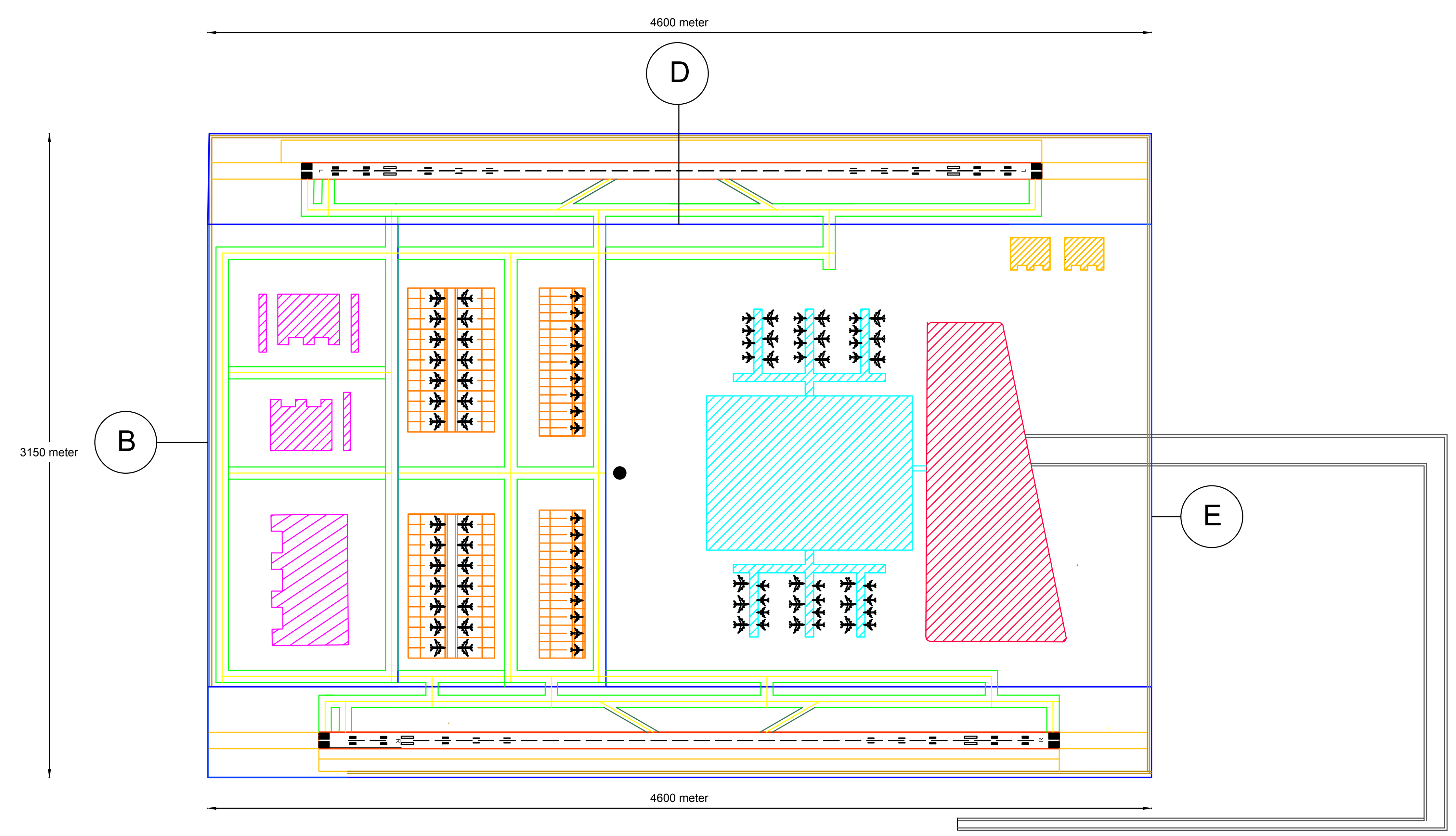

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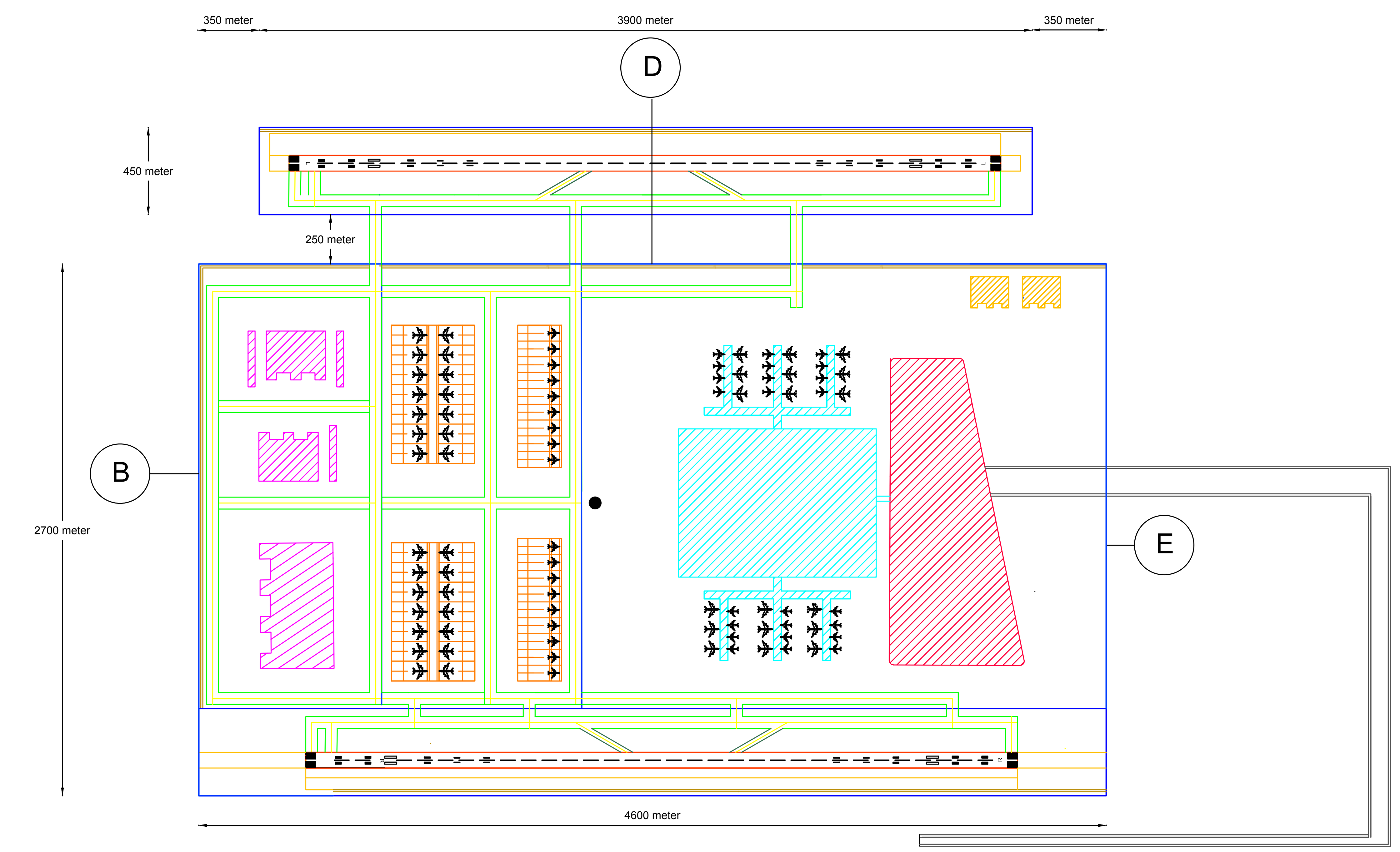
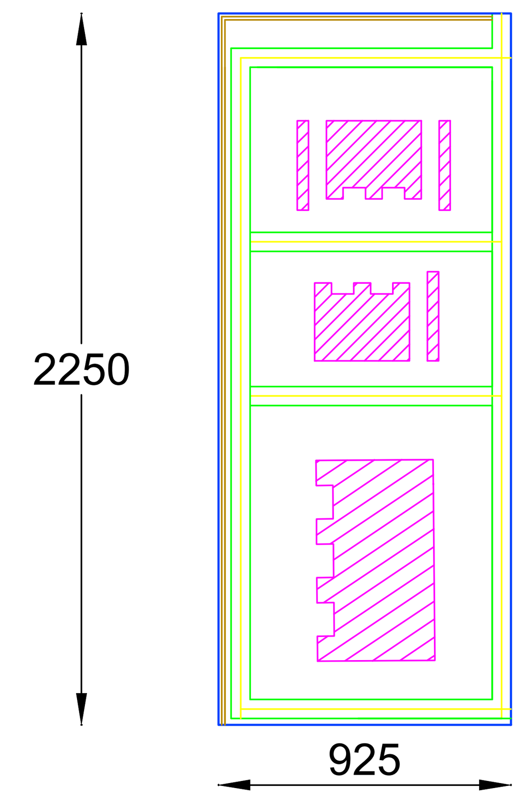
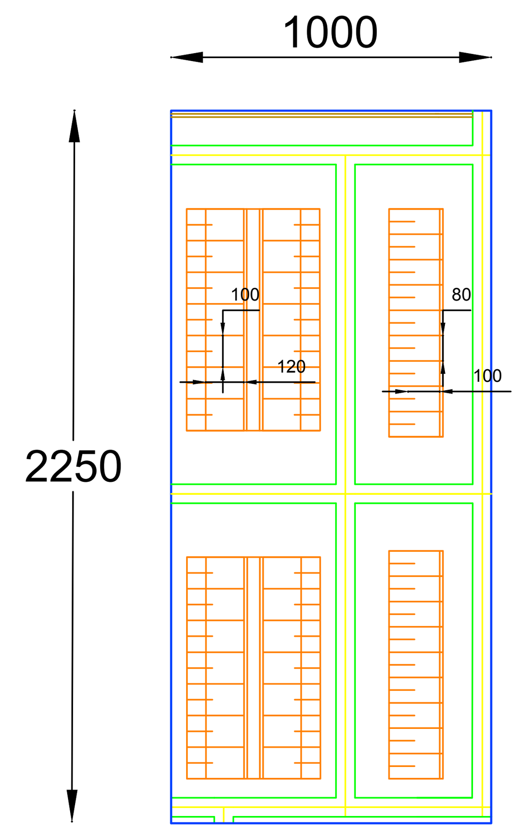


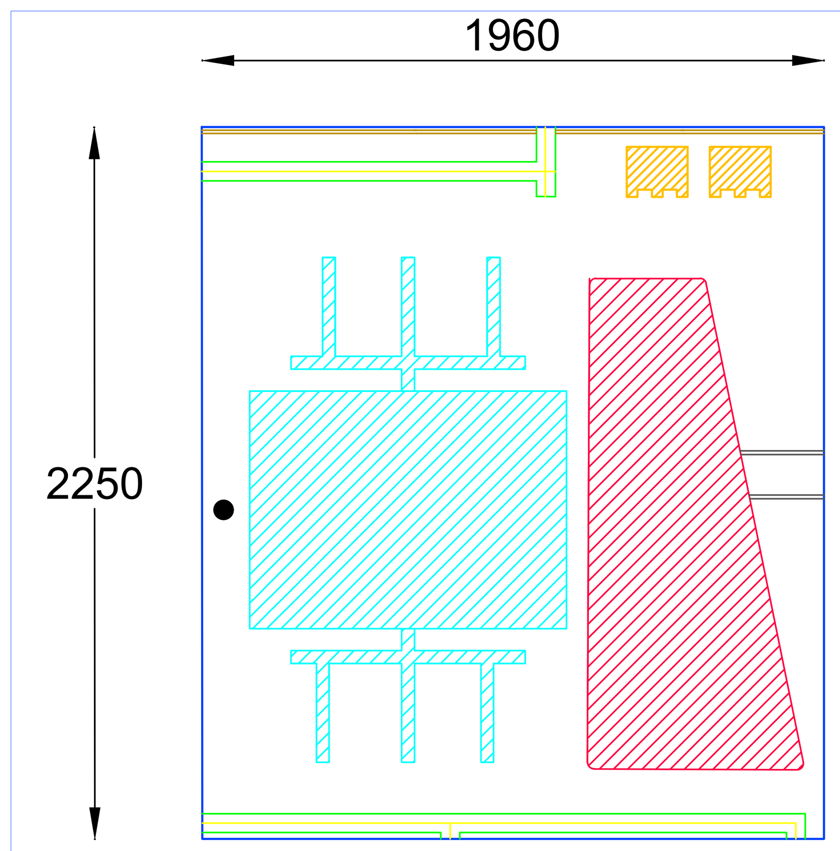
Hybrid alternative design



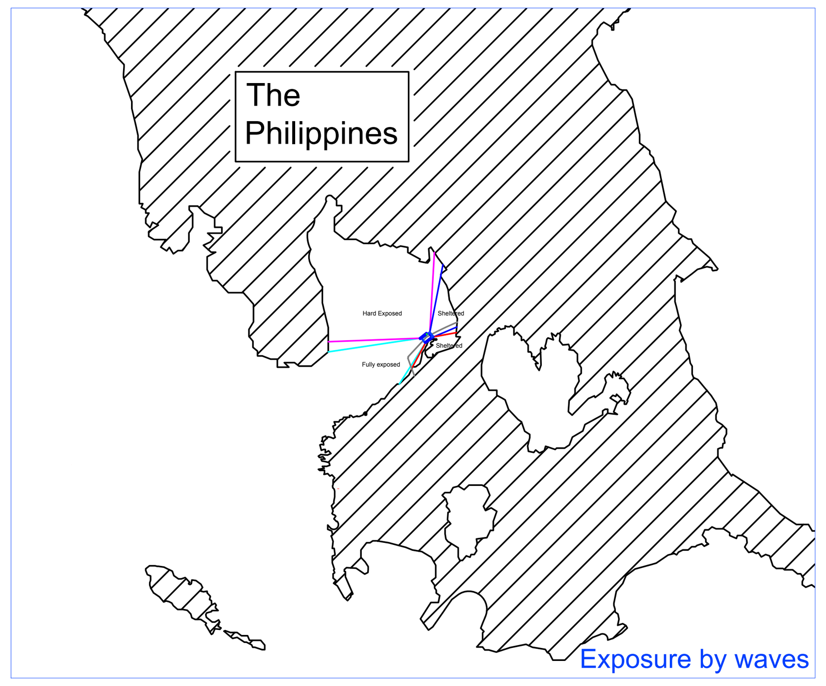
Module B Hangar



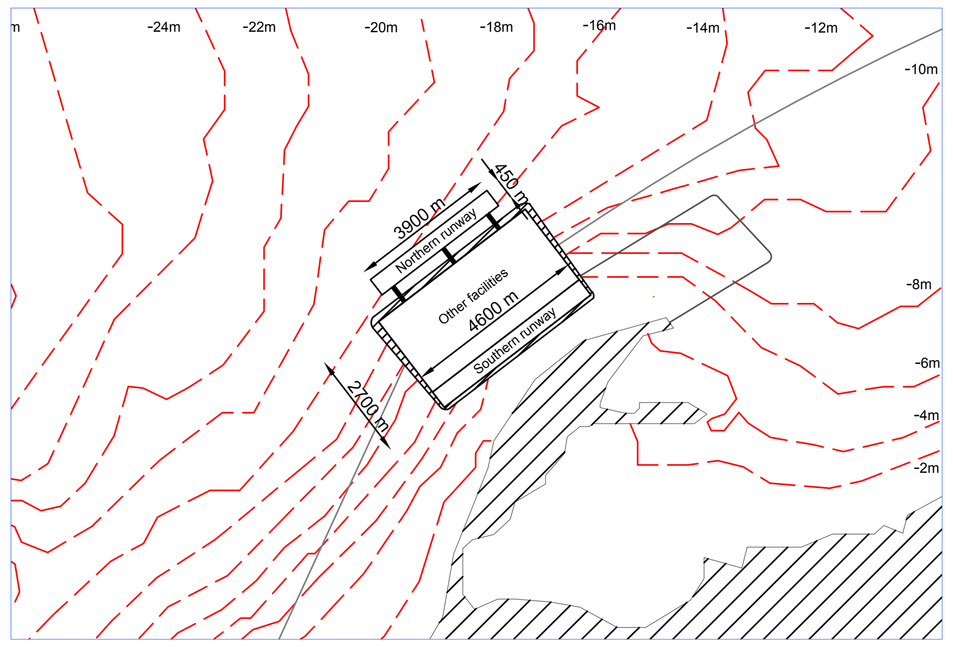
Module D Apron



Module E Terminal + Parking area



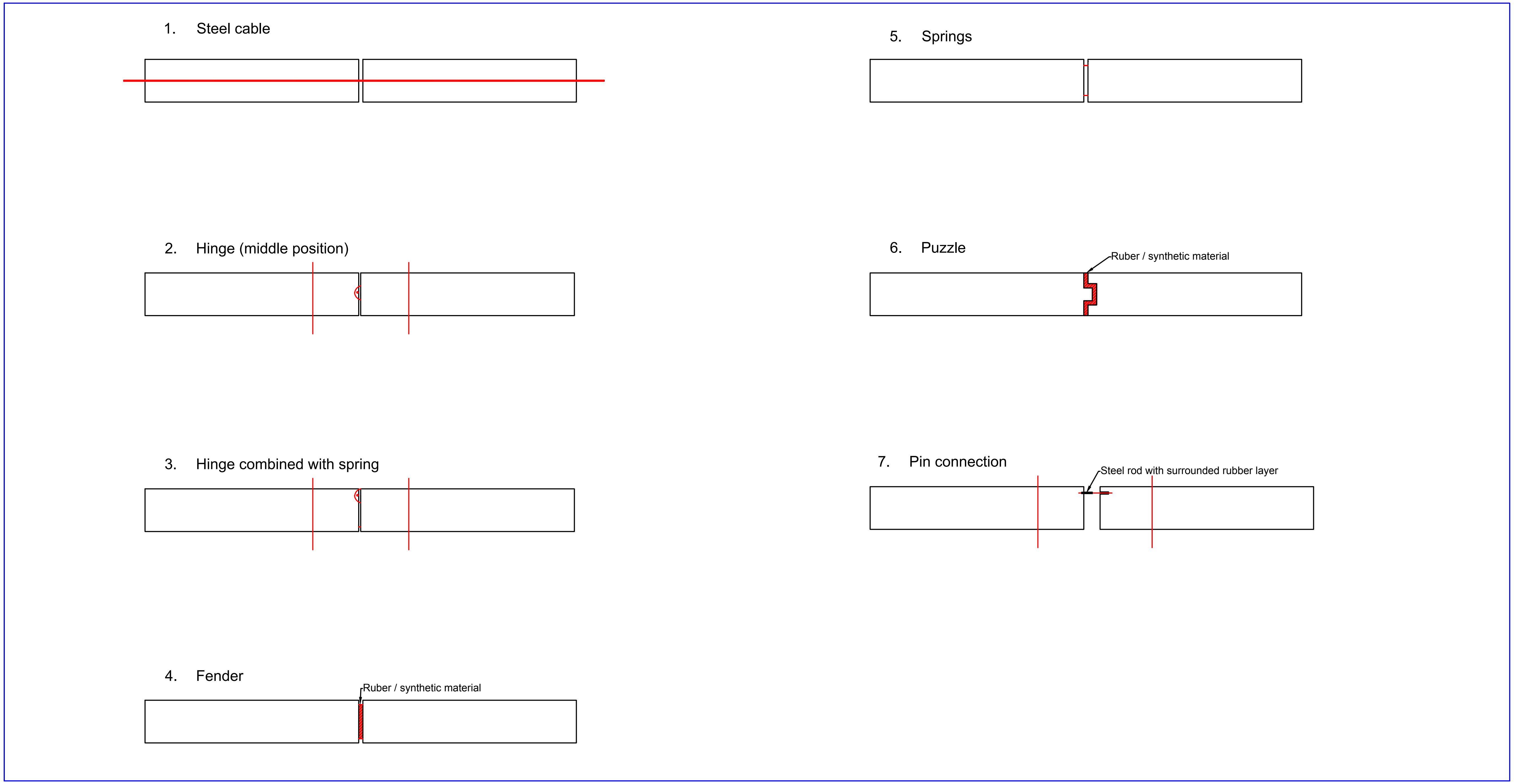
Exposure by waves



Bathymetry Hybrid alternative design

=	Terminal	=	Safety zone
=	Runway	=	Access roads
=	Taxiway	=	Maintenance road
=	Hangar	=	Airbus A380
=	Apron	=	Boeing 737
=	Parking area	=	Modules airport
=	Cargo	=	Rapid exit taxiways
=	Center line taxiway	=	Air traffic control tower
=	Rail line		

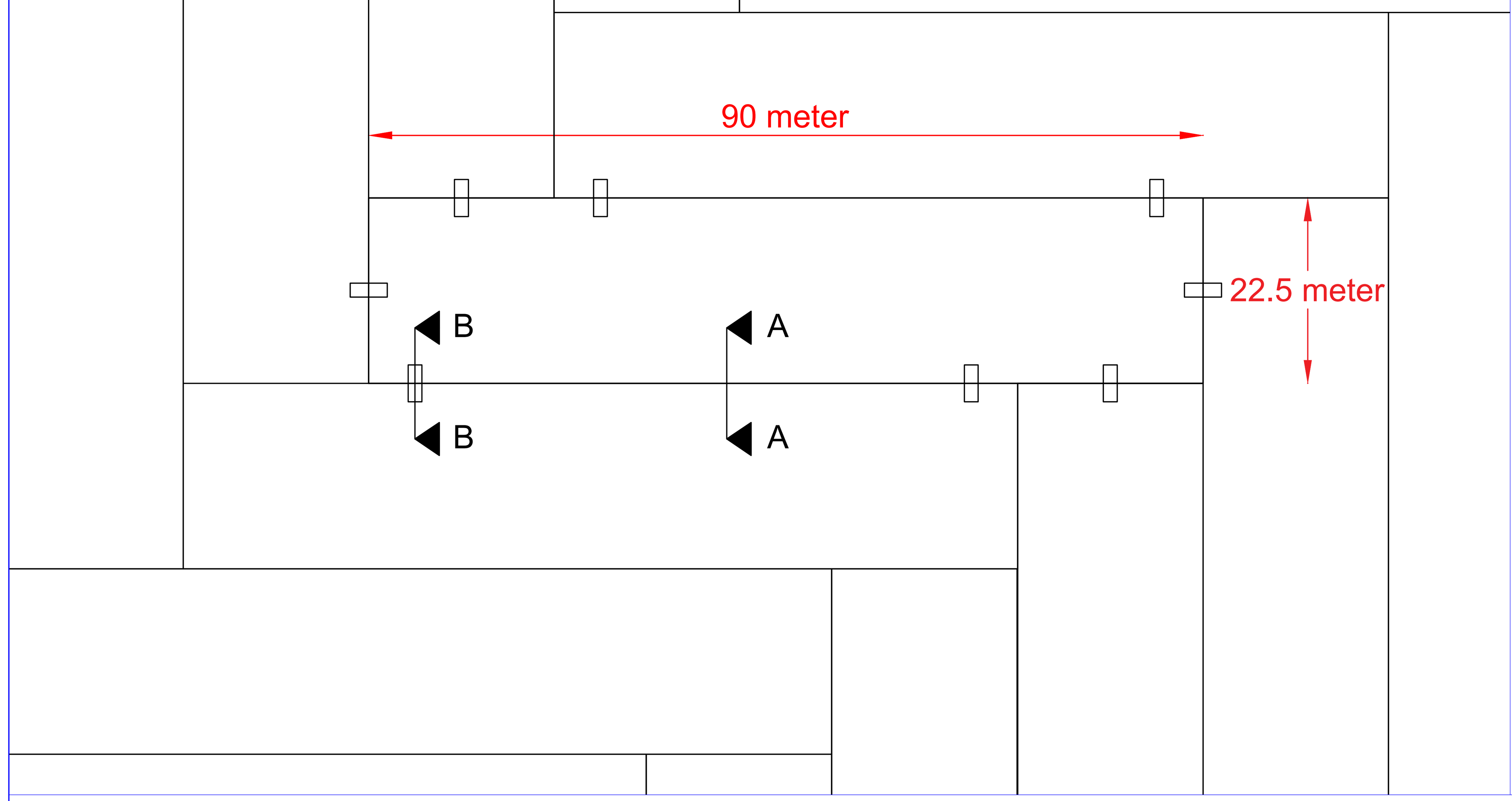
Rotterdam University of Applied Sciences			
Deliverable: Airport design			
Designed by: Victor van den Berg	Supervisor: Ronald Stive		Date: 14-03-2017
Name design: Reference airport (A1)			Company: Royal Haskoning DHV
Checked by: Sjaak Bijl	Scale: 1:20	Status: Final	Draft Number: Appendix C2



Rotterdam University of Applied Sciences

Deliverable: Connection System				
Designed by: Victor van den Berg	Supervisor: Ronald Stive		Date: 18-05-2017	
Name design: Longlist Connection Systems (A3)			Company: Royal Haskoning DHV	
Checked by: Sjaak Bijl	Scale: 1:20	Status: Final	Draft Number: Appendix H1	

Top view herringbone grid
Scale 1:1000



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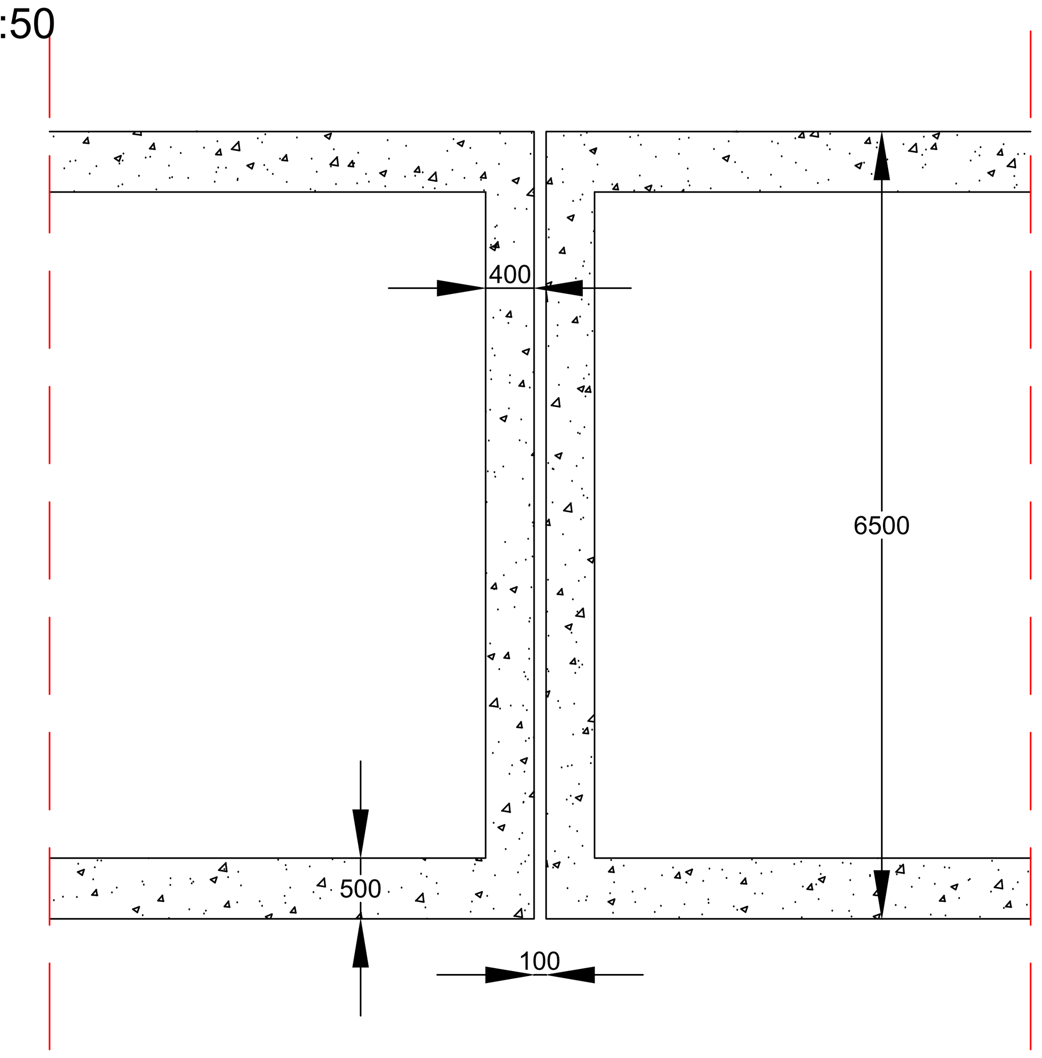

Cross section B-B
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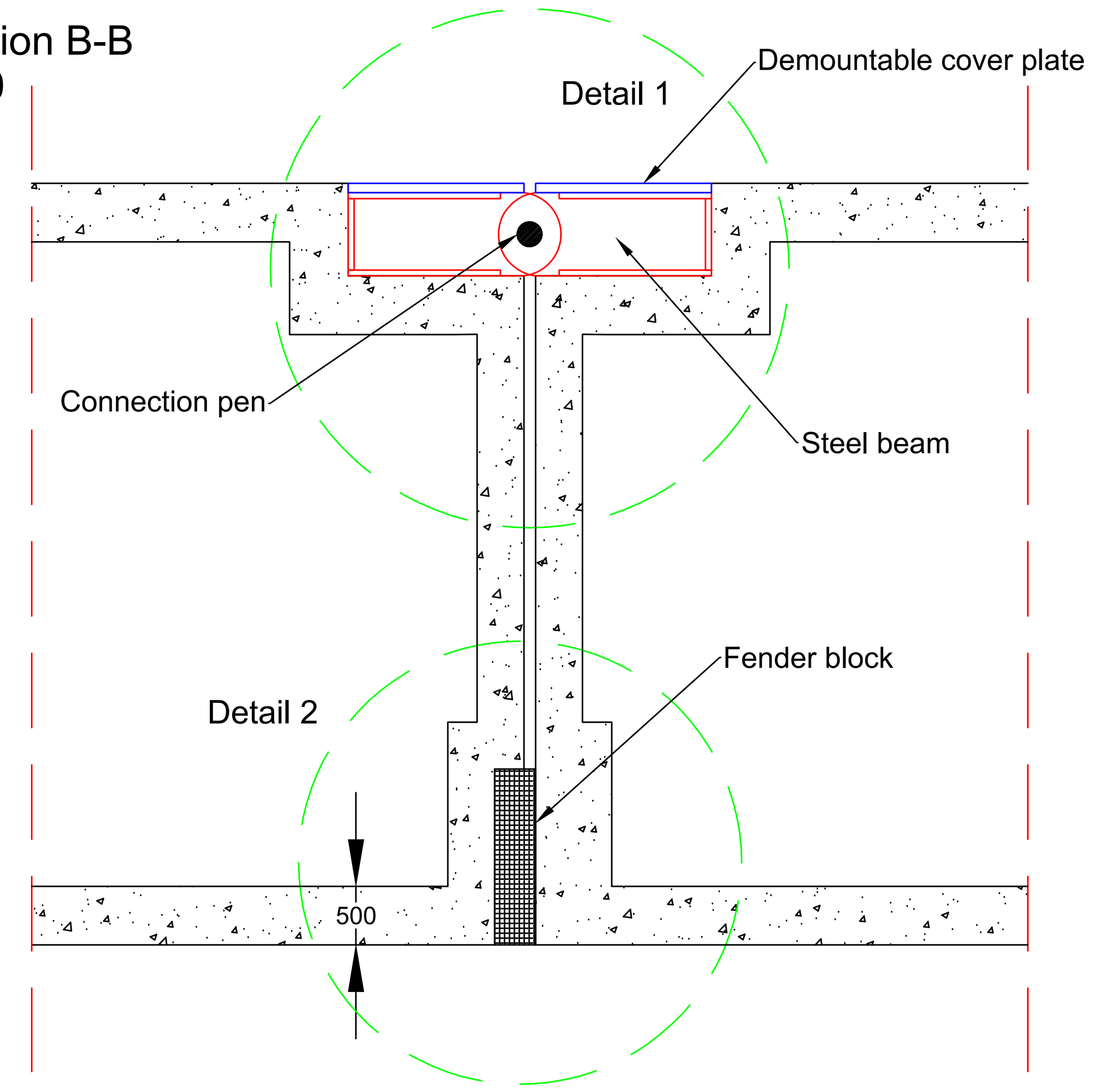

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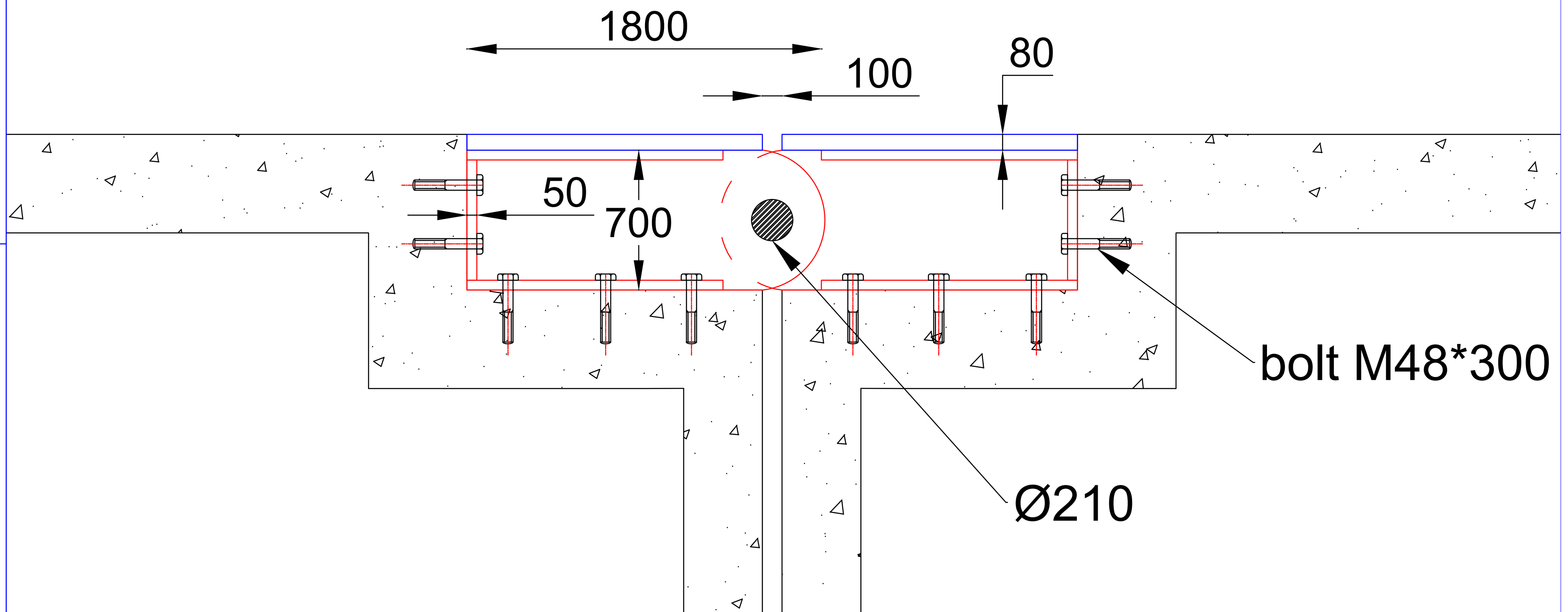

Top view detail hinge
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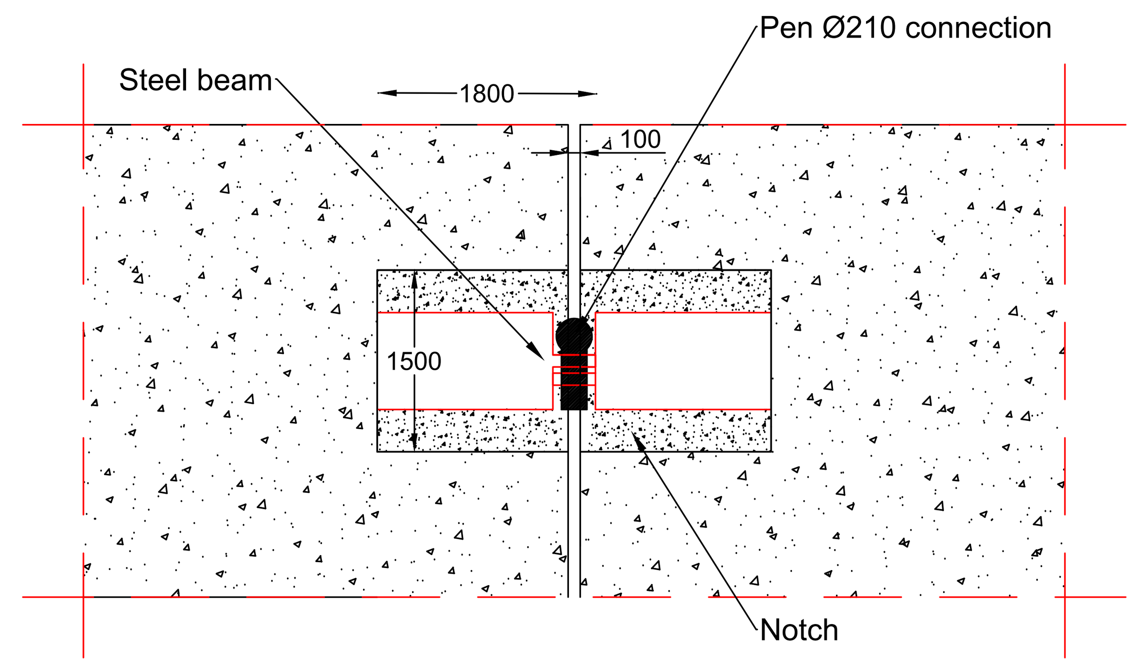

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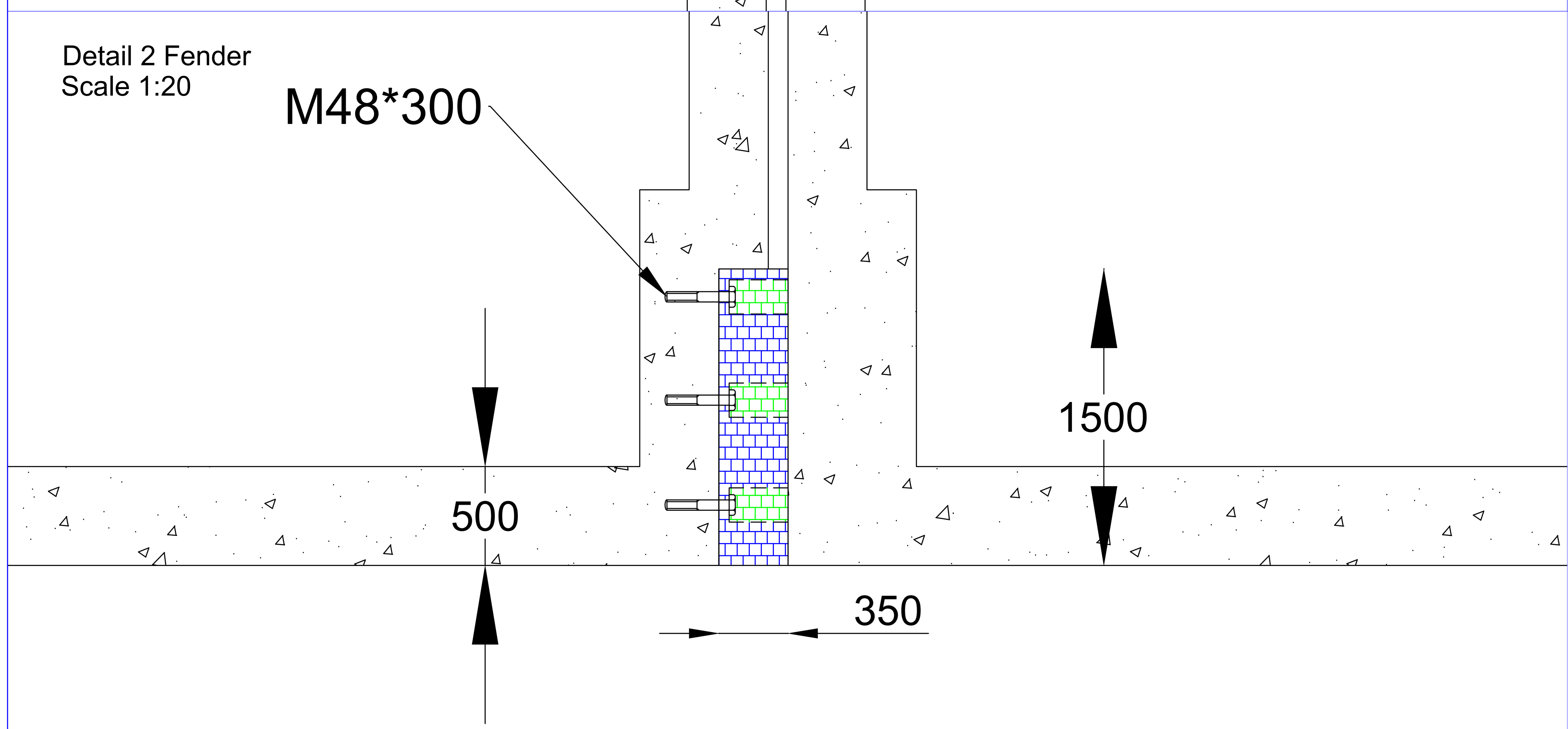

Rotterdam University
of Applied Sciences

Deliverable: Connection System

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Supervisor: Ronald Stive
Date: 08-06-2017
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Company: Royal Haskoning DHV
Checked by: Sjaak Bijl
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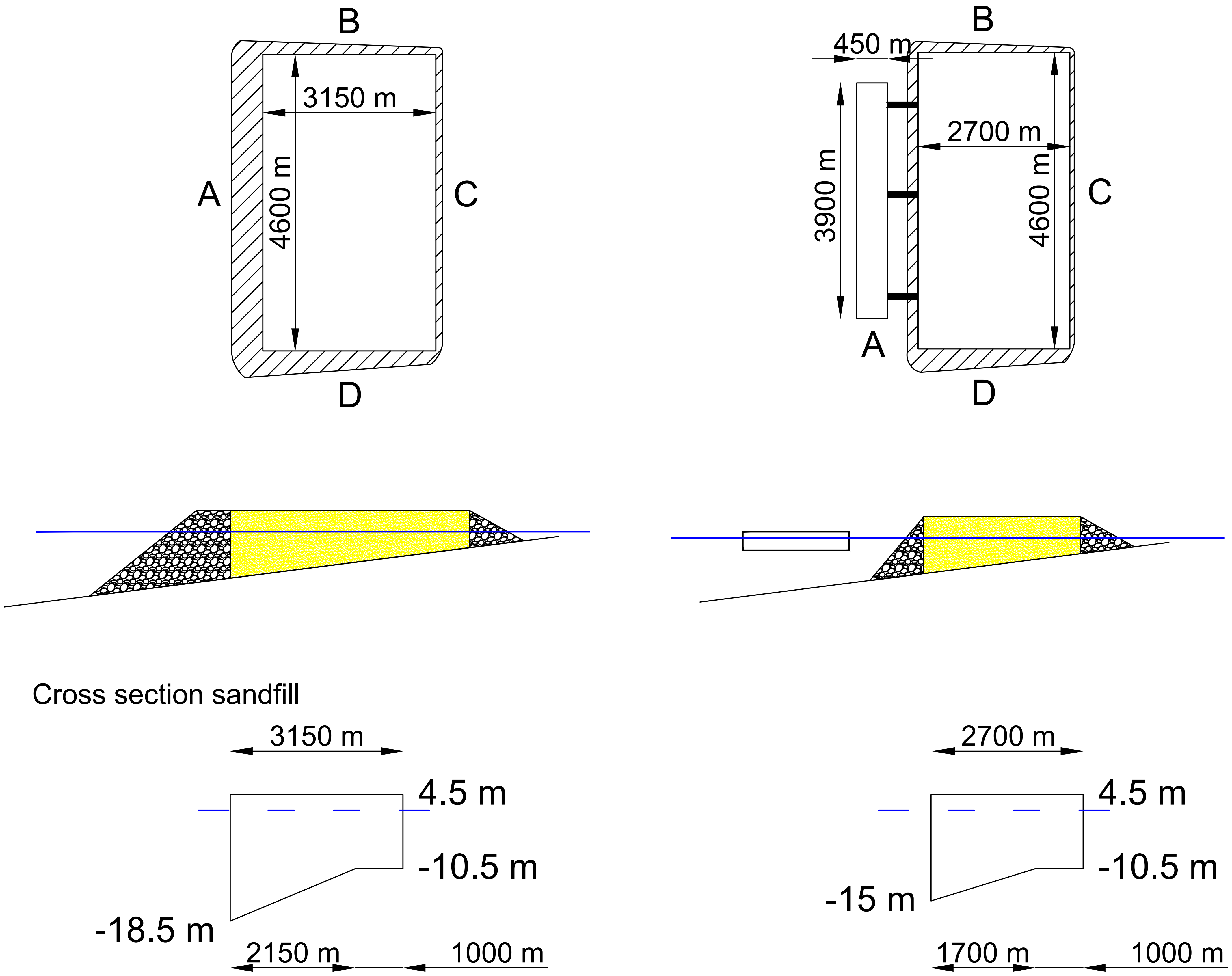
Status: Final
Draft Number: Appendix H2



Comparison traditional land reclamation to hybrid alternative design

Rotterdam University
of Applied Sciences

Deliverable: Cost comparison		
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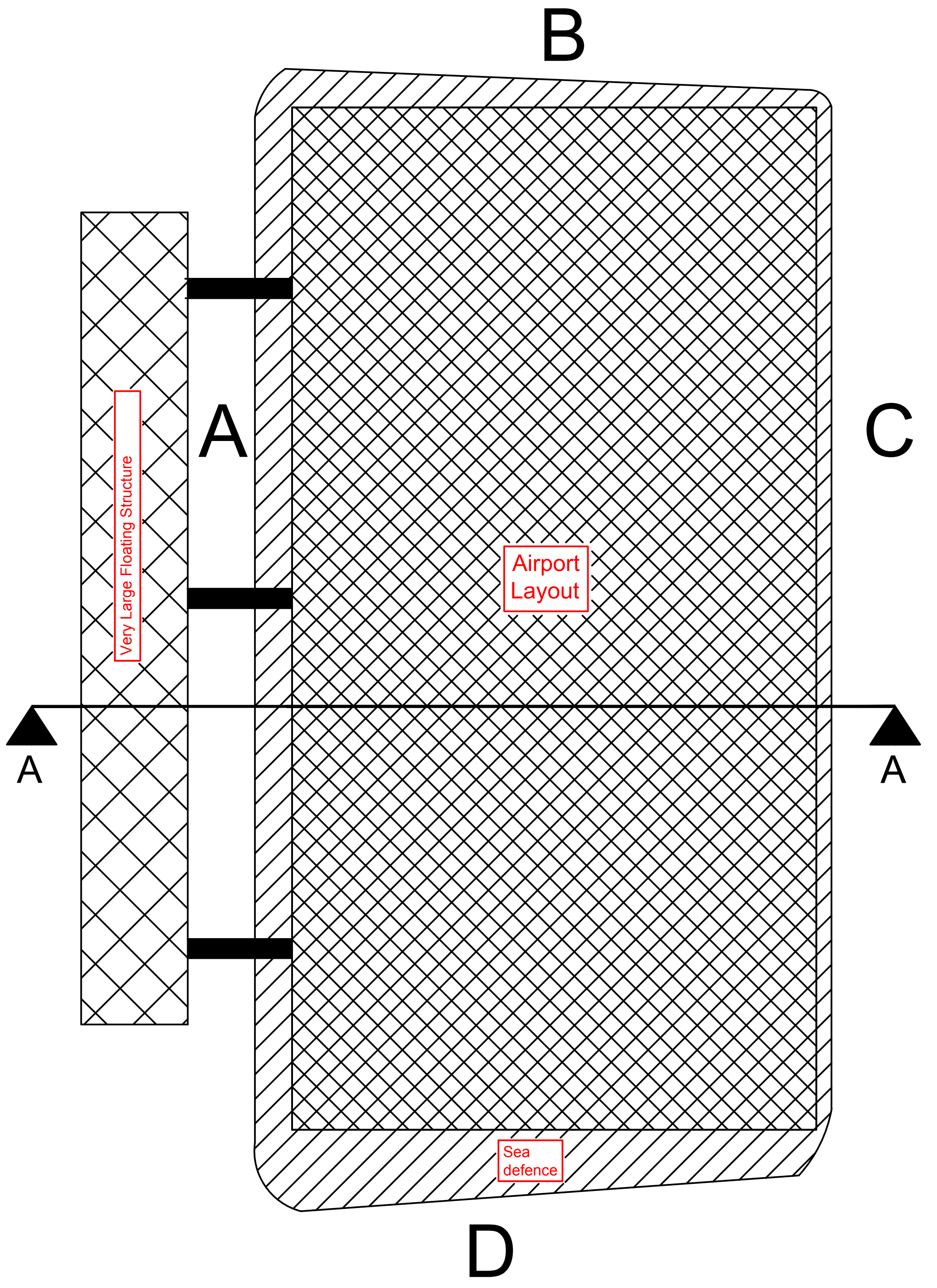
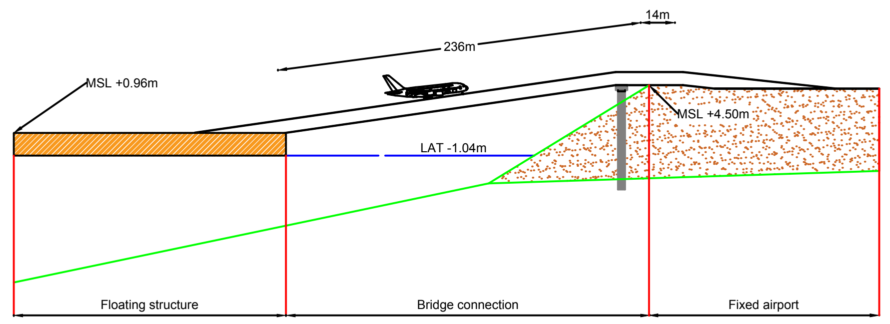
Checked by: Victor vd Berg	Scale: Status: Final	Draft Number: Appendix J1



Top view airport
Scale 1:100



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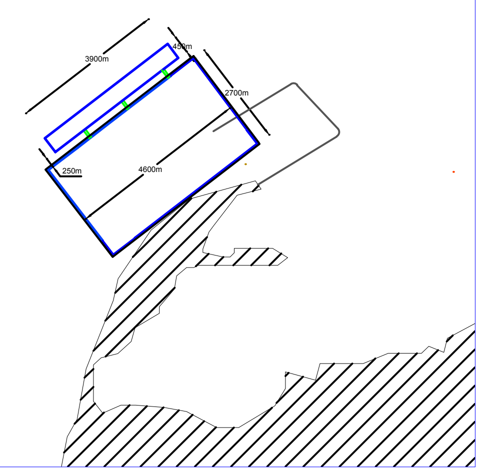
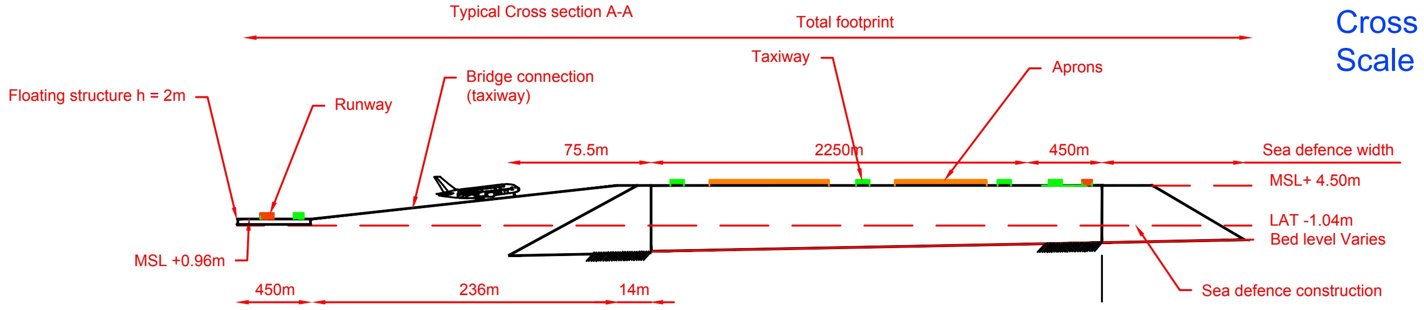
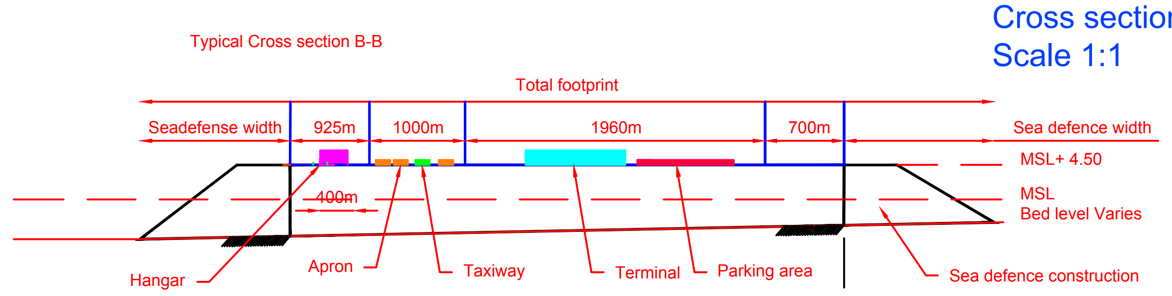


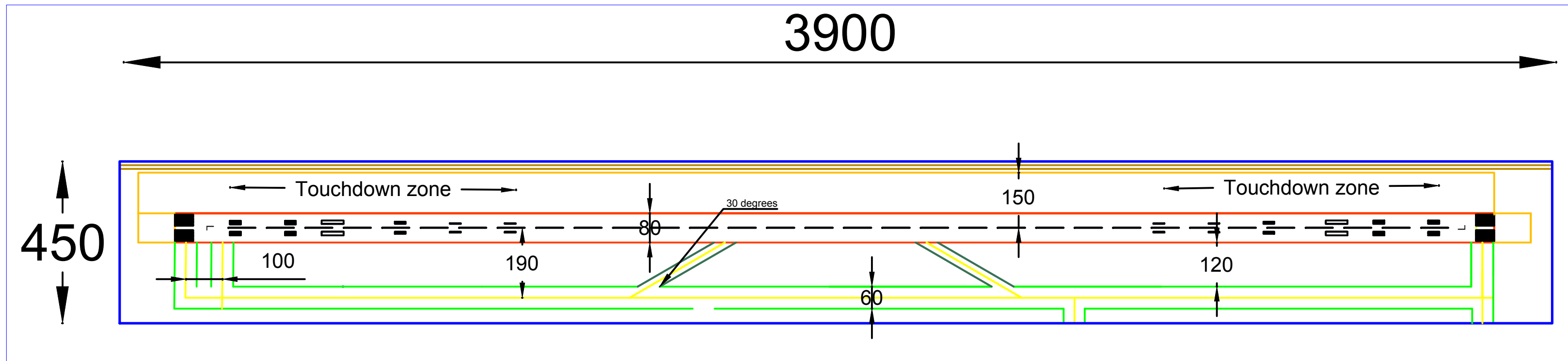
Location airport



Cross section A-A
Scale 1:1



Cross section B-B
Scale 1:1



Floating structure

Rotterdam University
of Applied Sciences

Deliverable: Airport design			
Designed by: Victor van den Berg	Supervisor: Ronald Stive		Date: 14-03-2017
Name design: Floating structure (A3)			Company: Royal Haskoning DHV
Checked by: Sjaak Bijl	Scale: 1:20	Status: Final	Draft Number: Appendix C3