The design of a modular, amphibious structure for a flood and typhoon-prone municipality; Hagonoy, the Philippines

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The design of a modular, amphibious structure for a flood and typhoon-prone municipality; Hagonoy, the Philippines

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Abstract

Introduction

The daily life of inhabitants of Hagonoy, the Philippines, is affected by tidal and fluvial floods. Ground subsidence is the main cause of a worsening trend of these floods. Excessive uncontrolled groundwater subtraction creates a ground level decrease up to 5 cm per year. In combination with yearly six to nine typhoons raging over the country, this leads to unliveable conditions. In order to contribute to the improvement of living conditions of the inhabitants, a modular amphibious structure is designed to keep buildings above the water level.

Part I -Background

In order to design a suitable amphibious foundation for Hagonoy, a research is done into modular, circular building concepts. Hereby a desired translation of the Dutch building concept of Finch Buildings into a Filipino concept can be made. In combination with criteria concluded from research into floating behaviour of structures and from an analysis of the location, a number of criteria is listed, on which the design of the floating modules and the connections is based.

Part II – Structural design

By analysing and rating several floating construction types and connection types, a concept design for a modular prefabricated amphibious foundation is made. Timber frame, filled with recycled 200L barrels is the basis for a flexible building concept.

Three scenarios in which the foundation must give a proper structural performance, are outlined. Due to change in water depth, the structure must be able to function in a dry, a just-floating and a floating position. Since this foundation must be able to carry varying configurations of buildings, multiple load cases can occur. The most unfavourable load cases occur during typhoons, due to high wind pressure and high and long wind generated waves.

By creating a parametric visualization and calculation model, a first insight in dimensions, and width and length of the amphibious foundation is determined. This concept design for both foundation modules and connections between modules is elaborated more in detail. A timber structure of 1,20m x 2,40m holds eight 200L barrels in place. Due to brackish water, the timber structural elements must be protected against shipworm attack. In a brief research several possible solutions are described, of which wrapping structural elements with coir is determined to function best, according to previously stated criteria. In this design, barrels can be replaced in case of damages.

Prefabricated foundation modules can be connected by a combination of a U-shaped bottom connection, and a relative fast fixable upper connection. By this connection a rigid wide body can be built in order to provide stability for all scenarios.

Two case-studies, one being a foundation with a single building and the second being a foundation with a configuration of eight buildings, are tested by means of SCIA Engineer. For the foundation with a single building in floating position, deflections are too high due to extreme wind-generated wave loads. By increasing the width and length, deflections decreases. The largest bending moments and shear forces occur when the foundation with a configuration of eight buildings touches the soil on one side, due to a large heeling moment. These occurring bending moments and shear forces form an input for optimization of both the foundation module and the connection.

In order to reduce the demand for groundwater, and thereby to contribute to reduce of ground subsidence, a design is made for making use of rainwater, and store it in the foundation. In addition waste water can be cleaned by integrated helophyte filters. Bamboo mooring piles create horizontal stability. By replanting bamboo, poles can be replaced over years.

Part III - Conclusions

A design for a prefabricated modular amphibious structure that is applicable in and adjusted to a flood and typhoon prone area, such as Hagonoy is delivered. Concluded from theory of floating behaviour and a rough cost estimation, a foundation for a single building is not recommended. In order to start building the pilot version, knowledge of actual behaviour of wind generated waves, optimization in the field of structural behaviour and costs are recommended.

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Chapter 1 Introduction

With typhoon Haiyan destroying effectively a considerable part of the Philippine's real estate, huge demands for disaster-proof buildings have arisen (Charlesworth et al, 2015). Multiple effects of natural disasters are noticeable in the current state of buildings. Overpopulated cultivated areas, such as Hagonoy, are dealing with major tidal and fluvial floods.

In the same time, western modular building concepts, such as Finch Buildings, provide solutions for (western) problems relating to the construction industry. Research is needed in order to investigate how a Dutch building concept can be translated into a Filipino concept, to contribute to the improvement of living conditions of inhabitants of natural disaster-prone areas, such as Hagonoy.

This chapter will first provide a description of the problem by overviewing the current housing situation in the Philippines and Hagonoy (1.1). This leads to the objective, approach and scope (1.2.) In section 1.3 the relevance of this thesis is described. In section 1.4 the most important research partners are mentioned. Section 1.5 describes the structure of this thesis.

1.1 Problem description

In order to define a problem description, first a brief context of the Philippines and Hagonoy is described.

1.1.1 Context Philippines

The Philippines consists of over 7000 islands that are categorized under three main divisions: Luzon, Visayas, and Mindanao. The capital city is Manila, which is part of Metro Manila. Due to its location, in the so-called 'Ring of fire', the Philippines are prone to earthquakes typhoons, but also has a lot of natural resources and a great biodiversity. The Philippines is the 64th- largest country in the world. (NSO, 2014)

With a population of about 100 million people the Philippines is the seventh-most populated country in Asia and the 12th most populated country in the world. (Rappler, 2015). Approximately, half of the population lives on Luzon, the largest Island of the Philippines.

The Philippines is ranked as the 39th largest economy in the world, with an, in 2014 estimated, gross domestic product (nominal) of $289.686 billion. (Bank, 2015) Service industries such as tourism and business process outsourcing have been identified as fields with some of the best opportunities for economic growth in the Philippines. Due to these opportunities, the country is included in the list of the "Next Eleven" economies. Despite the promising statistics for the Philippines, the daily income of 45% of the population of the Philippines today, still remains less than $2, which is below the poverty line.

Housing backlog

The need for housing is huge in the Philippines, because of a backlog in providing for land security and housing for the poor. The high density of population, together with the migration to urban areas, increase the demand for affordable land and housing. The migration to urban areas is one of the main reasons of the housing backlog. (UN-HABITAT, 2009)

Half of the world's population lives in urban areas. Presently, most of this urban growth is taking place in the less-developed regions of Asia and Africa. Metro Manila has joined the ranks of cities with populations exceeding 10 million. Consequently, by the year 2030 about 40 percent of the world's population will still need access to housing. This is translated into a demand for 96,150 new affordable units every day or 4,000 every hour worldwide. (UNFPA, 2007)

In the Philippines the magnitude of the housing need is huge and has been estimated to reach more than 3.7 million. In Metro Manila alone, the total backlog has been projected to reach close to 500,000 units. About 3,000 hectares of land is needed in order to cancel this backlog. This also suggests the need for a higher density housing strategy if the housing problem is to be solved. (Lagman, 2007)

One of the factors that has characterized the housing development process in the Philippines has been the explosive growth of urban areas. The future well-being of Filipinos will depend largely on the performance and efficiency of these urban areas. Metro Manila has large numbers of families living in various types of unauthorized housing units. Slum areas inhabited by informal settlers with a low income are often miserable, overcrowded, and lacking in standard conveniences such as electricity, water, drainage and health services (TheWorldBank, 2015)

Natural disasters

The Philippines has suffered from a large number of typhoons, earthquakes, volcano eruptions, floods and other natural disasters (Wingard & Brandlin, 2015). This is due to its location along the Ring of Fire, or typhoon belt. This is a region in the Pacific Ocean where many of Earth's volcanic eruptions and earthquakes occur. Annually, approximately 80 typhoons develop within this region, of which 19 will enter the Philippine region and six to nine make landfall. (JTWC, 2015) The Philippines is the most exposed country in the world in terms of tropical storms. Typhoon Haiyan, known in the Philippines as Typhoon Yolanda, was one of the strongest tropical cyclones ever recorded, devastating the Philippines, in early-November 2013. It is the deadliest Philippine typhoon in modern history, killing at least 6,300 people and displacing 2 million. The reason that typhoon Haiyan caused so many deaths and homeless people is the result of the past couple of decades wherein a lot of Filipinos have moved to risky, low-lying areas for cheap housing. These cheap houses are makeshift structures mostly in slum areas. To prevent a natural disaster causing this much damage, typhoon and flood resilient homes are needed. (Santos, 2013)

A more detailed analysis of the geographic, architectural history, climate, politics, economics, infrastructure and social aspects of the Philippines is described appendix 1.

1.1.2 Context Hagonoy

Hagonoy is a municipality in the South West corner of the province of Bulacan on the island of Luzon. The global distance between Metro Manila and Hagonoy is 54 kilometres. The same problems that can be seen nationwide can also be seen on a small scale in Hagonoy. Hagonoy has to deal with a housing backlog in combination with the future growth of the population. Additionally, there are multiple problems identified that specifically apply to Hagonoy.

As mentioned before, there is a major housing backlog in Hagonoy and the Philippines, which is growing due to the fact that houses and land are not affordable for a significant part of the population. This results in a high demand for affordable housing that can raise the quality of living and make better use of available land.

A more detailed analysis of the geographic, demographic, economics, infrastructure and utilities, and social aspects of Hagonoy is described in appendix 1.

Since the Philippines is exposed to several severe natural disasters, structures need to sustain during these hazards. The local problems in Hagonoy demand for local solutions. The main priority is to prevent frequent flooding of houses.

During a three-month field research in Hagonoy, observations and surveys had led to identifying five main problems which occur in the area; low housing quality, daily floods, ground subsidence, overpopulation and climate change. (appendix 2) After interviews and surveys (appendix 3) an integrated preliminary design has been made which covered solutions for these detected problems. One of the main design solution is building a prefabricated amphibious structure, in order to give protection to floods. Concluded form surveys, the idea of floating or amphibious houses excites all interviewed homeowners. In order to make steps towards realisation, a detailed research into how a prefabricated amphibious structures can be built in Hagonoy is necessary. So, this thesis aims to help Hagonoy with their housing problems by designing an affordable typhoon resilient foundation that contributes to the improvement of the living conditions.

1.2 Research objective, approach and scope

This section introduces the research objective and research questions, the approach used to achieve these objectives and the scope.

1.2.1 Research objective

The goal of this research is to design a modular amphibious structure that provides better living conditions for inhabitants of a typhoon and flood-prone area such as Hagonoy:

Design a prefabricated modular amphibious structure that is applicable in and adjusted to a flood and typhoon prone area; Hagonoy, Philippines.

In order fulfil the objective, following research questions must be answered. These research questions are divided over seven topics.

Building concept What are the main objectives of a modular and circular building concept? How can these objectives help solving problems identified in Hagonoy?

Floating behaviour What is the general theory behind floating behaviour and how can floating behaviour be improved?

Location What are the most important location-based requirements, which the structure must fulfil? What are possible scenario's in which the structure must be able to function?

Structural design foundation module How to create a proper and suitable amphibious modular foundation for Hagonoy?

Structural design connections How to create a proper and suitable connection for modular foundation modules for Hagonoy?

Affordability How to create an affordable structure for the lower part of the middle-income class? What optimizations can be made?

Integration How to integrate the design in its surroundings?

1.2.2 Research approach

To achieve the objectives all research questions must be answered. In order to answer these questions, and to accomplish a proper design, first criteria which the design must meet, are listed. Criteria result from analyses in the field of building concept, floating behaviour and the building-location. In combination with the research in the state of the art of amphibious foundation modules and connections, it forms the input for the design. After the design, design-analyses have been made in order to optimize the design.

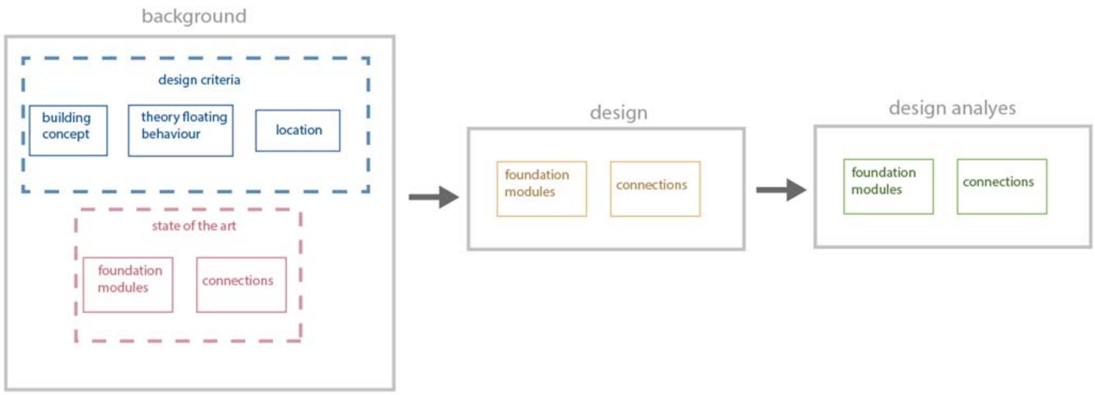


Figure 1.1: research approach

1.2.3 Scope

This research is part of bigger plan to improve housing in the Philippines. This research is the first step towards realisation. Parallel to this thesis, research is being done for the design of the building upon the foundation structure, by Joran van Schaik. The objective of this thesis is:

Design an economical typhoon resilient prefabricated home that is applicable in and adjusted to Hagonoy, the Philippines.

The design of the buildings is partly needed as input for the foundation structure. The design of the building, however, is not taken into account in this thesis. A combination of these two researches creates an integrated design.

In this research Hagonoy is pointed out as the first building location. Concluded from the field research the target group is the lower-part of the middle-income class. Vacant fishponds in barangay (town section) San Roque, are optimal building locations. In this thesis, this specific location is analysed, and the design is based on this location. However, the goal is to create a structure which can be implemented in multiple areas.

The output of this thesis is expected to be the first major step towards building a pilot building. However not every element is expected to be defined and detailed.

The main objects that will be researched and designed are a modular foundation and the connection between those modules.

1.3 Relevance of research

Social

The current building environment for the lower income class in the Philippines and Hagonoy is failing to meet the needs. Steps towards proper affordable houses are needed. Daily floods play a major role in daily life of inhabitants of Hagonoy, and specific for the lower income class. It is relevant to conduct research into an affordable prefabricated amphibious foundation, to provide lower income classes from proper houses, and thereby contribute to living conditions of inhabitants of Hagonoy.

Scalability

The problems that have been identified in Hagonoy are not fixed by location. The same problems can be seen throughout the coastal areas of the island Luzon, but also in the rest of the Philippines and even world-wide. Climate change, ground subsidence and urban compression are the main causes for the flooding and bad water quality in multiple Asian deltas (Van 't Veldt, 2015). In multiple Asian deltas are many populated or cultivated deltas that are subsiding fast, mostly due to excessive groundwater withdrawals. (Figure 1.2) (Rodolfo & Siringan, 2006). This increases the scalability of this research. Especially for other Asian countries like Taiwan, Vietnam and Thailand, this research can be applicable, because of comparable geology, climatology, and land-use.

The ground subsidence in the area is expected to worsen over time, which has a large influence on tidal and fluvial floods. The current rates for ground subsidence will cause the land to sink up to two meters in 50 years time. (Rodolfo & Siringan, 2006)The scalability and worsening trend increase the relevance of this research.

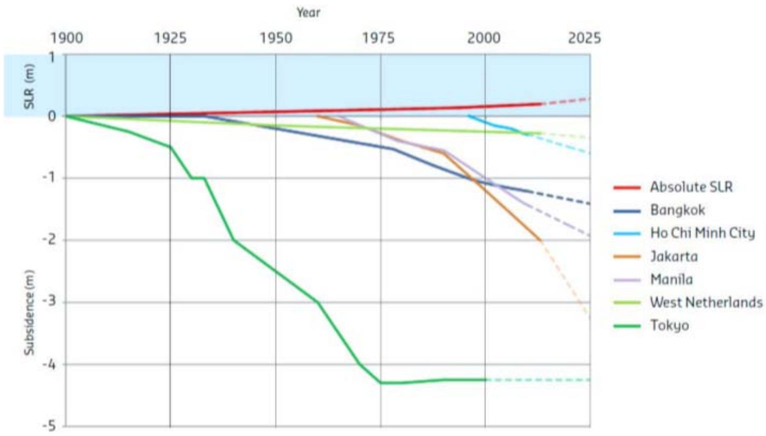


Figure 1.2: ground subsidence (Rodolfo & Siringan, 2006)

Knowledge

Several amphibious structures have been built all over the world. In addition modular floating foundations are being built in Western countries. However, an amphibious modular structure has not been commonly built yet, so research into this topic expand general knowledge in modular amphibious structures.

1.4 Research partners

This research is executed with multiple research partners. Brief profiles of involved actors are provided in the following paragraphs.

Finch Buildings

Finch Buildings builds wooden modular buildings, which are adaptable to location, target groups and function. The modular buildings are movable and can be used temporarily or permanent, resulting in flexible real estate. The key features of Finch Buildings are sustainability, flexibility, a healthy indoor climate and circularity. These features are incorporated in one design of a module. This module can be stacked and coupled to create endless configurations. Examples of applications are student housing, healthcare apartments, hotels or recreation homes.

The modular buildings are made of massive timber, called cross laminated timber (CLT). Timber as building material has health benefits and has a positive impact on indoor climate, but the most important aspect of building with wood is that it has a low impact on the environment.

The modules are energy efficient. Wood is a natural insulator, which in combination with an additional insulation layer, can reach high standards. This significantly reduces the energy consumption. The modules only use electricity, which is partly provided by PV panels. Smart home technology will moderate and visualize energy usage, enabling inhabitants to save energy. (Finch Buildings, 2014)

The vision of Finch Buildings is not only to improve the building environment in the Netherlands, but to improve the building environment worldwide. Sustainability is currently high on the agenda of countries worldwide. Houses use a significant amount of energy and materials. Conscious building design can improve the sustainability of housing and thereby reduce the impact on the planet.

However, large improvement in real estate can be made worldwide. After the typhoon hit the Philippines at the end of 2013, Finch Buildings has the dream to help and improve the building quality in the Philippines with their knowledge.

Delft University of technology

The Delft University of technology is an internationally highly renowned institute for high quality research and education. The Building Engineering department of the faculty of Civil Engineering has a broad experience with different forms of innovations in building projects in both the Netherlands and foreign countries.

Filipijnen Groep Nederland (FGN)

Filipijnen Groep Nederland is an information- knowledge and activity center with the aim to support basic initiatives for lower income classes in the Philippines. FGN contributes to activities and campaigns in the Netherlands, to create a proper imaging of the situation in the Philippines. Furthermore, FGN, supports a knowledge transfer of technical innovations between the Philippines and the Netherlands.

1.5 Thesis structure

This thesis is divided in three parts. In part I, the necessary background is given. Concluded form this part a number of criteria are listed, on which several foundation module types, and connection types are tested. In part II, after a brief design approach, a structural design of foundation modules and connections is described and analysed. In Part IV, research questions are answered, conclusions are described and further recommendations are given.

1. Introduction

Part I: Background

2. Modular, circular building concept
3. General theory floating behaviour
4. Location factors
5. State of the art

Part II: Structural Design

6. Design approach
7. MCA
8. Scenario analysis
9. Parametric models
10. Final design
11. Design – Analysis
12. Design - Integration

Part III: Conclusions and recommendations

13. Conclusions
14. Recommendations

Chapter 2: Circular, modular building concept

Chapter 3: Theory floating behaviour

Chapter 4: Location analysis

Chapter 5: State of the art

Part I Background

First a background study is made, in order to create an overview of all criteria that a proper design for an amphibious foundation must meet. This part I is divided in three chapters.

In chapter 2 a brief overview of aspects is provided, which are important for a modular and circular building concept. These aspects form the basis of Finch Buildings, and by using these themes a translation of Dutch modular system into a Filipino modular system can be made.

The third chapter gives required theoretical information of floating behaviour. Several criteria are listed, which the design of the modular foundation must fulfil.
In the fourth chapter of this part, most important location- based criteria- are listed, by analysing the area of Hagonoy.

design criteria

building concept

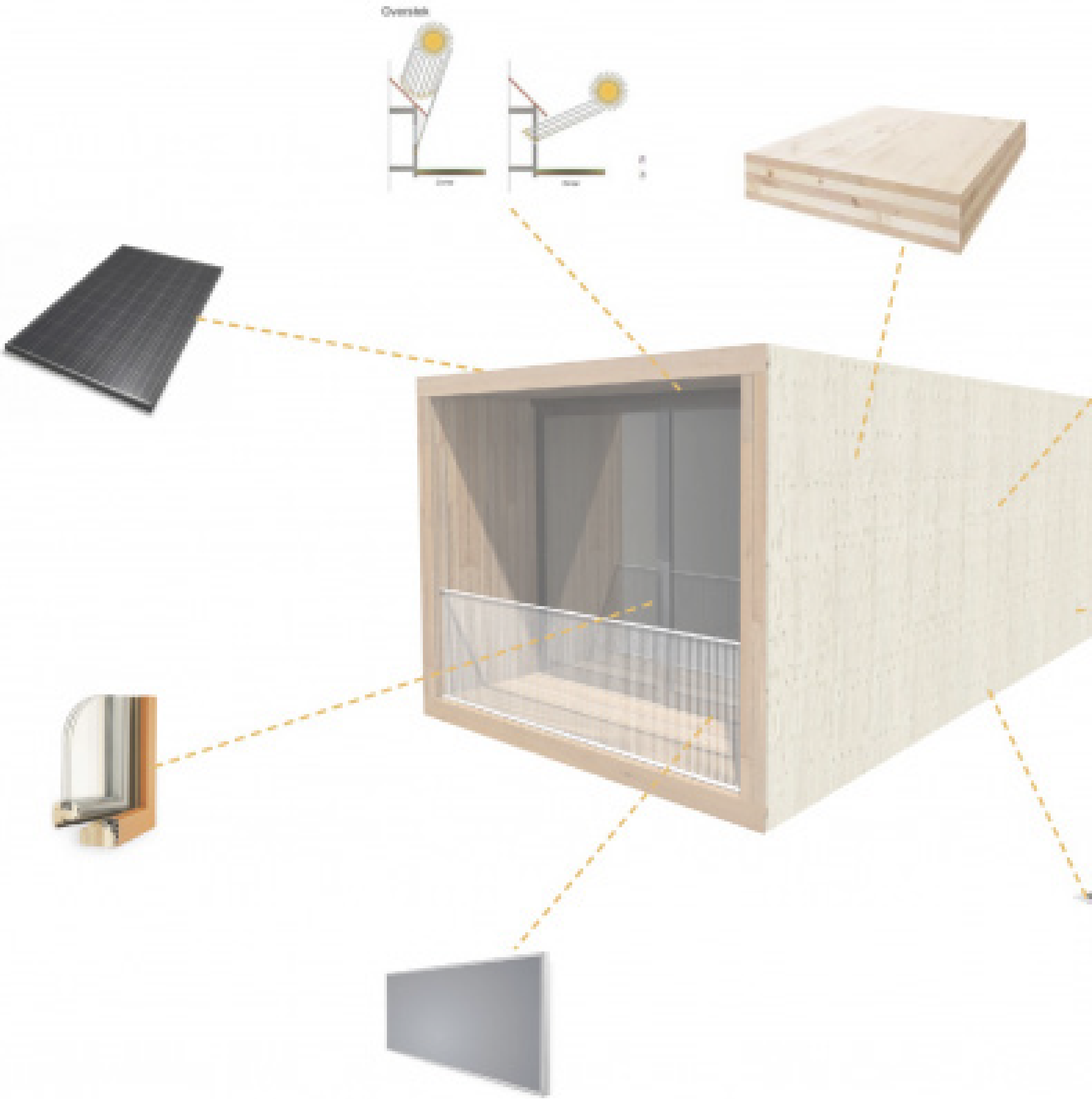
theory floating behaviour

location

state of the art

foundation modules

connections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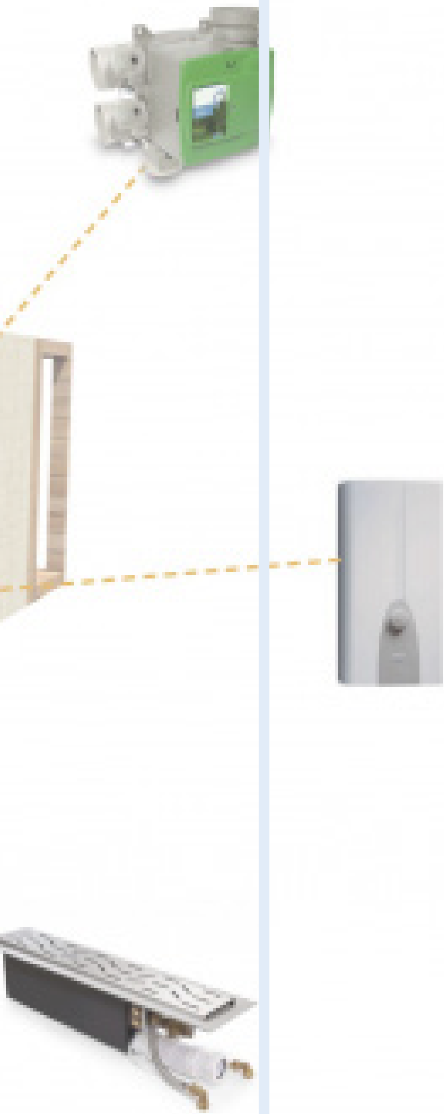
Chapter 2 Circular, modular building-concept



This chapter provides a brief overview of aspects, which are important for a modular and circular building concept. These aspects form the basis of Finch Buildings and they fully integrated these criteria into its business. By understanding and using these themes a translation of Dutch modular system into a Filipino modular system can be made. The design, described in part III, must meet these building-concept-criteria.

2.1 Main criteria

Innovation

Innovation can be defined as the process of translating an idea or invention into a good or service that creates value or for which customers will pay. (BusinessDictionary, Innovation, 2015) Innovation is one of the core principles of Finch Buildings. In order to create a sustainable building concept new technologies, but moreover new ways of thinking are used. The principle innovation will be used when designing a foundation module for the Philippines.

Flexibility

Flexibility can be defined as the ability to be easily modified. (BusinessDictionary, Flexibility, 2015) By creating a flexible building module, which is easily movable and adjustable to different target groups, vacancy and demolition is prevented. Furthermore, endless possibilities can be made with module, in order to create buildings that can function for varying target groups. For Finch buildings, this flexibility does not stop with the building module itself. It is extended to the interior as well, in order to create an adaptable indoor environment. This has as advantage that the modules can be easily changed from function. Flexibility is desired as well for a Filipino building concept. Buildings have to be able to function on their own, but they also have to be able to be stacked and connected. To configure this flexible buildings, a flexible modular foundation, which can be adapted in size is expected.

Circularity

The circular economy is an economic system with the goal to maximize recycling and to minimalize value destruction of products and materials. This circular system is the opposite of current linear systems, in which materials are transformed into products which at the end of their service lives will be destroyed. (MacArthurFoundation, 2013)

The circular system consists of two cycles, being a biological and a technical cycle. In the biological cycle, rest materials can flow back into nature after use. The technical cycle holds product elements that are designed and marketed in a way that reuse with a high qualitative value is possible. Hereby, the economic value remains on a high level. A circular system is both ecological and economical restorative. (MacArthurFoundation, 2013)

Finch Buildings aims for a building system that is 100 per cent circular, for both biological and technical aspects. For Finch Buildings, biological circularity is gained by construction materials, and by the way of using energy. For each tree, which is used as material for CLT panels, new trees are planted. Energy use is limited and it is aimed to use natural resources for energy generation.

Technical circularity can be gained by the previously described flexible design. Modules are adaptable to its location and target groups, which eliminates the need for demolition. If demolition is the only option, for any reason, the design of the building modules ensures a reuse of building materials. As a result, hardly any decrease in value of product (elements)

Circularity is not only important in the Netherlands, but applies to the world. Both technical and biological circularity is taken into account in the design process.

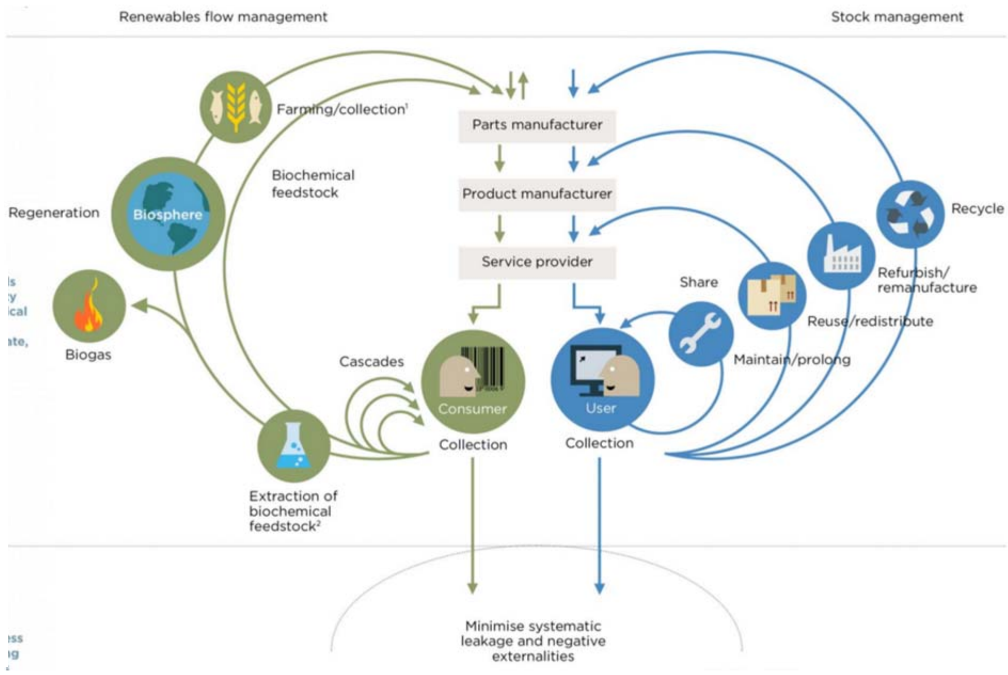


Figure 2.1: Circular economy (Braungart & McDonough, 2002)

Healthy

Healthy can be defined as being in a good physical or mental condition. (Dictionary, Healthy, 2015) Health can be influenced by a range of different factors. In Europe, humans spend most of their time indoors, therefore a healthy indoor environment is important. Unfortunately this is currently not always the case. Finch Buildings changes this, by building with healthy natural materials and by creating a healthy indoor climate. Buildings have also influence on our mental health; well-designed architecture can benefit this health. The Finch module is therefore designed to let in abundant natural light and the dimensions are optimized. This aspect counts both the Netherlands as the Philippines.

Affordability

Affordability is measured by the cost relative to the amount that the purchaser is able to pay. Affordability is strongly dependent on the country that is worked within and is connected to the target group that is focussed on. Affordability is a big part of the business plan. In the Netherlands the modules are mostly offered in a lease construction.

Affordability is one of the most influential parameters of the feasibility of a housing project, both in the Netherlands as in the Philippines.

2.2 Conclusions

Five criteria, which play a big role in modular and circular building concepts, such as Finch Buildings' concept, will be taken into account in the design for an amphibious structure, in order to create a proper translation of the Dutch concept to a Filipino concept.


LONA
4.Sale

Chapter 3 General theory, floating behaviour

In order to make a proper structural design, which performs well on both on ground and in water, first the basic theory of floating behaviour is studied. In the first section states of stability are elaborated

The basic of floating and the basics of static stability are elaborated in section 3.2. Section 3.3 introduces dynamic stability. The fourth section describes external forces, which influences both static and dynamic stability. As conclusion of this chapter, a number of criteria is listed, on which the design for the amphibious modular structure and the connections are based. As well multiple measurements are given, about how the stability of a floating structure can be improved.

3.1 States of stability

A (floating) structure is said to be in a state of equilibrium when the resultant of all the forces acting and the resulting moment of these forces is zero. Three different states of equilibrium or types of stability can be distinguished for a structure which is subject to a small disturbance from an equilibrium position. (Tupper & Rawson, 2011)

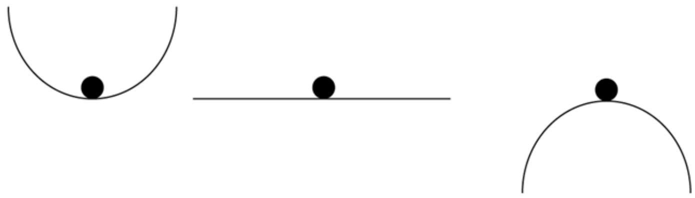


Figure 3.1: states of stability

1. If, following the disturbance, the structure tends to return to the equilibrium position it is said to be in a state of **stable** equilibrium or to possess positive stability.
2. If, following the disturbance, the structure remains in its new position, then it is said to be in a state of neutral equilibrium or to possess **neutral stability**.
3. If, following the disturbance, the excursion from the equilibrium position tends to increase, the structure is said to be in a state of unstable equilibrium or to possess **negative stability** *(Rawson and Tupper, 2011)*

3.1.2 Two types: static stability, dynamic stability

In this thesis two types of stability are studied: being static stability and dynamic stability. A proper floating structure must be able to behave properly under a static loading. Static loading can be divided into dead loads and live loads.

Besides static loads, dynamic loads, like (wind)waves can act on a floating structure. Dynamic loads act with a certain frequency. If the frequency is unfavourable, large movements can occur, which can lead to serious damage. (Baars, et al, 2009) In order to prevent these movements, dynamic stability is studied.

The goal of designing a floating structure is to create a structure which is stable for all possible motions.

3.2 Static stability of floating structures

In this paragraph the basic principles of stability of floating objects are explained.

3.2.1 Signs

In this thesis, the following signs are used:

D = Depth
B = width
L = Length
d = Draught

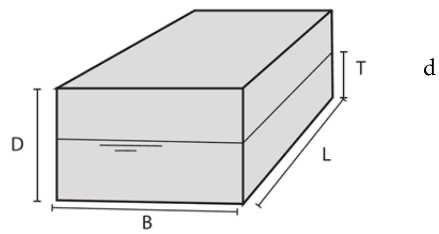


Figure 3.2: Signs

An object can translate in the following directions: :

- **surge** in the longitudinal x-direction, positive forwards,
- **sway** in the lateral y-direction, positive to port side,
- **heave** in the vertical z-direction, positive upwards.

An object can rotate among the following axes:

- **pitch** about the x-axis, positive right turning,
- **roll** about the y-axis, positive right turning,
- **yaw** about the z-axis, positive right turning.

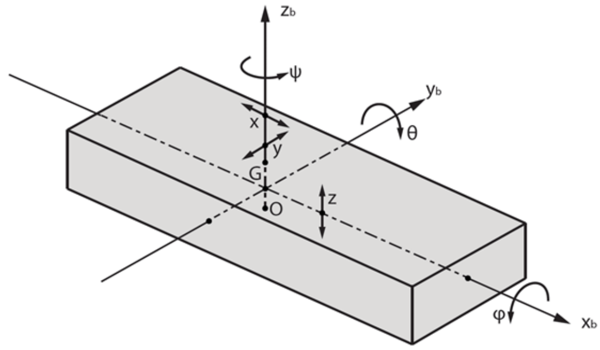


Figure 3.3: motions

3.2.2 Hydrostatics

In any body of fluid, hydrostatic pressure results from the weight of the fluid column above the point at which that pressure is measured. At a free water surface, the pressure will be zero, relative to the atmospheric pressure. In fluid, the pressure p increases, when height h increases:

In equation:

$$p = \rho g h$$

in which:

g = acceleration of gravity
h = distance below the fluid surface
p = pressure (= force/area)
ρ = mass density of the fluid

In diagram:

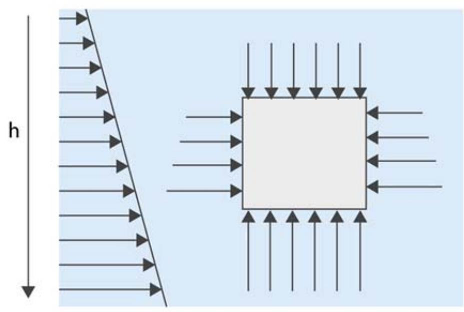


Figure 3.4: hydrostatic pressure, (author)

In this example an object B is submerged in a fluid F, where $p_2 \geq p_1$

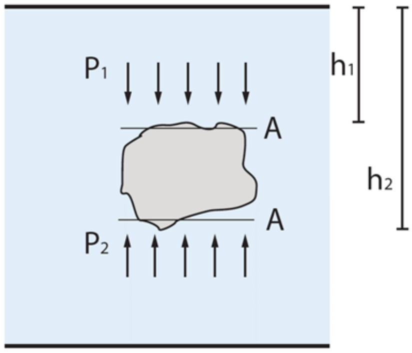


Figure 3.5: hydrostatic

In this situation:

$p = \rho g h$

$h_2 > h_1 \rightarrow p_2 > p_1$

$p_2 - p_1 = \rho g \cdot (h_2 - h_1)$

$(A_1 = A_2) \rightarrow F_2 - F_1 = \rho g \cdot (h_2 - h_1) \cdot A$

The netto force $F_2 - F_1$ is called, Buoyancy or F_b, and points in upwards direction.

$F_2 - F_1 = F_b = \rho g \cdot (h_2 - h_1) \cdot A$

$(h_2 - h_1) \cdot A = \nabla$

$F_b = \rho g \cdot \nabla$

So, the Buoyancy force equals the weight of the fluid the floating body displaces.

With:

F_b= Buyancy force [N]

g = Gravity accel. [m/s2] 9.81

ρ = Density [kg/m3] 1025

∇ = Volume of displacement [m3]

Three positions of an object in a fluid are thinkable:

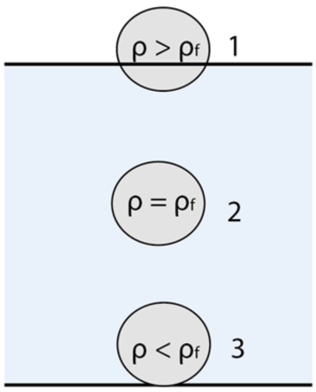


Figure 3.6: three possible positions

1.) **Floating object**: In this situation there is an equilibrium at the water surface, where the object is partly submerged (figure 3.6). In this situation the buoyancy force equals the gravity force. The object has a lower density than the displaced fluid. If this object is submerged, then the weight of the object is lower than the weight of the displaced fluid, so Fb is larger than Fg. The resulting force will make it move upwards, until the object is in equilibrium again, since the volume of displacement is decreasing. (figure 3.7)

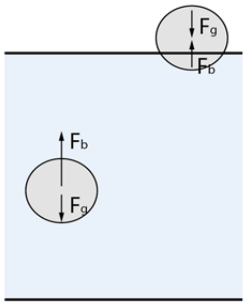


Figure 3.7: floating object

2.) **Submerged object**: In this situation there is an equilibrium when the object is fully submerged. The buoyancy force equals the gravity force. The object must have the same density as the fluid. (figure 3.8)

3.) **Sunk object:** In this situation the object will be in equilibrium on the bottom. The gravity force equals the buoyancy force plus the reaction force of the soil. If an object will be released at the location in figure7 and because in this situation the density of the object is larger than the density of the water so, the object weights more than the displaced fluid, then the Fg > Fb, and a resulting downwards force will make the object sink. (figure 3.9)

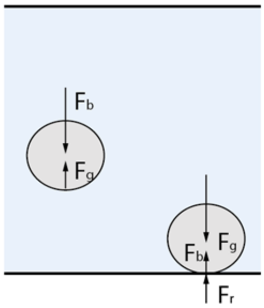


Figure 3.9: sunk object

3.2.3 Vertical equilibrium floating object

In a floating object, two resulting vertical forces will form equilibrium. One upwards pointing buoyancy force, caused by the vertical hydrostatic pressure, is equal to a downwards pointing gravity force.

The vertical buoyancy force acts on the centre of buoyancy B, and the gravity force acts on the centre of gravity G.

B = point about which first moment of submerged volume = 0
G = point about which first moment of mass or weight = 0

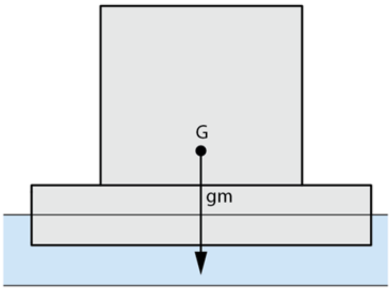


Figure 3.10: gravity force

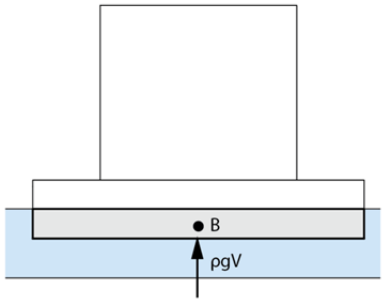


Figure 3.11: buoyancy force

3.2.4 Horizontal equilibrium

A translation in a horizontal direction does not lead to a resultant hydrostatic force, so - unless other external influences, such as a mooring system is involved - the structure is in neutral equilibrium for this type of disturbance.

Swaying and surging are undesired movements in case of a floating house. A mooring or anchoring system has to prevent the floating structure from horizontal translations.

In the following situation both resulting horizontal hydraulic forces are equal.

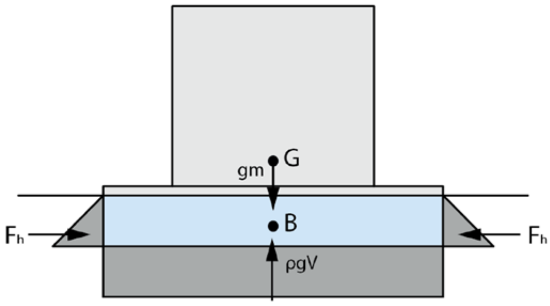


Figure 3.12: horizontal equilibrium

3.2.5 Rotational equilibrium

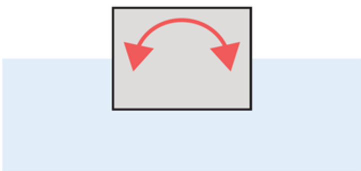


Figure 3.13: rotational equilibrium

Righting moment

An external eccentric vertical load, a horizontal load, or an external moment acting on a floating structure leads to certain rotation around the centre of Buoyancy. This leads to a certain amount of tilt of the floating structure. The structure may display a stable, a neutral or even an unstable equilibrium.

As a result of the rotation caused by external heeling moment M_H, the shape of the underwater part of the structure will change, and so changes the centre of buoyancy. The centre of gravity (g) will shift as well, so the lines of actions are not in the same line anymore. An equilibrium will be achieved when the righting stability moment M_r equals the (external) heeling moment M_H.

$$M_H = M_r = \rho g \nabla \cdot y = gm \cdot y$$

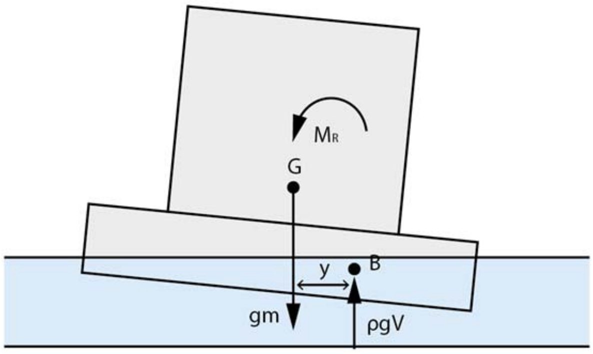


Figure 3.14: righting moment M_r

Meta centre

To consider whether a floating object is initial static stable or not, research in the height between its centre of gravity and its meta centre, the metacentric height (GM), should be made.

An external heeling moment acting on a structure, results in a rotation and a shift of centre of buoyancy. The intersection of vertical line upwards from the shifted point of buoyancy B with centreline of the structure (through G) is called metacentre. (Journee & Massie, 2001)

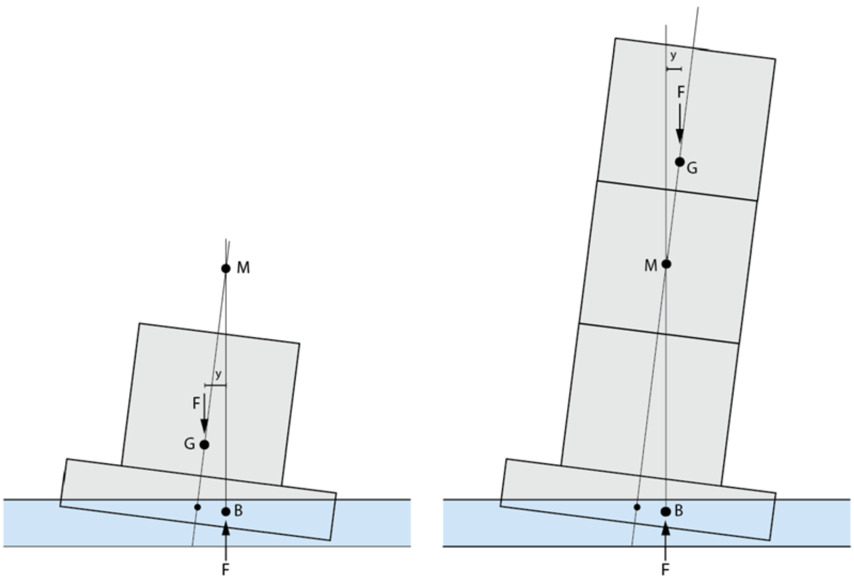


Figure 3.15: metacentric height

M = Meta centre
B = Centre of buoyancy
F = F_B (Buoyancy force) = Fg (gravity force)

In the left figure the metacentre is above the centre of gravity, and so an uplifting (stabilizing) moment M_s arises:

In which the righting stability moment, M_s, is defined by:

$M_s = F_B * GZ$
Since $F = \rho g \nabla$
$M_s = \rho g \nabla \cdot GZ$

The righting stability lever arm, GZ:

$$GZ = GM \cdot \sin \varphi$$

And so the righting moment M_S:

$$M_s = \rho g \nabla \cdot GM \cdot \sin \varphi$$

In the right figure the meta centre is above the centre of gravity. In this situation a heeling moment arises.

Heeling moment: $M_H = F_B * y$

This heeling moment makes the floating structure tilt more and the structure is thereby unstable.

The height between G and M, is the metacentric height (GM).

When the meta centre is above the centre of gravity, metacentric height **GM is positive** and a structure is said to be **stable**. If GM is positive a righting stability moment M_S the structure its stability. A larger GM means a larger stability lever arm GZ, which means a higher the uplifting moment M_s and a more stable structure.

When the metacentre is below the centre of gravity metacentric height **GM is negative** and a structure is said to be **unstable**. Gravity force and buoyancy force will provide a rolling moment M_r. (Journee & Massie, 2001)

Location of metacentre
In this paragraph an explanation of how the location of the metacentre can be find is given.

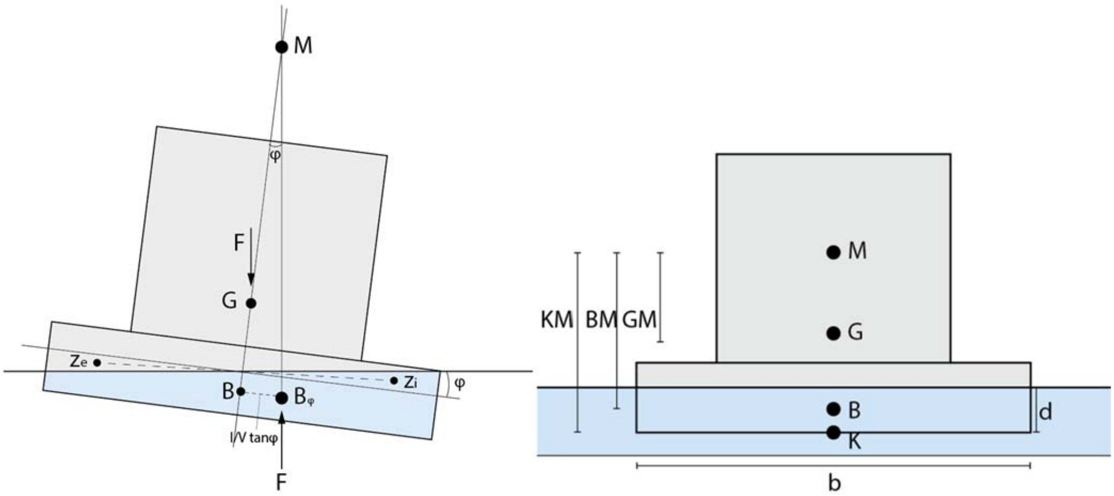


Figure 3.16: location of metacentre

The meta centric height can be calculated with GM:

$$GM = KB + BM - KG$$
$$= KB + I_t/\nabla - KG$$

With
$\nabla = l*b*d$
$I_t = 1/12\ l\ b^3$ (for a floating body with a rectangular shape)

$BM = b^2/12d$

The height of the point of buoyancy from of the keel is for a rectangular floating half the draught:

$KB = ½\ d$
$KM = KB + BM = b^2/12d + ½\ d$
$GM = KM – KG = b^2/12d + ½d - KG$

The stability in both orthogonal directions is not equal if the width and length are not equal. In the direction of the smallest length the floating body is less stable.

Calculation of the rotation
For a structure with vertical sidewalls, righting moments can be determined as follows:

$$M_s = \rho g\nabla \cdot GZ$$

$$M_s = \rho g\nabla \cdot GM \cdot \sin\varphi$$

This method works for an angle smaller than 10^o. When the metacentric height is determined, the rotation under an imposed load can be calculated. The righting moment can be calculated by:

The rotation is a result of an acting (external) moment. If a structure is stable, the righting moment M_s has to be equal with the acting moment (M_s). So the resulting rotation of this action moment can be calculated:

$$\sin\varphi = M_s / (\rho g\nabla \cdot GM\ )$$

3.3.9 Conclusions static stability

Light foundation structure
In order to create vertical stability the gravity force may not exceed the buoyancy force. A light structure is preferred, for both the building as the amphibious foundation.

Increase stability
To minimize tilt, roll and pitch, the stability of a floating object can be enlarged. Four measurements can be taken to increase its stability.

Increase metacentric height (GM)
A larger metacentric height GM, means a more stable structure. A several measurements can be done to increase the metacentric height. One option is to decrease the value for KG. The other is to increase the value for KM in the following formula (Journee & Massie, 2001):

$$GM = KM – KG$$

Weight stability (decrease KG)
A low centre of gravity, will give a low value for KG. The lower the KG, the higher GM and the more stable the structure will be. By lowering centre of gravity, the heeling moment will raise, since the lever y will raise (Journee & Massie, 2001). (figure 3.17)

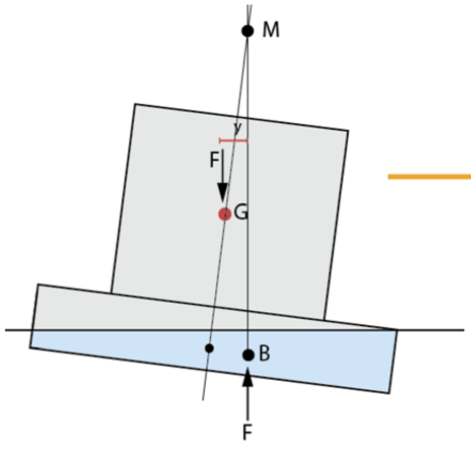


Figure 3.17: weight stability

For a structure with a centre of gravity located lower than the centre of buoyance, the structure will always relocate itself. In this situation, the righting moment will increase at an increase of the heeling angle.

Shape stability (increase KM)

The base of shape stability lies in the shift of centre of buoyancy, under an imposed rotation. With a larger shift of the centre of buoyancy, under an imposed rotation, the metacentre will be higher. So the structure will be more stable. (Journee & Massie, 2001)

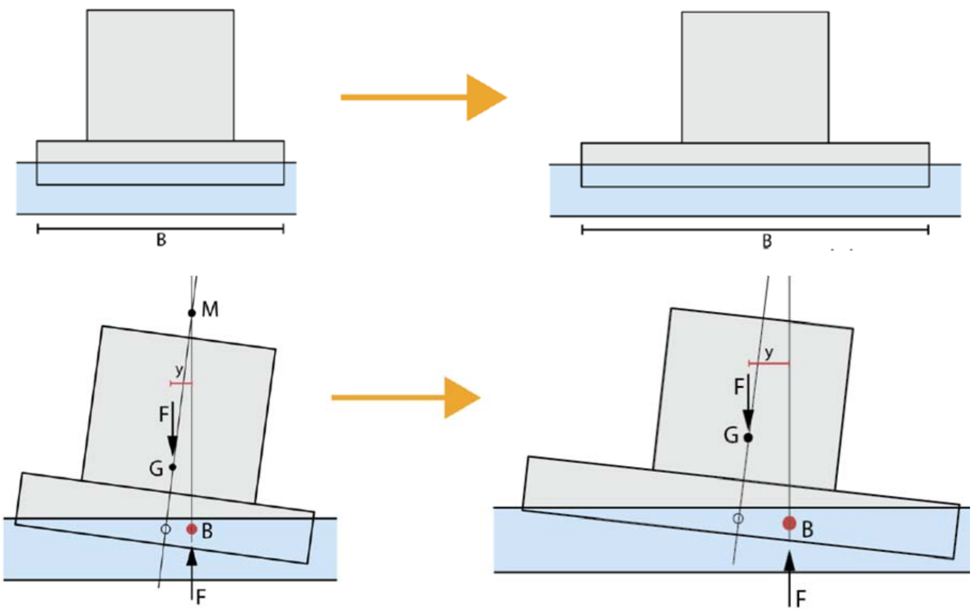


Figure 3.18: shape stability

Since a floating body with a rectangular vertical section has to displace more water under an imposed rotation, than cylindrical or triangular shapes, a floating body with a rectangular vertical section will be more stable.

KM can be calculated by the following formula:

$$KM = b^2/12d + ½d$$

In this formula the width to the depth ratio is decisive, since the width of the floating body works quadratic. By increasing the width b of a floating structure, the KM will increase. By that GM will increase, so the structure will be more stable. With a wide rigid body, the centre of buoyancy will shift largely under a small imposed rotation. A wide floating body with a small draught will have a high initial stability.

However, when the rotation increases more, the GM will decrease, so the righting stabilizing moment will decrease again.

Additional measurements

By adding ballast weight, tilt by permanent loads can be countered. In addition the shape of the foundation can be changed in order to prevent tilt by permanent loading. Another way to enlarge the stability is to make use of movable ballast. This principle is common for vessels. Where they use for example with ballast tanks or water cellars. By adding movable buoyancy, for example by placing extra floatable material under the structure, the stability can be enlarged.

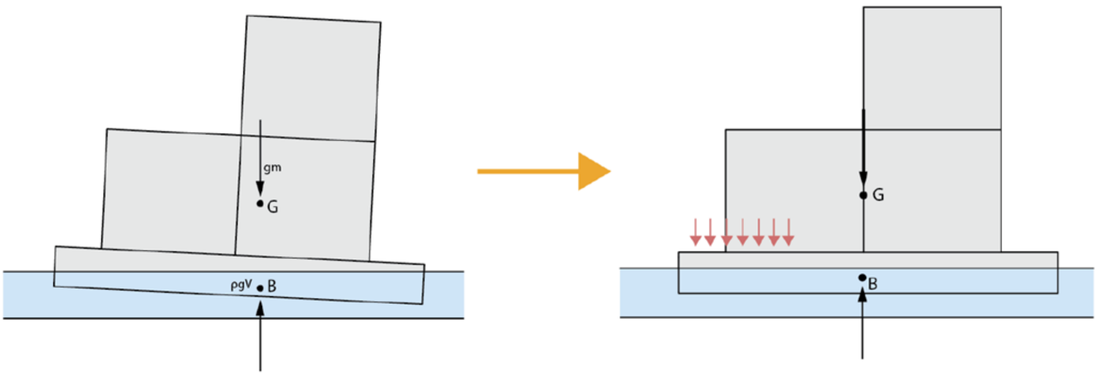


Figure 3.19: additional ballast

3.4 Dynamic stability

Besides static stability, the dynamic behaviour of a floating object is reviewed.

3.4.1 Motions

A floating object has six degrees of freedom. By mooring, movements in x and y direction (surge and sway), and rotation around the z-axis (yaw) cannot occur. To deal with change in water level, the floating structure must be able to move in z direction (heave) and to rotate around the x- and y-axis (roll and pitch). These possible movements make the structure a free floating body. All motions have been mentioned in chapter 1.4.7.

3.4.2 Surge and sway

Surge and sway will be prevented by mooring piles. Hereby oscillating movements cannot occur. However, waves can cause oscillating forces on the structure. Connections and mooring piles will absorb those forces.

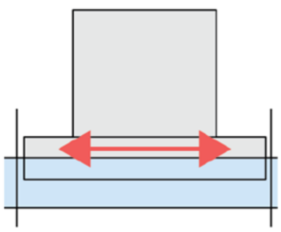


Figure 3.20: surge and sway

3.4.3 Dynamic heave oscillation

The floating structure can move freely in z-direction. A free floating structure will follow the height change of the water level. External forces, likes waves, can put a floating object in vertical motion. By the oscillating behaviour of waves, dynamic vertical forces will act on the floating body and oscillating heave motion will occur. If the frequency of the dynamic load is unfavourable, the heave motion can increase, which can lead to large movements, which can lead to serious damage or unliveable situations. If the oscillation of loads configures with the natural oscillation period (Eigen period) of the floating structure, a large increase of movements will occur. In order to prevent this, the natural oscillation period of the floating structure has to be significantly larger than the oscillation period of the dynamic loads. To reach this prevention a study in oscillation in all possible motions needs to be done.

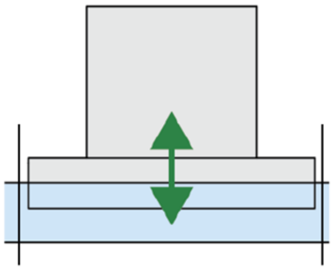


Figure 3.21: heave

The Eigen period of heave oscillation can be calculated by the following equation.

$$T_0 = \frac{2\pi}{\sqrt{\dfrac{g}{d + \frac{1}{8}\pi B}}}$$

(Journee & Massie, 2001)

3.4.4 Dynamic roll and pitch

Roll and pitch can occur in a static and a dynamic way. The static roll and is called heeling or tilting. Heeling or tilting, occurs by an external static moments, or external horizontal or vertical (eccentric) forces.

The dynamic roll and pitch movement can be derived in the same way as the heave motion. The Eigen period of a floating structure depends mainly on the metacentric height. As stated in 3.2.5, the metacentric height depends mainly on the width of the floating body. Structures with a larger width will have a lower Eigen period for roll and pitch. Increasing the length and the width of a structure will shorten natural oscillation periods, and it will decrease rotating of the floating structure. So a large floating structure will oscillate relatively fast with relatively small movement. The oscillating effect will be worst if the length and width of a structure are equal to or smaller than the half of the wavelength. (Journee & Massie, 2001)

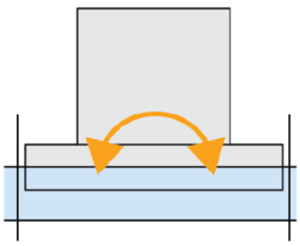


Figure 3.22: roll and pitch

The eigen value of dynamic roll and pitch oscillation can be calculated by the following equation.

$$T_0 = \frac{2\pi \cdot j}{\sqrt{GM \cdot g}}$$

(Journee & Massie, 2001)

3.4.5 Yaw

Mooring piles prevent the structure of rotation around the z-axis (yaw)

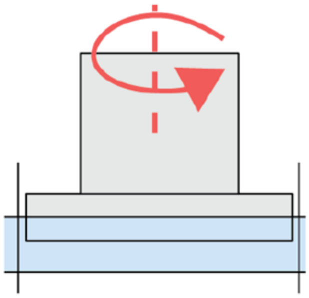


Figure 3.23: yaw

3.4.6 Conclusions dynamic stability

Conclusions from the dynamic stability form important input for the structural design phase.

Firstly, allowable motions are, heave and a limited roll and pitch. Prevented motions are: surge and sway, and yaw. Secondly some measurements can be taken order to reduce heave oscillation.

Reduce heave oscillation

Heave oscillation can be reduced by creating a floating body which is significantly larger than the wave length. Furthermore a floating structure with an Eigen period, which is significantly larger than the natural period of waves is less susceptible for heave oscillation. The following formula shows that that can be achieved by enlarging the width and draught.

Reduce roll and pitch oscillation

By decreasing the length GM, the oscillation period of a structure can be increased, and the structure will gain dynamic roll and pitch stability. GM can be decreased with a higher center of gravity or by decreasing the width and length of a floating body. This measurements however have negative influences on the static stability and on heave oscillation.

When dimensions become larger, an increase or decrease of dimension, does not influence the oscillation period that much.

However, roll and pitch oscillation is worst when the length and width of the structure are smaller than the half of the wavelength.

3.5 External forces disturb stability

External forces working on a floating body, brings the object out of its equilibrium state. In a following scheme all external forces are displayed that need to be examined.

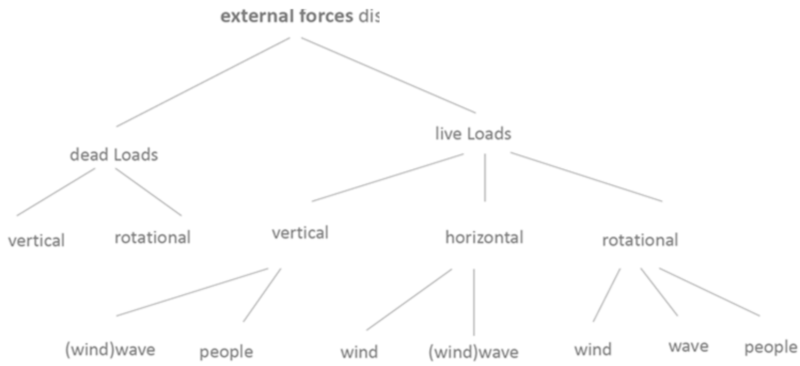


Figure 3.24: external forces

These external forces can make a floating body move in several directions. All forces depicted in the tree diagram of Figure 3.24 are elaborated in the following paragraphs.

3.5.1 Motions

By these external forces, the floating object has the intention to move in 6 particular ways, as described in 3.2.1. A floating object has six degrees of freedom. By mooring, surge and sway and yaw cannot occur. To deal with change in water level, the floating structure must be able to heave and to roll or pitch. These possible movements make the structure a free floating body.

3.5.2 Dead loads

First dead loads are depicted.

Vertical displacement by dead load

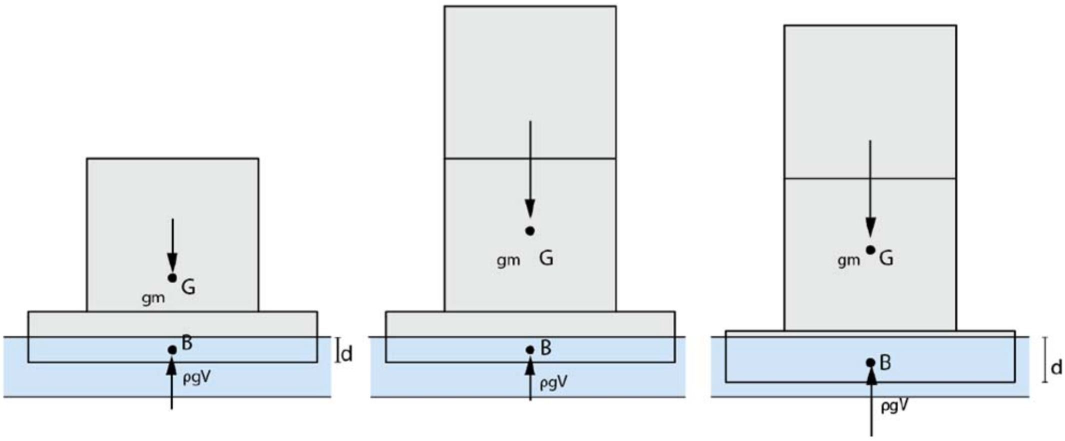


Figure 3.25: vertical stability

The floating structure can move freely in z-direction. The draught will change after a change in the gravity force. Obviously at a higher gravity force, the floating body will sink deeper and the buoyancy will force will increase, since more water needs to be displaced. Now, a new static equilibrium will be formed.

The load combinations to determine the straight draught must be calculated as follows: (NTA8111)

$$F_{\Sigma;d} = 1{,}0 \times G_{rep;1} + 1{,}0 \times Q_{1;\,rep} + \sum_{i \geq 2}^{n} 1{,}0 \times \psi_i \times Q_{i;\,rep}$$

With:

$F_{\Sigma;d}$	is the total calculation value for the combination of vertical loads for the straight draught, in kN
$G_{rep;1}$	is the representative value for the dead load according to method 1, kN
$G_{rep;2}$	is the representative value for the dead load according to method 1. In kN
$Q_{i;\,rep}$	is the representative value for the live load for story number i, in kN
$Q_{1;\,rep}$	is the representative value for the live load for story number 1, in kN
Ψ	is the instantaneous factor for story number i, according the Eurocode, dimensionless
N	is the amount of stories, dimensionless

Rotation due to dead load

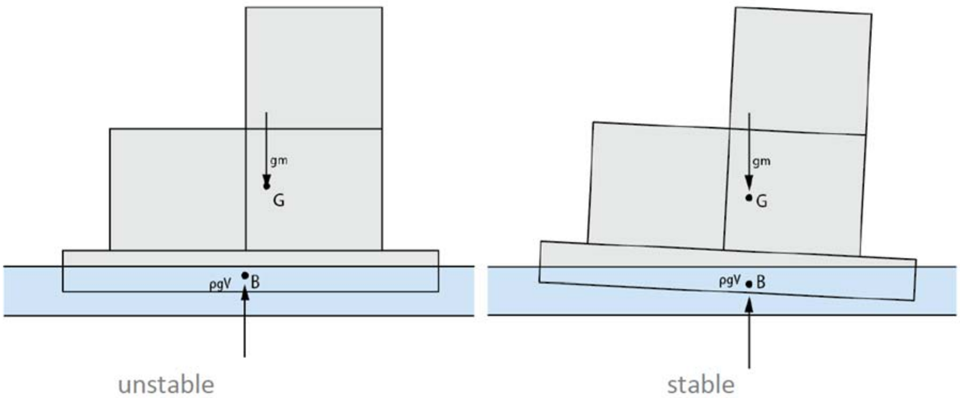


Figure 3.26: rotational stability

An eccentric loading such as depicted in figure 3.26 can cause a static heel or tilt. The shape of the submerged body changes, so the point of buoyance shifts, and a new static equilibrium can occur.

3.5.3 Live loads

In this paragraph the live loads which can act on the structure are elaborated.

Vertical live loads

(wind)wave

Wave load is an important load case for floating structure since waves result in horizontal and vertical forces and in moment of the floating structure. Vertical forces can cause relatively large moments.

The main cause of waves is the wind. By knowing the depth, the fetch, the durance of the wind and the wind speed, an approximation of the period, amplitude and frequency can be made. This can be done by using Bretschneiders formula. This method is shown in appendix 5.

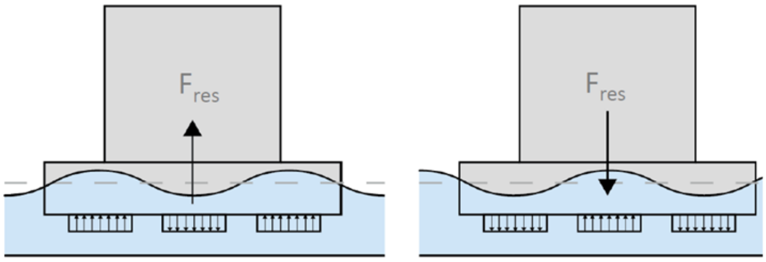


Figure 3.27: vertical resulting forces by waves

People

For the live load caused by people the NTA8111 code is used, which configures NEN1991.

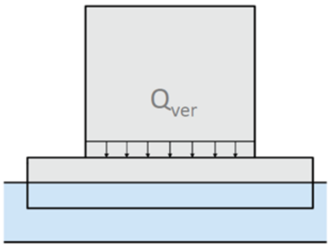


Figure 3.28:: live load by people

Horizontal live loads

Wind

The loading of the wind on a building is determined by the wind speed. There are several factors that influence the wind speed and the loading. The probability of occurrence, the recurrence interval, the importance of the building, but also how the wind speed is measured. In order to design a typhoon resilient building a wind speed should be determined to design for.

Wind causes a distributed horizontal force. Horizontal reaction forces in the mooring piles, provide horizontal stability (figure 3.28).

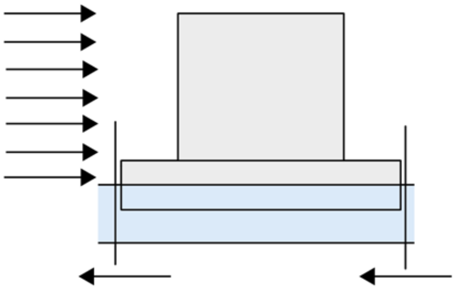


Figure 3.28: horizontal loading, caused by wind

In chapter 4.1 is descripted how wind load can be derived from wind velocity by using the Eurocodes and American code (ASCE) on which the building codes of the Philippines is based. Next chapter it will be applied on the situation for Hagonoy, Philippines.

(wind)wave

Horizontal hydraulic forces can disturb the horizontal stability. Due to wind waves a higher water level can occur on one side of the structure. A higher water level at one side causes a higher hydraulic pressure at that side, and so a resulting horizontal force arises. Reaction forces in mooring piles, prevent the structure from moving. This is elaborated in detail in chapter 12.

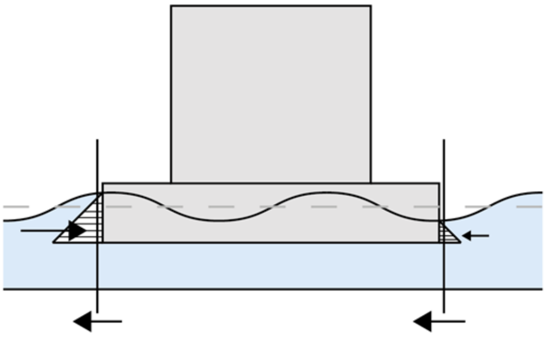


Figure 3.29: horizontal loading, caused by (wind)waves

Rotation by live loads

The load combinations to determine the maximum heeling must be determined on base of the most undesired combination: (NTA8111)

$$M_{\Sigma;h} = 1{,}0 \text{ x } M_{wind} + 1{,}0 \text{ x } M_{wave} + 1{,}0 \text{ x } M_{2nd\ order} + 1{,}0 \text{ x } M_{overige}$$

$M_{\Sigma;h}$ is the maximum heeling moment, in kNm;
M_{wind} is the moment as a result of the wind load, in kNm;
M_{wave} is the moment as a result of the wave load, in kNm
$M_{2nd\ order}$ is the moment as a result of the second order effect, in kNm;
M is the moment as a result of potential remaining horizontal forces, like current, or anchoring, in kNm
$M_{1;rep;ecc,\ floor}$ is the moment as a result of the representative eccentric floor load, by people, in kNm

Wind

Since this wind load works eccentric on the structure it causes an external moment around its centre of buoyancy.

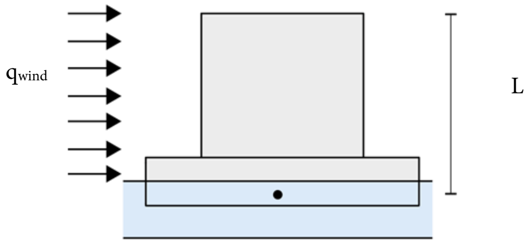


Figure 3.29: heeling moment, caused by wind

(wind) Wave

Waves can act on the structure in multiple ways. (chapter 8.3.4) In the situation as depicted in figure 3.30, waves cause an external heeling moment, since an increase of the water level on one side of the structure, and a decrease of the water level on the other side of the structure occurs. Hereby an upward pointing distributed force acts on one side of the structure and a downward distributed force acts on the other side of the structure. This behaviour is elaborated more in detail in chapter 8.3.4

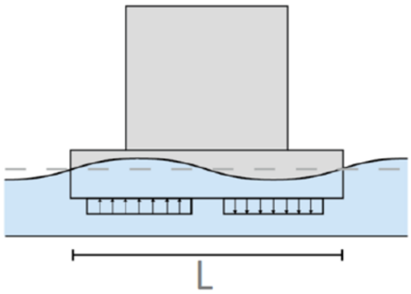


Figure 3.30: heeling moment, caused by (wind)waves

People

Eccentric loading by people causes a heeling moment. The eccentric load by people can be calculated by placing a load at one half of the structure, as depicted in figure 3.31. The distribution of people must be the most unfavourable, from stability point of view. A is explained how the eccentric loading can be calculated.

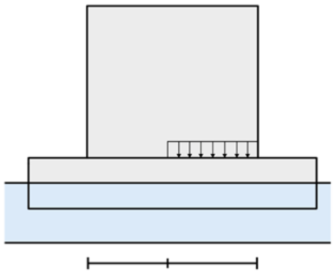


Figure 3.31: eccentric loading by people

Second order

An extra heeling moment caused by the eccentric acting gravity force of the structure must be taken into account. After calculating the intimal tilt, the second order moment can be calculated by multiplying the gravity force with the vertical distance between buoyancy force and gravity force. (NTA8111)

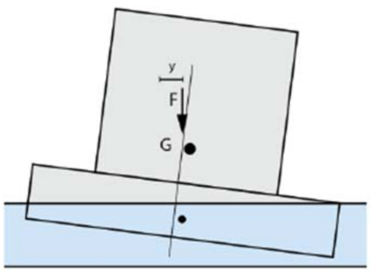


Figure 3.32: second order effect

3.6 Hog and sag

A hogging or sagging moment describes the internal bending moment caused by (wind)waves. Hogging describes a floating object which curves upwards in the middle, and sagging describes a beam which curves downwards. By non-rigid flexible foundation internal moments due to hag and sog will decrease. A disadvantage about building a flexible foundation is that large moments can occur. In addition the structure will be much more susceptible for heave oscillation. An unliveable situation can occur. (Molenaar, Baars, & Kuijper, 2008)

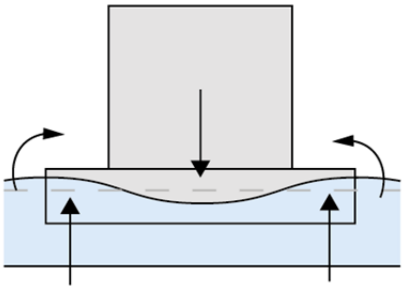


Figure 3.33: sag

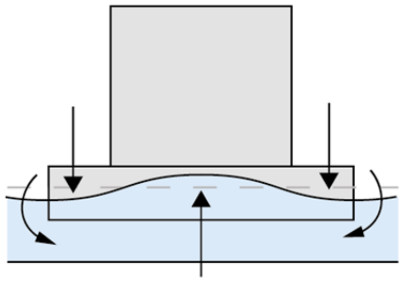


Figure 3.34: hog

3.7 Conclusion floating behaviour

As concluded in the theory chapter, the static and dynamic stability increases strongly by increasing the length and width of a structure. A large rigid floating body is less susceptible for movements by imposed loads. A modular rigid foundation can be created by building rigid modules and rigid connections between modules.

With rigid connections, not only the relative movements are prevented, but also overall motions decrease. A rigid connection functions as long as the internal forces stay within the limits of the strength of the structure.

Several criteria can be concluded which form an input for the (structural) design of the amphibious foundation modules and connections:

Criteria floating behavior:

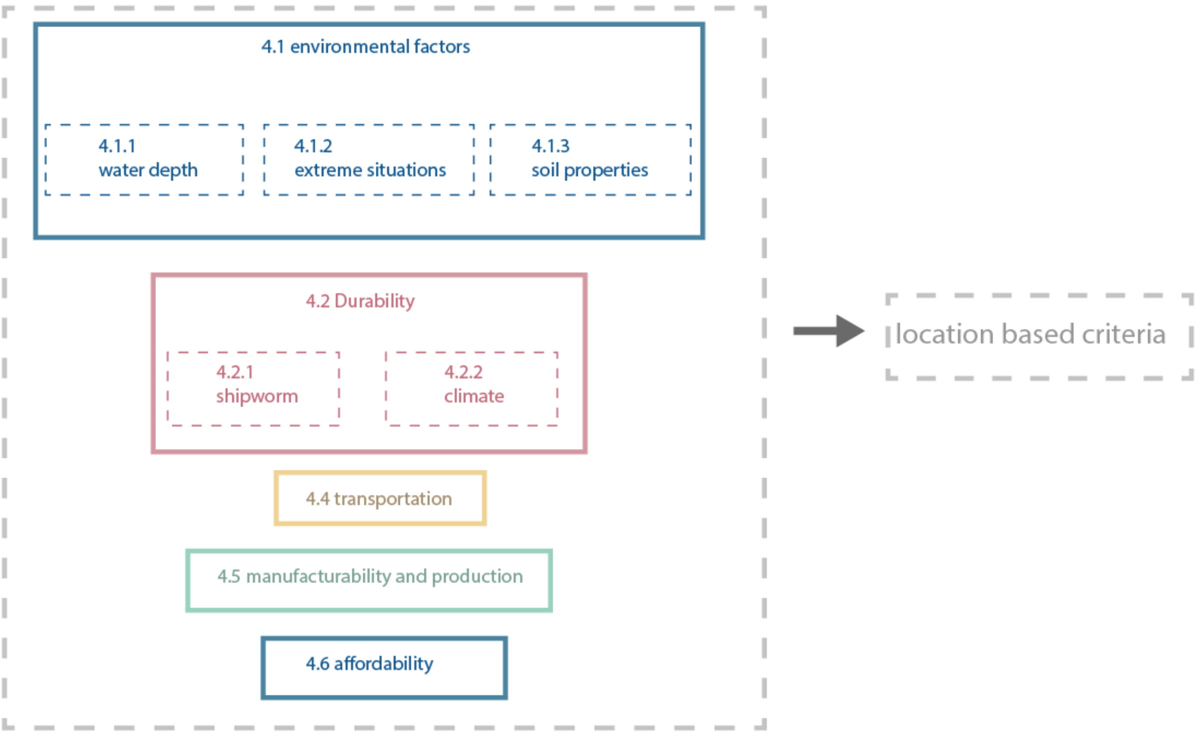
- a light-weighted structure for both the foundation as the upper building is preferred, however oscillation behavior can be decreased by increasing the draught.

- a low center of gravity is preferred to increase static stability.

- in most situations, a large and wide foundation is preferred, so the possibility to extend in length and width is an advantage.

- a rigid body is required, so rigid foundation modules with rigid connections between modules are required.

- creating a (integrated) system in which extra ballast can be gained is an advantage.


4.1 environmental factors
4.1.1
water depth
4.1.2
extreme situations
4.1.3
soil properties
4.2 Durability
4.2.1
shipworm
4.2.2
climate
4.4 transportation
4.5 manufacturability and production
4.6 affordability
location based criteria

Chapter 4 Location analysis

It is concluded from the field research that San Roque can be a suitable location for the first amphibious structures. San Roque is a so called barangay (town section)of Hagonoy. It is situated in the south area of Hagonoy close to the sea. In San Roque multiple former fishponds are unused nowadays. Vacant fishponds are interesting locations to build the first building modules.

In the field research several conclusions are made according the location. Both similarities and differences between building in the Netherlands and building in the Philippines are detected.

Similarities: The main criteria of the described building concept in chapter 2, which are fully integrated into Finch Buildings' concept, do count for the design of a Filipino concept to. Being, flexibility/modularity, circularity, healthy, and affordability. Additionally, for previous described reasons, prefabrication is a large advantage.

Differences: In addition to similarities between building in the Netherlands and the Philippines, differences have been detected, being (1) climate conditions, (2) lack of proper infrastructure, (3) labour costs and (4) available proper building materials. (appendix 2)

In this chapter further research into the building location is elaborated in order to create a list with criteria which are based its location.

In section 4.1 environmental factors; water depth, soil properties and extreme load situations due wind and waves are elaborated. In 4.2 a description of location-based factors which influences the durability are described. In addition, relatively bad infrastructure influences limitations among transportation. This is elaborated in 4.3. In 4.4 manufacturing and production criteria are given. In section 4.5, the affordability is briefly discussed. Together with building concept-criteria and floating-behaviour-criteria, these location-based criteria are the main demands the design needs to fulfil.

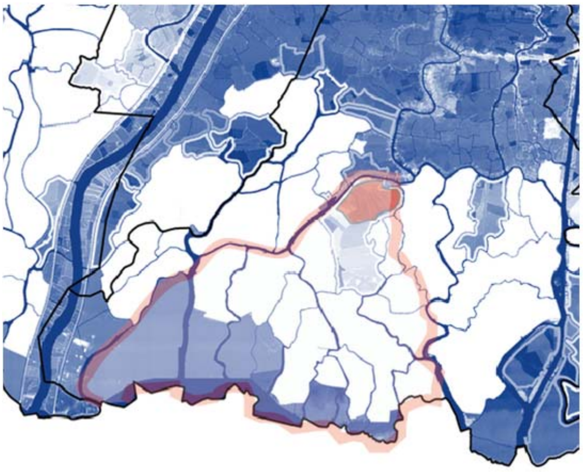


Figure 4.2: Papanga Delta; San Roque

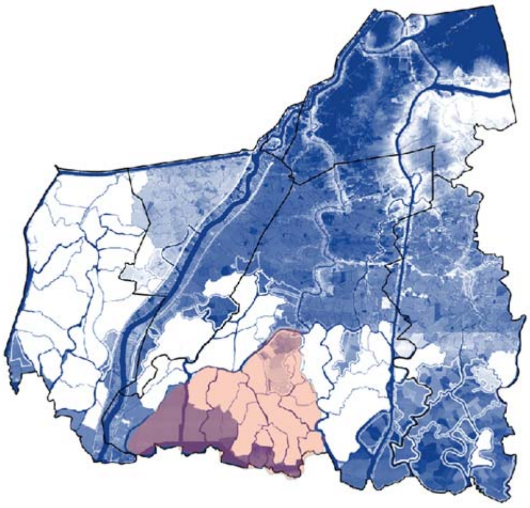


Figure 4.3: construction site

4.1 Environment

In this section an overview of environmental factors that influences the design is given. Firstly the water depth and future plans to avoid major floods are elaborated. Secondly characteristic information of the soil is described. In the third paragraph extreme conditions due wind and wind generated waves are elaborated.

4.1.1 Water depth

As stated, The Papanga Delta, where Hagonoy is located, deals with major flood problems. The current situation and possible future scenarios concerning the flood problem are outlined in this section. Actual water level forecasts are concluded for San Roque. Outcome of this research is a certain are taken into account by designing the foundation modules and connections.

Current situation

Van t Veldt (2015) described six main phenomena that cause floods:

a) Sediment increase due to eruption of the Pinatubo volcano;
b) Deforestation upstream in the catchment and along the bay;
c) Control restrictions of the upstream dams;
d) Subsidence mainly due to ground water extraction;
e) Channel encroachment by squatters;
f) Incomplete flood control systems

Due to excessive ground water extraction the area of the Pampanga delta sinks with an average of 5 cm/year. (Rodolfo & Siringan, 2006) The high population density raises the demand for fresh water. This high demand, in combination with poorly regulated extraction, causes an enormous ground subsidence in the Manila Bay area. This has caused a ground subsidence of San Roque, to ±2 meter below MSL ground level. (Van 't Veldt, 2015)

Figure 4.4: groundsubsidence in Hagonoy

The municipality of Hagonoy has implemented several remedies with the goal to reduce the impact of floods. One of the remedies is an increase of the height of the road, in order to create accessible connections. This remedy however, blocks the water outflow to lower areas. This worsens the effect of the tidal and fluvial floods for certain areas. Due to ground subsidence and increased height of roads, the first floor is unusable for many buildings. In addition, due to ground subsidence, drains, situated under buildings, are damaged and disconnected. This has led to polluted water in this water, since waste water cannot be drained in a proper way.

In the area of Hagonoy, the depths of the annual floods have increased from 0.2 to 1.0 m between 1991 and 2002. (Van 't Veldt, 2015) Cities situated in the area from coastline to about 20km further inland, are flooded up to nine months a year. In Bulacan province, the situation changed from floods with durations of about two hours, which were mainly caused by high tides and typhoons or southwest monsoons, to floods with durations of half a day to a day only caused by high tide. (Rodolfo & Siringan, 2006). Hagnoy is the most effected city of the area. Hagonoy is flooded to seven days every month due to high tide, due to its relative low elevation height. (0.5 – 1.0 m below mean sealevel). The Papanga River, the Hagonoy River and the Labangan floodway provide a direct connection between Hagonoy and the sea, so the tide can freely enter Hagonoy. Due to poorly maintained tidal gates, tidal floods reach a depth up to 0.5m. Fluvial floods have an even larger impact on the area. (Van 't Veldt, 2015). The water levels during Pedring 2011 are sketched in figures 4.5 and 4.6. The average current flood depth in Hagonoy is 0.74 m. In San Roque, tidal floods have even a bigger impact, because it is situated closer to the coastline. More upstream, fluvial floods are the major problem. The maximum water depth in San Roque during Pedring 2011 was up to 2 m.

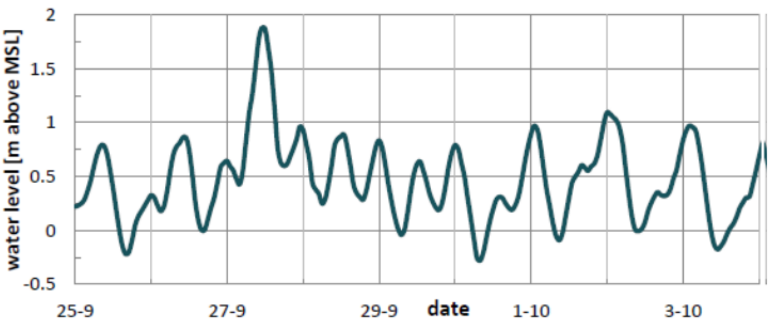


Figure4.5: estimated water levels, Hagonoy, typhoon Pedring (2011)

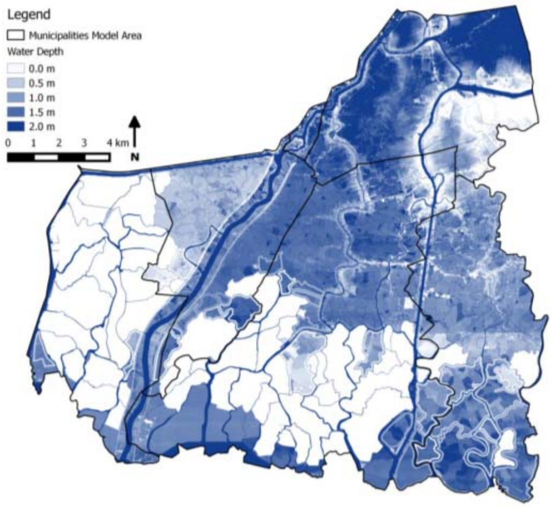


Figure4.6: maximum water depth during Pedring (2011)

Future scenarios

As stated previously, remedies, as uplifting the road are taken by the municipality of Hagonoy. In addition, solutions on a larger scale are being discussed by governmental parties. Several future scenarios are sketched, which have an influence on the water depth in San Roque and so on the design of the amphibious modular structure.

Three possible future scenarios are elaborated:. Two models describe the future scenarios for 20 and 50 years. The model for 50 year subsidence shows that most of the fishponds are submerged. A third model is made with the assumption that the fishponds dikes remain at the same level, by dike maintenance by fishpond owners. (Van 't Veldt, 2015)

The results from the model for the three future scenarios with subsidence are summarized in figure 4.7 to figure 4.9 . The figures present the water level difference compared with the baseline scenario.

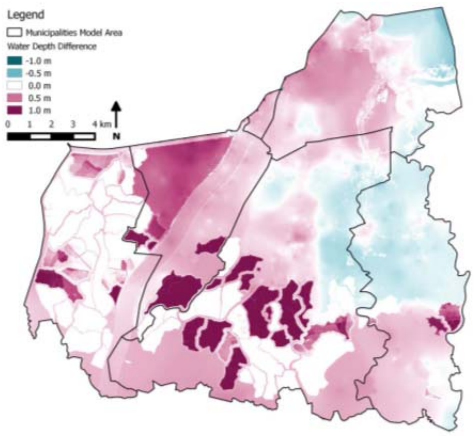


Figure 4.7: water depth difference for the future scenario, 20 years without dike maintantance

For both the scenarios with 20 and 50 years of subsidence, fishpond areas subside, causing a large increase of the flood area. However, for the 20 years scenario, a connection with the Manila bay is not yet created. This means water is stuck at fishponds. Combined with the upstream subsidence, this causes an increase in water depths in the total area.

For the 50 year scenario, an open connection to the sea arises. This open connection makes drainage to the bay for the fluvial flood much easier and a large decrease in flooded area and water depth is measured. For both models the flow velocity does not vary much compared the baseline model with average flow velocity differences of respectively 0.04 and 0.05 m/s.

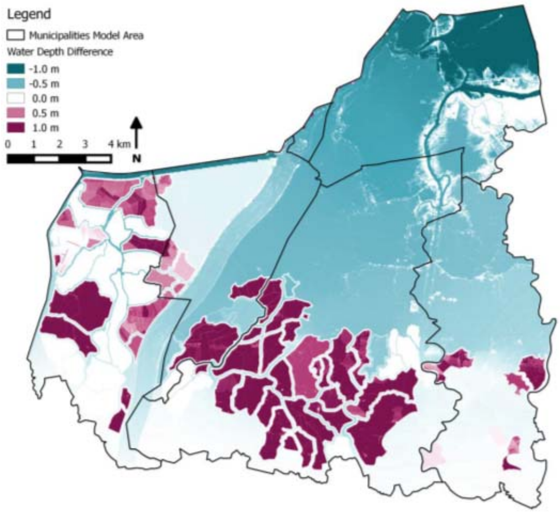


Figure 4.8: water depth difference for the future scenario, 50 years subsidence without dike maintenance.

However, this open connection is not likely to happen, since it is expected that the rich fishpond owners maintain their dikes, which leads to less submerged fishponds. During an extreme typhoon the total area will be flooded up to 2.70 m.

Recommended scenario

The best fitted option to reduce floods is to regulate the fishpond dike heights just above spring tide and opening the fishpond gates. Hereby a more open connection to the bay is created, so drainage of fluvial floods is improved. A first phase of this measure could be a fishpond flood channel. Such a channel restricts the dike heights and opens the gates of a couple of neighbouring fishponds, while the other fishponds are still free to determine their dike height. Still not a major current occurs in this situation. This recommended situation is taken into account in this chapter. In this scenario a water level difference of 1,0m with the current situation is expected.

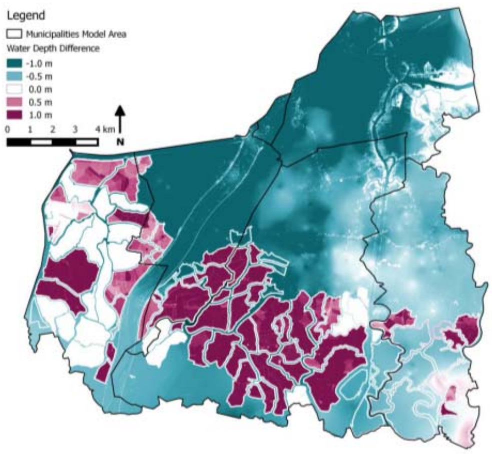


Figure 4.9: water depth difference with dike regulations (20 years)

4.1.2 Extreme conditions

Strong winds, caused by typhoons, cause high distributed loads on the building, which causes relatively high horizontal forces and bending moments on the foundation. In addition strong winds in combination with a certain fetch and water depth causes high wind waves, which cause large horizontal forces, vertical forces, bending moments and hogging and sagging moments. In this paragraph these loads are described in order to apply these loads on the design amphibious structure in following chapters.

4.1.2.1 Wind

Extreme typhoon winds play an important role in the horizontal and rotational stability of the amphibious structure. Since the Philippines is located in the ring of fire, yearly eight to nine typhoons rage across the area. (JTWC, 2015) Winds with a relative high velocity creates relatively high wind pressures.

Peak velocity

In the Western Pacific, cyclonic winds with wind speeds of 121 km/h are classified as typhoons with stage 3 according to (PAGASA, 2015). The next typhoon stage is a typhoon with wind speeds of 171 km/h. Stage 5 are violent typhoons with 220 km/h wind speeds and more. Sustained wind speeds are defined as the 10-minute mean velocity at a height of 10 meter.

In Hagonoy (Bulacan) the 3-second gust factor is 200 km/h with a yearly recurrence interval of 0,02. According to EC1, the reference wind velocity is the mean velocity of the wind averaged over a period of 10 min, determined in open terrain exposure at an elevation of 10 m and having 0.02 annual probability to be exceeded (50 year mean recurrence interval). In order to compare this wind speed to the 10-minute mean velocity, the wind speed needs to be converted. According to ASCE7-95 code the averaging time interval of the wind velocity is a 3 second gust interval. A conversion of the wind velocity is possible using the relation (in open terrain) (Lungu, Gelder, & Trandafir, 2013)

$$1.05\ V_{ref}\ (1\ \text{hour}) = V_{ref}(10\ \text{min}) = 0{,}84 * V_{ref}(1\text{min}) = 0{,}67\ V_{ref}.$$

A 200 km/h 3-second gust factor corresponds with a 10-minute mean velocity of 134 km/h. This wind speed is internationally classified as a typhoon and meets the regulation of the Philippine building code; therefore this is the velocity that the building has to withstand. The 10-minute mean velocity of 134 km/h is used in order to schematise wind generated waves, and to calculate the heeling moment acting on the building. As well, the maximum 3-second wind gust of 200km/h is applied on the floating structure in order to calculate the largest heeling moments acting on the building.

Peak velocity pressure

The peak velocity pressure at height z, includes mean and short-term velocity fluctuations, and is determined by the air density, the mean wind velocity and the turbulence intensity, and is 1,91 kN/m^2. (appendix 7) A wind gust of 200km/h leads into a wind pressure of 2,6 kN/m^2.

4.1.2.2 Waves

In addition, the floating foundation will be loaded by waves. The main cause of waves in this area is wind. These wind waves will result in forces in both horizontal and vertical direction. In this paragraph the wave characteristics and wave load for waves in San Roque are determined. Since strong typhoon winds rage over Hagonoy, relatively high wind generated waves are expected. An approximation of waves is given, since it is not clear how a wave during a typhoon will behave. Literature describes both an increase as a decrease of waves by obstacles.

Decrease

Some factors can decrease wave heights and wavelengths. Dikes, which enclose fishponds, create a decrease in water depth. Waves will theoretically break if they become too steep, or if the water depth becomes too little with respect to the wave height. (Baars, et al, 2009)

If water waves run into an obstacle, they will break or reflect. Partial reflection or complete reflection might occur. At partial reflection waves lose energy. Standing waves can occur when a wave acts orthogonally on a structure and reflects completely. In this case the wave height can reach up to twice the normal. With reflection under a certain angle the following situation occurs. (figure 4.10)

This behaviour results in a less regular wave field, and waves become less long crested after reflection. (Baars, et al, 2009)

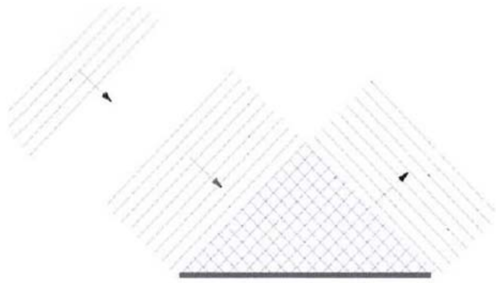


Figure 4.10: reflection

Diffraction
Obstacles placed in water can create decrease the wave height significantly. However wave motions still occur in the shadow zone behind the obstacle. Waves bend around the obstacle, and form a circular shaped arches. This so-called diffraction is depicted in figure 4.11. In this situation the wave height will decrease with by a certain diffraction coefficient.

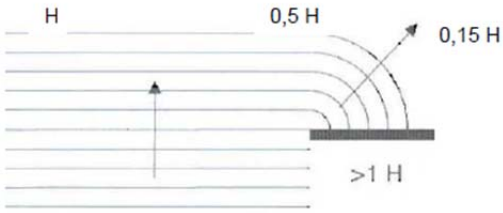


Figure 4.11: diffraction

Increase
The breaking of waves can create an increase in wave height as well. In typhoon areas, destructive tsunami-like waves can be generated. Storm surges due to typhoons can cause coastal flooding due to setup of the water surface resulting from atmospheric pressure, surface winds and breaking waves. The setup generated by breaking waves can oscillate with the incidence of large and small wave groups. This causes a steeper, tsunami-like wave. This oscillating behaviour of breaking waves, might occur in this area, since during floods, fishpond dikes can break waves, which can cause an oscillating effect. (Roeber & Bricker, 2015)

Calculation method
More investigation is needed in order to create a precise overview in how waves under typhoon winds precisely behave in this area. In this thesis an approximation is made, where the structural design is based on. In this thesis Bretschneiders method is used.

Characteristic wave properties
Characteristic wave properties (figure 4.12) must be determined in order to calculate corresponding loads due wind waves.

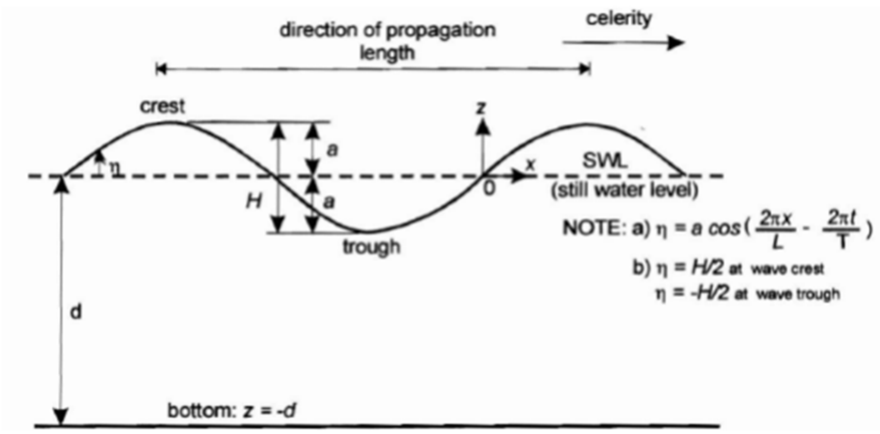


Figure 4.12: wave characteristics (Baars, et al, 2009)

L	Wave length; the horizontal distance between two successive wave crests (or troughs)
H	Wave height; the difference between the highest and lowest point
a	Wave amplitude, H =2a
T	Wave period; the time which passes between two consecutive wave crests
f	Wave frequency; f =1/ T

The following input determines the characteristic wave properties.

Wind Velocity

The wind velocity is relatively large since typhoon winds are considered. The 10-minute mean velocity of 38 m/s is used in this thesis. This value is used as input for the calculation of the height and period of wind waves.

Water depth

The water depth is determined earlier in this section. It is stated that the water level on fishponds in San Roque can vary from 0m to 2.5 m. As input for calculation of wave properties a depth of 0 m to 2,5 m with steps of 0,5 m will be used.

Strike Length (Fetch)

Figure 4.13 and 4.14 show the depicted location of the construction site in San Roque.

Figure 4.13: fishpond san roque

Figure 4.14: schematic section, san roque

On these fishponds, dikes ensure the first protection against floods. At a certain level, for especially at springtides, in combination with storm surges, fishponds will overflow, which increases the fetch enormously.

Research of (Van 't Veldt, 2015) shows a certain difference in water level between the northern area of the in figure 4.13 depicted red line and the southern area. It can be concluded that dikes of this river gives a certain protection. For this reason a maximum fetch is approximated at a length of 500m.

Several small dikes of about 1 m are located in this fishpond. These dikes will overflow during the expected floods of 2.5 m.

Output
With the Bretschneider method, as elaborated in appendix 8 the wave heights and wave period can be calculated. (Bretschneider, 1964)

$$\overline{H} = 0,283 \tanh(0,53\overline{d}^{0.75}) \tanh\left(\frac{0,0125\overline{F}^{0.42}}{\tanh(0,53\overline{d}^{0.75})}\right)$$

$$\overline{T} = 7,54 \tanh(0,833\overline{d}^{0.375}) \tanh\left(\frac{0,077\overline{F}^{0.25}}{\tanh(0,833\overline{d}^{0.375})}\right)$$

With:
F = maximum strike length (fetch): 500 m
U = wind velocity: 38 m/s
d = water depth: 0 to 2.5 meters.

With Bretschneider the undisturbed significant wave height is determined. Table 4.1 shows the output of this calculation.

d (m)	U (m/s)	F (m)	d' (m)	F' (m)	H' (m)	H (m)	T' (s)	T (s)	L (m)	design H
0,5	38	500	0,003	3,397	0,002	0,308	0,584	2,262	4,679	0,693803
1,0	38	500	0,007	3,397	0,003	0,486	0,649	2,513	7,035	1,094323
1,5	38	500	0,010	3,397	0,004	0,596	0,679	2,630	8,622	1,341898
2,0	38	500	0,014	3,397	0,005	0,666	0,697	2,700	9,757	1,497541
2,5	38	500	0,017	3,397	0,005	0,711	0,709	2,747	10,621	1,59998

Table 4.1: wave characteristics

Design wave height

The wave height H_s is the average of the highest 1/3 of the waves. It is assumed that wave heights are distributed according a Raleigh distribution. (Prevosto, et al, 2000) Following this assumption the maximum wave dosing height H_d is calculated by a exceedance probability. With an exceedance probability of $P(H>H_d) = 0,10$ the H_d has a value of $2,2 \cdot H_s$. The maximum design height of a wave is $H_d = 2,2 \cdot 0,71 = 1,60$ m.

Length
The length and period will be taken as calculated with Bretschneider.

Breaking behaviour
In order to calculate the breaking behaviour the ratio between the wave height and the wave length and the ratio between the wave height and the water depth are calculated. (Baars, et al, 2009)
Waves break at a steepness of $H_{wave} / L_{wave} = 1/7$.

For a wave at a depth of 2.5 m wave the ratio equals the H_{wave}/L_{wave} ratio. A proper prediction of the breaking behaviour cannot be made. A wave loses energy after it breaks. The most unfavourable situation, a non-broken wave, is considered.

$$H_{wave} / L_{wave} = 0.14$$

A wave breaks when the H_{wave} / d_{water} ratio exceeds 0,78. At a depth of 2,5m the ratio will not exceed this value.

$$H_{wave} / d_{water} = 0.67$$

At the lower dikes (1m) the remaining water depth is 2,5m. In this location the wave will break since the H_{wave} / d_{water} ratio is higher than 0.78.

$$H_{wave} / d_{waer} = 1.06$$

However, as stated previously, due to oscillating behaviour of broken waves, with the incidence of large and small wave groups, waves can generate energy instead of losing energy. A further research is needed in order to determine wave characteristic in a more precise way. For this reason, breaking of waves is not taken into account in this thesis.

4.1.3 Soil properties

In December 2013 several soil tests have been made. These tests have been executed on a distance of about 1 km from the San Roque, and they give the best possible indication of the soil in San Roque.

A standard penetration test has been executed. It is performed every 1.0 meter of depth measured from the ground surface. Initially the NW-casing was driven into the ground using a driver hammer weighing 63,5 kg. The standard penetration test was used to extract relatively distributed samples from the borehole at intervals not exceeding 1.50 meters. Tests has been made in three location, with a depth of 20, 24, and 30 m.

The layers of the soil at certain depths are given in the following figure:

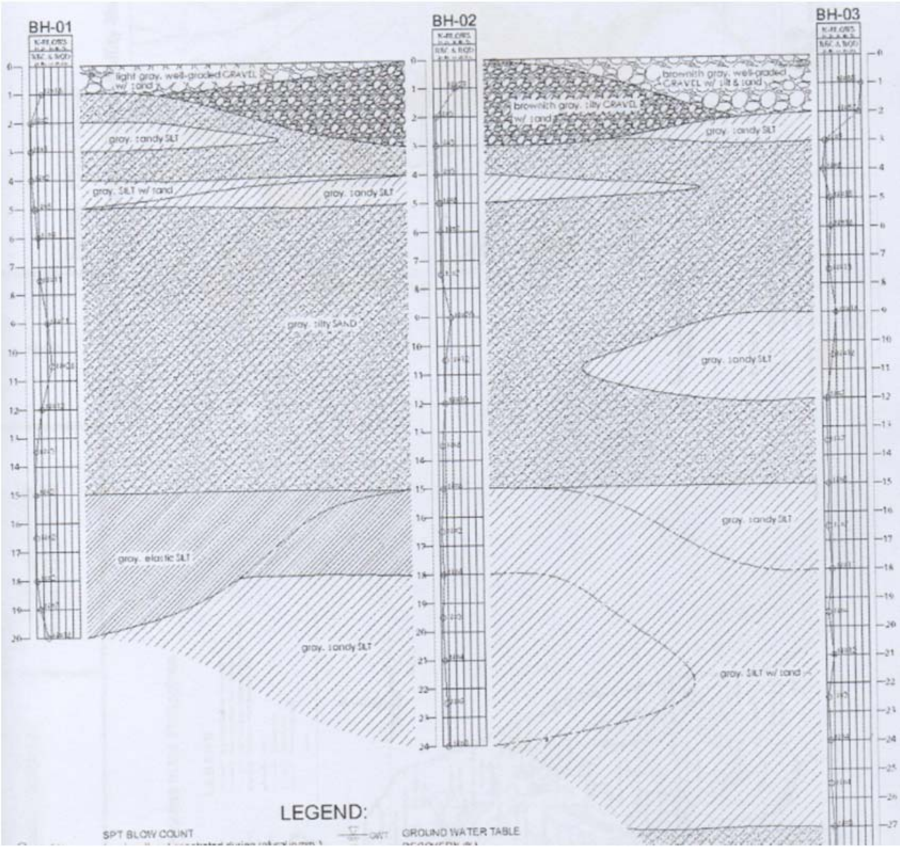


Figure 4.15: soil test, Hagonoy

The corresponding n-blows give an indication of the loadbearing capacity of the ground. Load bearing capacity in vertical and horizontal direction can be calculated. This will be used as an input in the calculation models used in this thesis.

The upper layer at the locations of the soil tests, is an added layer to increase the loadbearing capacity. The loadbearing layer in San Roque is considered to be equal to the second layer; a sandy silt or silty sand layer. The K-value of this layer is the same as the k_0 of a sand/clay mixture and is 30.000kN/m^3. (Leijendeckers, et al, 2006)

Since mooring piles need to take horizontal external forces, the horizontal loadbearing capacity is calculated. (descripted in appendix 6) In chapter 13 dimensions, materials and depth of mooring piles are explained and calculated.

4.1.4 Conclusions environment

Water depth

The main cause of an increase in water depth during floods is ground subsidence due to excessive groundwater use. Several future scenarios with and without interventions have been elaborated. Since this research is recently discussed by governmental institutions in the Pampanga Delta, future plans are not yet created. For this reason the recommended scenario is used, in this thesis. This situation predicts a water level difference of 1,0 m for San Roque. Since during the storm in Pedring a water level of 1,5 m was detected at the building location, a maximum water level of 2,5 m is taken into account in this thesis. Besides an increase over years, water level changes daily by tidal and fluvial floods.

The current can be neglected, since a very low flow velocity is expected for all modelled scenarios. (Van 't Veldt, 2015)

Wind

Typhoon winds cause wind with relatively high velocity. This causes relatively high distributed forces of 1,9 kN/m^2.

This distributed force causes heeling moments and a resulting horizontal force. These load cases are applied on the structure in chapter

Wind waves

A schematized wave, creates vertical and horizontal loads, which influences the stability of the structure. These load cases are depended on the $L_{foundation}/L_{wave}$ ratio. These load cases are applied on the designed structure in chapter 11.

Criteria

As descripted, typhoon winds, cause large horizontal forces. This forces cause bending moments and heeling moments on the floating structure. Additionally, relatively high wind generated waves, lead to large horizontal and vertical forces and large bending and heeling moments. To provide a sound and robust design, the modular foundation and the connections must be able to cope with these extreme circumstances during its lifetime as during execution. A **robust or disaster resilient design** is required.

4.2 Durability

In this section, factors which influences the durability are elaborated.

4.2.1 Shipworm

Because of the descripted ground subsidence, the incoming seawater at high tide has shifted further inland. This shift has ensured that inflowing water in the Hagonoy area has become brackish. Due to brackish water, rice fields have been transformed into fishponds.

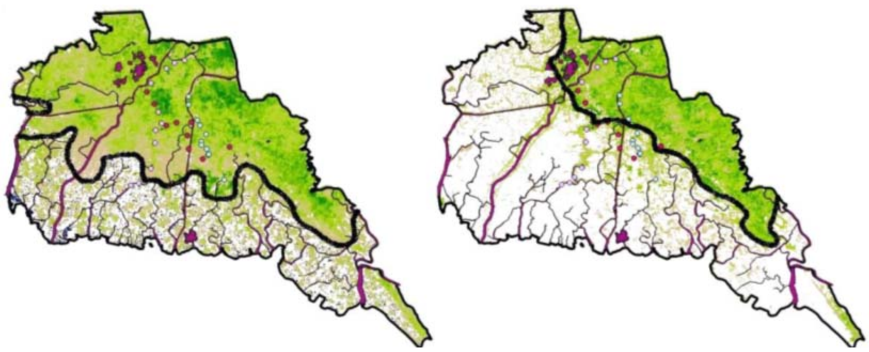


Figure 4.16: shifted boarder rice fields – fishponds

Besides a shift in the boarder rice fields–fishponds, the incoming brackish water entailed the presence of shipworm. Shipworm (Teredo navalis) is one of the most devastating wood-boring organisms. Shipworms live in both hardwood and softwood the wood which is immersed in salt or brackish water. (CentrumHout, 2013)

Shipworm attack will only occur when larvae are present in water. After a short period of swimming in the salt or brackish water, larvae will settle on the surface of the timber structure. Thereafter the larvae will bore in the timber elements. Shipworms are molluscs with a wormy body. They drill passages by means of a pair of very small shells, with which they rasp their way through. Shipworms can grow to a length of 40 to 120 cm .The presence of the shipworm in Hagonoy is mainly visible through infested wooden boats. (CentrumHout, 2013)

Figure 4.17: shipworm attack

Several measurements can be taken against shipworms. These measurements are elaborated in chapter 10.

4.2.2 Climate

Under influences of extreme climate conditions, specific structural material can decay. In this decay, salt water can function as a catalyst. For example carbonation in reinforced concrete, or in steel structural parts can decrease the structural performance. At high temperature several materials (plastic) might lose strength or might soften. (Lampman, 2003)

Conclusion durability

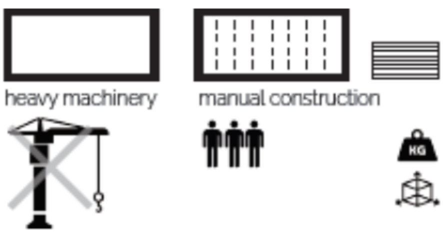
Besides extreme climate conditions, the structure must be able to withstand hazards by insects and other micro-organisms like shipworms. There are multiple ways of how a structure can deal with those hazards. Designing an extremely robust structure can be a good option. On the other hand a structure which can be affected quite easily, but which can be replaced in an easy and cheap way, can provide a good solution as well. A certain level of **durability** must be gained for both the foundation module as the connection.

4.3 Transportation

As stated in conclusions from the field research, a design for a prefabricated structure, can be a solution for low quality of the current structures, due to its relatively fast construction time, quality, sustainability, adaptability and affordability. (MBI, 2015)

Due to the relative underdeveloped transportation system, the transport duration and cost are relatively high. This is partly due to the country's mountainous areas and scattered islands, and partly as a result of the government's persistent underinvestment in the nation's infrastructure. The lack of proper infrastructure makes it hard to bring heavy machinery to the construction site. In contradiction with the Netherlands, where one entire Finch module of around 25m^2 can be transported from one place to another, in the Philippines only smaller vehicles can be used for transportation of structural elements. This leads to restrictions in dimensions and weight of the prefabricated floating structure.

4.4 Manufacturing and production



Due the lack of proper infrastructure, heavy machinery cannot reach the construction site. Consequently, the foundation needs to be manufactured by hand and by small machinery. This leads again to restrictions in dimensions and weight of the prefabricated amphibious structure.

In addition it is, important is that the modular system can be connected in an easy but proper way. If the design does not allow any but one way to connect structural elements, it is expected that the structure will be constructed quickly and with the highest (controlled) quality. By decreasing the amount of operations, execution can go faster, which reduces the costs. In addition the chance of mistakes during execution reduces. By self-alignment of modular building elements, placement of modules in the right position can be done easier and more precisely, which improves the structural behaviour.

Local production

A construction project can benefit the local community as long as most of the work is done locally. A locally built project can give a financial boost to the community, therefore one of the goals is to manufacture the building locally and preferably use local materials. Furthermore, involving the community in building the structure enhances the acceptance of the building. It could be possible that using local timber species and manufacturing locally is currently not possible, because of unsustainable forest management or the lack of labour force. However, there should be aimed for making this possible in the near future. When material is concerned the aim should always be to use material that is fabricated or has grown in the Philippines.

4.5 Affordability

An important parameter of the feasibility of a building project are implementation and affordability of the building. The affordability determines if the building can be built on large scale. Since the target group is the lower part of the middle income class the building needs to be relatively cheap. Local parameters which influences the maximum price, are discussed during the field research in a meeting with the mayor of Malolos, Christian D. Natividad, the former Mayor of Hagonoy, Angel L. Cruz, Jr., a manager of the DBP, Maria Dolores C. Guevarra, and a board member of the First Congressional District, Michael C. Fermin. Generally, the houses that are provided by social housing have a size of 25 to 30 m2. A house may cost 10.000 pesos/m² (210 $/m²). So a house of 25m² may cost 250.000 pesos ($5300). When public services are also taken into account an average of 300.000 pesos (€6000 or $6700) is taken. Public services are facilities like a bakery, sports, etc. Adding these things to a social housing project creates a better livelihood.

4.6 Conclusion – Location based criteria

Water depth, extreme situations, and building requirements which are depended on its location are elaborated. It can be stated that at a typhoon wind, the structure experiences the worst situation. In that situation the water depth is at its highest point, and the largest wind loads acts on the building. Additionally, by overflowing dikes, the fetch is at its largest. Due to a long fetch, strong wind, and deep water, the largest wind waves arise, which causes extreme situations.

Besides depicting extreme situations, several location based criteria can be concluded from previous paragraphs. Both the structure of the foundation modules and connections between modules must meet those criteria in the best way. In combination with previous listed building-concept-criteria and floating-behaviour-criteria, the location-based criteria form the entire design criteria. An overview of the collected design criteria is depicted in table 4.2.

Building concept criteria
Innovative
Flexible
Circular
Healthy

	Affordable
Floating behaviour criteria	
	Light structure is prefered
	Wide and long structure (or able to be extended)
	Additional ballast
Rigid body	
	Location-based criteria
	Robust during execution and during its service time
	Durable and/or replaceable
	Manufacturable
	Transportable
	Affordable
	Local production

Table 4.2: design criteria


KURT

Chapter 5 State of the art

In this chapter, the state of the art of both floating foundation modules and connections are described. In the first section, modules categorized in several types are briefly elaborated. An addition is made to the work of (Koekoek, 2010). In the second section, the similar is done for connection between foundation modules. In chapter 7 all types are rated by means of a multiple criteria analyses. The criteria used for this analysis are listed in chapter 4.

5.1 State of the art - Foundation modules

Last decades, experience has been gained with multiple options for floating structures. In this paragraph an overview of these options are described. The options for floating bodies are divided over multiple types.

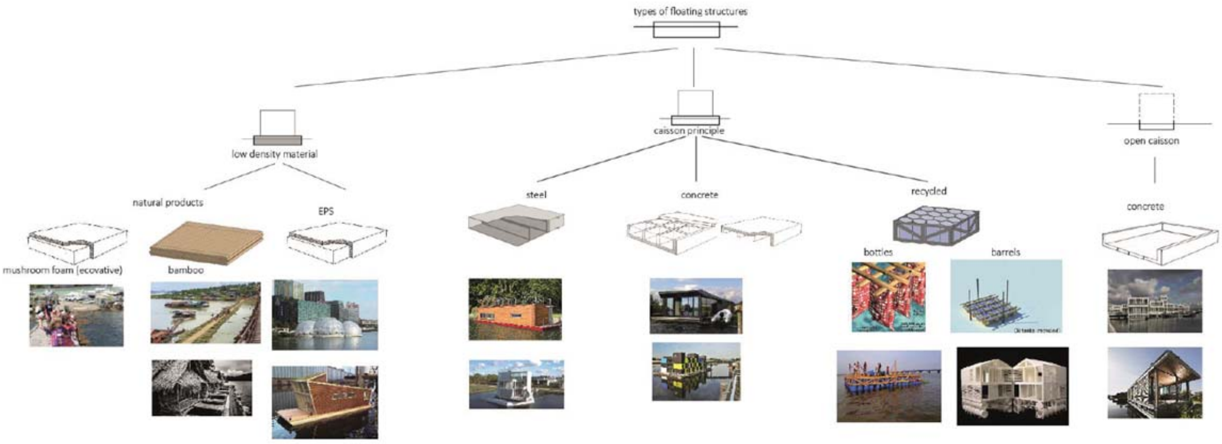


Figure 5.1: state of the art

5.1.1 Low density

The first type contains objects that float by the principle of a lower density than water. Because of a certain porosity of a material, an object gets a lower density then water, and creates floating capacity. This type is subdivided into three objects.

Foam made out of natural products, (ecovative)

Figure 5.2: ecovative foam

By growing environmentally-friendly materials as fungi, foam-like material can be produced. Companies as Ecovative produce this foam material, and sell it as packaging material, insulation materials. In addition, investigations are being made in order to use the material as buoys or other marine applications. The so-called Myco Foam is naturally buoyant and can withstand water for 2-3 moths. In an on-going research, solutions in the field of coating techniques are sought, in order to give the material a longer service life. (ED, 2015)

Bamboo

Figure 5.3: floating bamboo structures

Several floating structures have been built by using bamboo as floating material. In many countries in South East Asia, fisherman's houses are built on bamboo floating objects. Bamboo consists of nodal zones and internodal zones. Thanks to these internodes, bamboo consists of watertight modules, which give the bamboo its floating capacity.

EPS-concrete

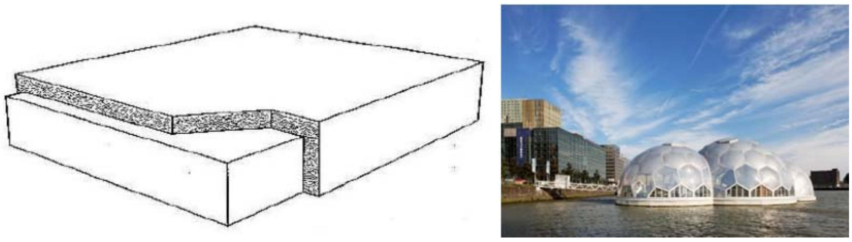


Figure 5.4: EPS- concrete foundation

International Marine Floatation Systems (IMF) introduced the technology of constructing buildings on water by making use of the very light polystyrene foam. This system is based on a core of EPS and a concrete shell. The system thanks its buoyancy to the EPS, with a density of 20kg/m3, which is 50 timer lighter than water. The purpose of the concrete are, stiffness and protection of the EPS. The structure is ought to be unsinkable, because by the presence of EPS, water cannot enter the foundation. The EPS-concrete system can be executed lighter than the current caisson systems, due to a reduction of concrete. For the floating pavilion in Rotterdam, Flexbase used this type as floating structure. (Koekoek, 2010)

EPS - steel

Besides an EPS–concrete floating object, a combination of EPS and steel can be built. This principal works the same as the EPS-concrete system, but concrete is replaced by steel. Aluminium can also be used in combination with EPS. Aluminium is less susceptible for corrosion and it is lighter, but it is more expensive.

5.1.2 Watertight structures

Secondly, an object can float by creating a watertight, air-filled structure. Three options are descripted.

Steel watertight caisson

Steel is a commonly used material in offshore industry and ships. Rectangular steel pontoons are mostly used for temporary structures at construction sites. Steel pontoons provide the ability to create foundations in multiple forms. In Figure 5.5 a floating house designed by Herzberger is depicted. For this floating structure six hexagon formed shapes, are welded together. Steel floating bodies can have small wall thicknesses, which results in a small self-weight, so a high level of buoyancy can be gained. This results in small weight stability. This can be counteracted by adding ballast weight. (Olthuis & Keining, 2019)

Figure 5.5: steel watertight caisson

Figure 5.5: Floating house by Herzberger

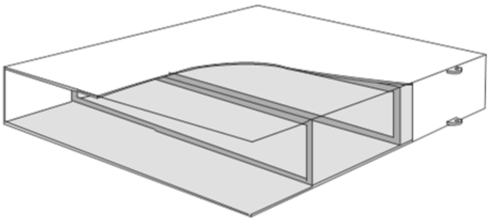


Figure 5.6: steel watertight caisson

Concrete watertight caisson

Floating concrete caissons are commonly used in civil engineering, for constructing bridges, piers, jetties and tunnels. Caissons can be transported while floating, and be immersed at the right location. (Voorendt, 2009)

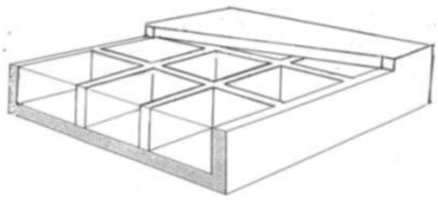


Figure 5.7 concrete caisson

A watertight pontoon by using recycled materials

PET bottles

For several building projects, PET bottles have been used. With a serious housing shortage, but no shortage of plastic bottles littering the streets, the Development Association for Renewable Energies (DARE) – an NGO based in Nigeria – decided to build a bungalow entirely out of plastic bottles. (Sinclair, 2012)

Figure 5.8: PET bottles as building material

Besides housing projects, floating structures have been constructed with PET bottles as floating material. One of the most innovative and famous projects is Spiral Island by the British artist Richard Sowa. For this artificial island Sowa filled nets with empty discarded plastic bottles to support a structure of plywood and bamboo.

Figure 5.9: PET bottles as floating material

Recycled barrels

In several projects all over the world, recycled barrels have been used as floating material. Water tight barrels, often executed with a supporting structure, form the foundation for a floating or amphibious building. For Mokoko, Nigeria, NLE architects designed a floating school following this principle. In this project a timber frame holds multiple 200L barrels together. On the timber frame a triangular shaped school building is constructed. (NLE, 2015)

H&P Architects designed amphibious bamboo houses. A bamboo framed structure is filled with recycled plastic barrels. Upon the bamboo foundation a bamboo building is built. (Zimmer, 2015)

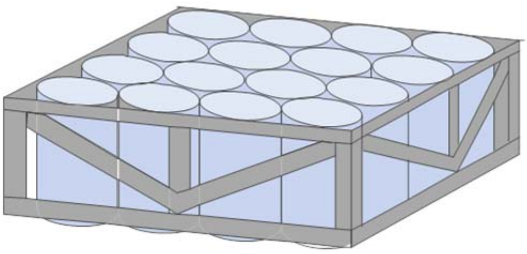


Figure 5.10: H&P architechts, bamboo floating building

Figure 5.11: NLE architects: floating school Makoko

The third category consists of an open caisson. This type is mainly executed in concrete.

5.1.3 - Concrete open caisson / concrete tray

A rectangular concrete tray works the same as the standard caisson, but with an open top. In case of large floating foundations, there can be built in the tray. Mostly a structure is built on top of the side walls. This is system is commonly used for houseboats in the Netherlands.

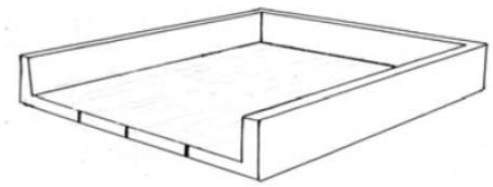


Figure5.12: open tray caisson

Figure5.13: open tray caissons

With this system amphibious buildings have been constructed in Maasbommel, the Netherlands. A concrete barge with a relatively light timber frame structure on top is built. This provides the structure a low centre of gravity, which gives the structure its demanded stability. Waterproof concrete barges make the building float when the water level rises. (Pötz & Bleuzé, 2009)

5.2 State of the art - Connections

In this section, multiple realized connection types are listed, and categorized. First a division is made into floating modules connected under a certain distance, and placed directly to each other. When two floating modules are placed with a certain spacing, the connections can be designed in a way that the structures are able to move independently in vertical direction. Then the connection does not have to transfer any vertical forces. So, the connection and beams of the floating module can be dimensioned lighter. Since a rigid connection is desired, this connection type will be ignored.

A connection that influence each other's movement in vertical direction gives more stability for the floating structures and leads to less movement of the structures. In both ways a rigid connection is possible, but by placing modules directly to each other, a rigid connection can be reached most easily.

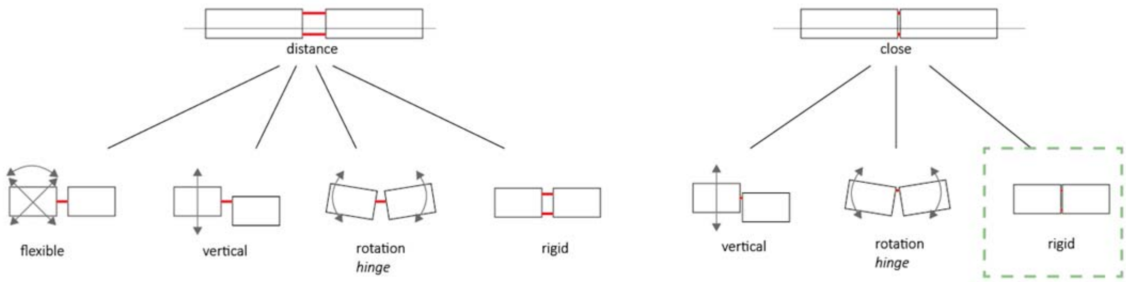


Figure 5.14: connection types

Several types are analysed. Types which can be placed directly to each other and which can be connected rigidly are reviewed. All types are rated with a multiple-criteria-analysis in chapter 7.

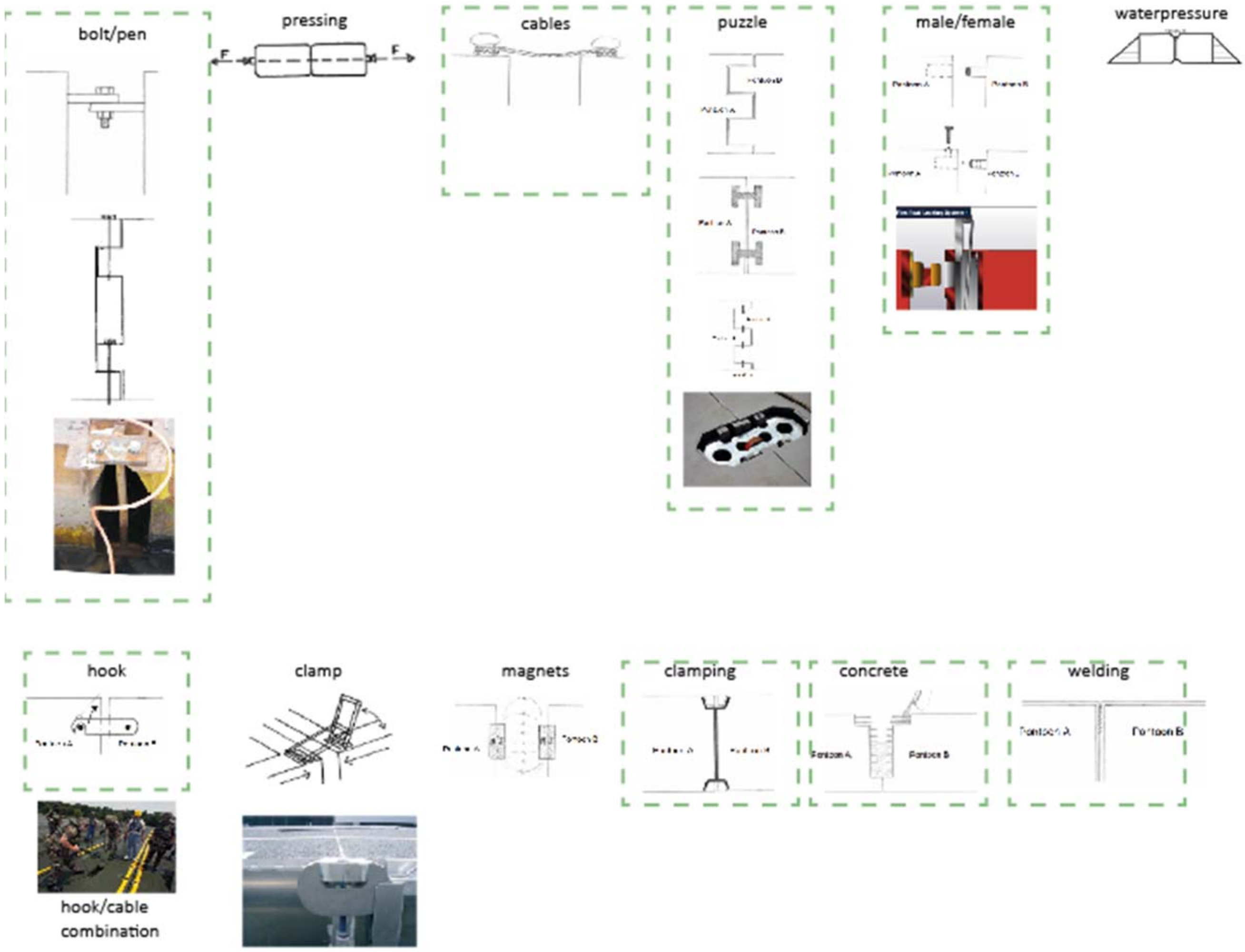
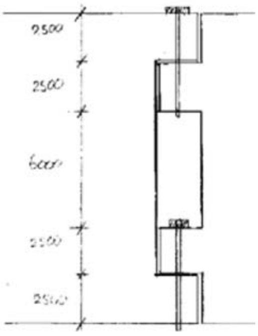


Figure 5.15: connection types

5.2.1 Bolt/pen

A bolt/pen connection can be used in different directions. A variation in orientation results in different degrees of freedom and different accessibility. In figure 5.16 connection with vertical pens is depicted. This option was designed by de Rooy (2006) for a rigid connection of floating elements for a floating container terminal. Groenendijk stated that pens in this design will deform too much, resulting in a connection which cannot be disconnected properly. By increase the amount of locking plates a deformation can be reduced. (Groenendijk, 2007) Vertical bolts or pens commonly used to couple (temporarily) pontoons shows a vertical bolt/pen connection of the pontoons of the Heijsehaven. (Koekoek, 2010) Designed a connection for the floating pavilion in Rotterdam (figure5.18). This connection consists of a long pen with a threaded end, in order to connect the upper and the lower part of the modules.



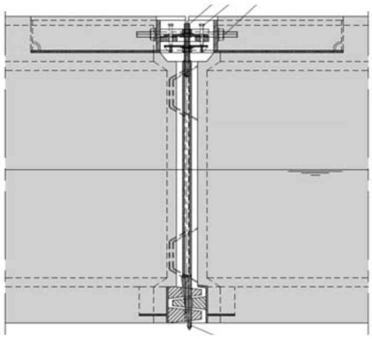


Figure 5.16 connection by de Rooy (2006) *Figure 5.14: connection Heijsehaven* *Figure 5.18: connection floating pavilion Rotterdam*

5.2.2 Cables

The connection with cables is mostly seen as less robust and permanent as some other alternatives. A combination of cables and hooks is used for the Improved Ribbon Bridge.

5.2.3 Puzzle

By creating puzzle shaped modules, modules will fit exactly into each other. Depending on the shape of the puzzle piece, forces in multiple directions can be taken. With puzzle-shaped floating bodies, the floating bodies can be shaped in a way they will fit exactly into each other. An example of a rigid puzzle connection is Willy's design. (figure 5.19) A puzzle shape in combination, with separate puzzle pieces in used at the pontoons of Hann-Ocean. (Hann-Ocean, 2015) In this design a puzzle connection in the top of the foundation and on the bottom of the foundation is implemented, in order to create a rigid floating object.

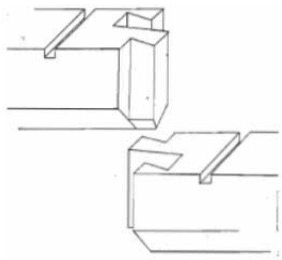


Figure 5.19: Willy's design *Figure 5.20: Hann-Ocean design*

5.2.4 Male/female

A male/female connection is a connection based on the shape. A shape connection can be beneficial for self-alignment. In Figure 5.21 the Flexifloat connection is depicted, an example of this principle. (Flexifloat, 2015)

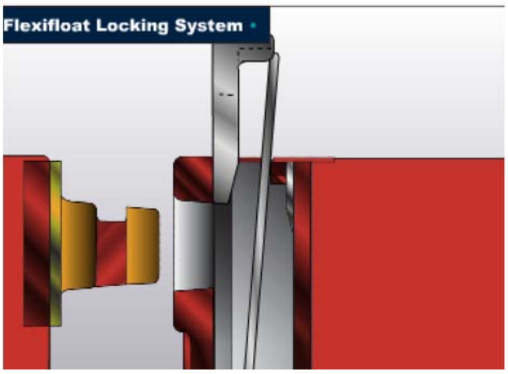
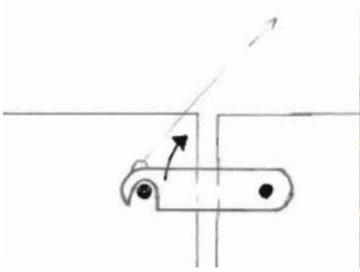


Figure 5.21: flexifloat connection

5.2.5 Hook

With a hook a quick and easy connection can be made. Single hooks, however might come loose with certain movements. This can be prevented, by creating a closable hook. With the Ribbon Bridge connection, a hook is attached to a steel cable. By connecting the hook, and coiling the cable, the (hinged)connection is made relatively fast. (GDELSG, 2015)



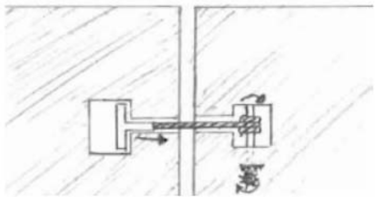


Figure 5.22: hooked connection *Figure 5.23: improved ribbon connection*

5.2.6 Clamping

At a clamping connection, a structural elements clamps around two foundation modules. A clamping connection can be made from centre in outwards direction or the other way around. The floating road in Hedel used a clamping connection from the centre in outwards direction.

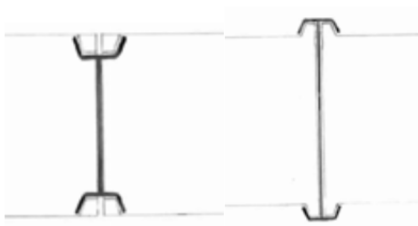


Figure 5.24: clamped connections

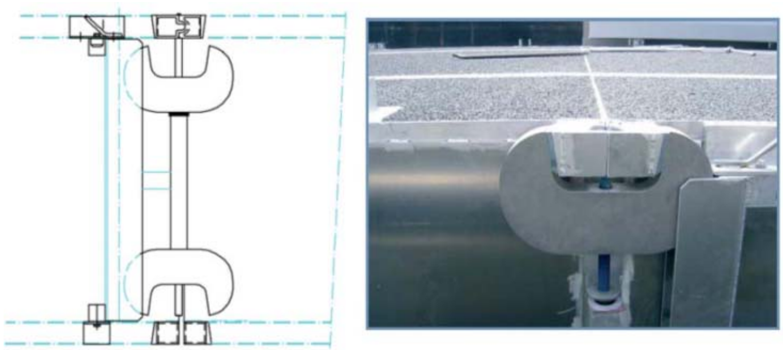


Figure 5.25: clamped connection Hedel

5.3 Conclusion

In order to create a brief overview of the state of the art of both amphibious/floating foundation modules and connection between foundation modules, multiple types are listed and several reference projects are given.

In previous chapters all criteria, which the foundation module and connections must meet are listed. By rating all types among listed criteria, an insight will be given of suitable types. This is done in chapter 7.

Chapter 6: Design Approach

Chapter 7: MCA

Chapter 8: Scenario Analysis

Chapter 9: Parametric Models

Chapter 10: Final Design

Chapter 11: Design - Analyses

Chapter 12: Design - Integration

Part II Structural design

In this Part II, the final (structural) design for the amphibious structure is elaborated. Input for this design are the criteria stated in previous chapters. Criteria are divided over three categories: building concept-criteria, floating performance-criteria and location-based-criteria. When the design of the amphibious structure fulfils all criteria in the best possible way, a proper and appropriate design is delivered.

In chapter 6, the first chapter of this part, the methodology is described in the form of a description of the design approach. In chapter 7 a multiple criteria analysis is done, in order to know which foundation- and connection types, meet listed criteria. In chapter 8 a scenario analysis is described. The ninth chapter describes a parametric visualization and calculation model, in order to create a design concept. Hereafter, in chapter 10, the final design of both the foundation module, and connections are described. In chapter 11, the design is analysed with Matrix Frame and SCIA Engineer in order to check its structural behaviour. As well an estimation of costs is made. Chapter 12 describes multiple ways of integrating these foundation modules with its environment.


BULLS

Chapter 6 Design Approach

In this chapter the design approach is briefly elaborated.

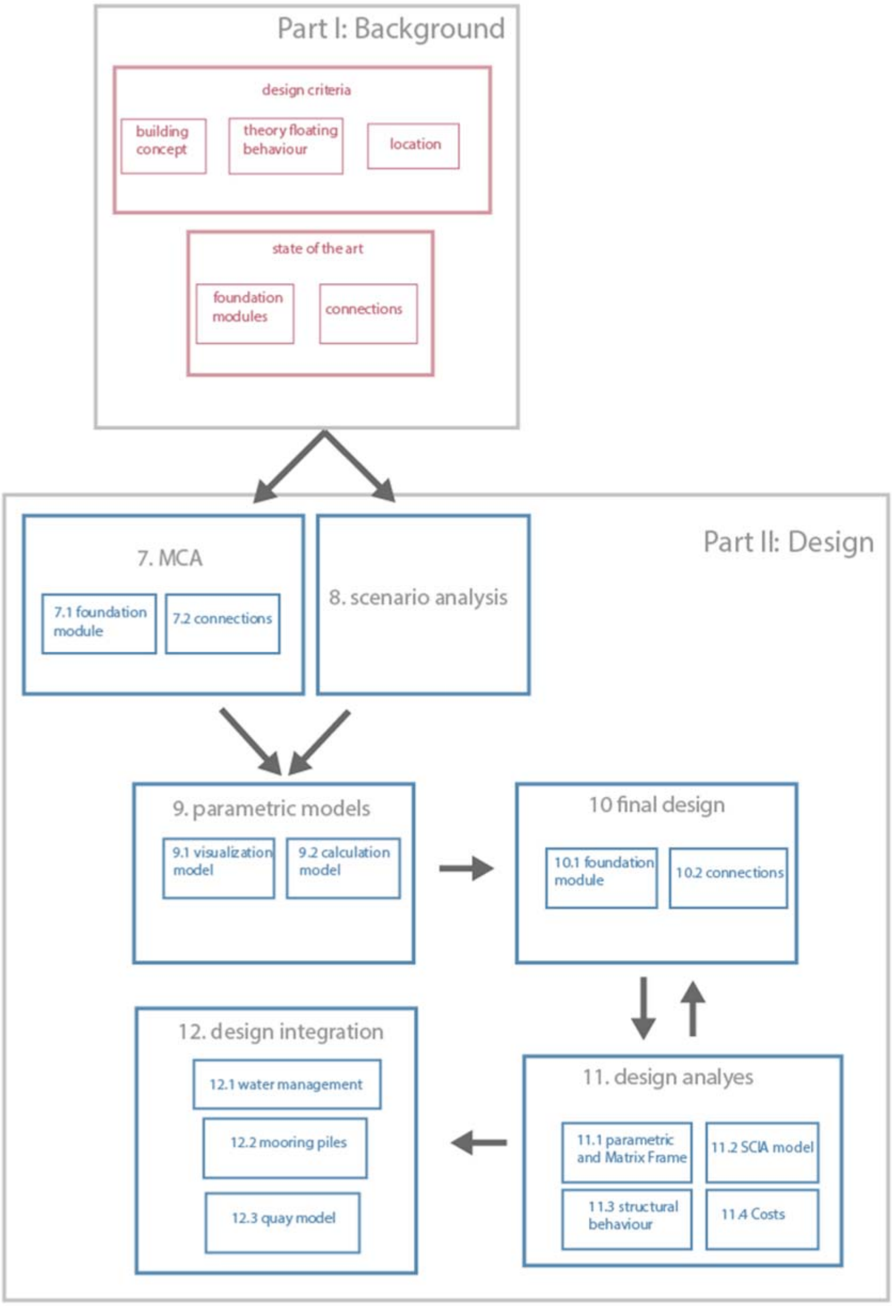


Figure 6.1: design approach

Firstly, a background study is made, as input for a multiple criteria analysis (MCA). In this background all criteria are discovered, and types of foundation modules and connections between modules, which must be analysed are elaborated. So the background is in input in for the MCA. By means of the MCA, the best fitted foundation module type and connection type are determined.

Parallel to the MCA, a scenario analysis is sketched, in order to create an overview of all scenarios that can occur. By that all possible load cases are gained. This is done in chapter 8.

Knowing the best fitted types and scenario's parametric models are made. These models give a first insight in the structural behaviour of the amphibious foundation, for a varying configuration of buildings. (chapter 9)

Following on these first estimations, a design is made for both foundation modules and connections between modules, taking all criteria from the background into account. (Chapter 10)

After the design is made, an analyses in the field of structural behaviour and costs is made. Based on this analysis the design can be optimized. However, not all iterations are described in this thesis. (Chapter 11)

The last step is to implement and integrate the foundation modules in its surrounding, with again taking all criteria into account. Again, an optimization is made. (Chapter 12)

Chapter 7 Multiple Criteria Analysis

In this chapter, described foundation types and connection types are analysed by means of listed criteria to discover which types fits well according the building-concept, floating behaviour, and location-based criteria. In section 7.1 the foundation module is analysed. In section 7.2 a similar analysis is made for connections between modules.

7.1 MCA – Foundation module

In this analysis grades between 0 and 5 are given to all described types. Since some criteria are more important than others, criteria are weighted with factors.

7.1.1 Scores

		building - concept criteria				floating behaviour criteria				Location-based criteria							score
		flexibility	circularity	healthy	innovative	rigid body	wide pontoon possible	additional ballast	light weighted	manufacturable	transportable	affordable	durable/sustain local hazards	locally produced	integrated design	sustainable	
low density material	EPS	5	2	1	3	5	5	1	5	2	5	4	5	2	3		77,5
	natural product bamboo	5	5	5	4	1	4	1	5	5	5	5	3	5	2		83,5
	natural product foam	5	5	5	5	5	5	1	5	2	5	4	0	5	1		77,5
caisson	Steel pontoon	5	1	2	1	5	5	3	3	4	3	2	2	5	5		75,5
	Concrete pontoon	5	1	1	1	5	5	3	2	4	3	3	2	5	5		75
recycled	recycled barrels	**5**	**4**	**3**	**4**	**4**	**5**	**5**	**4**	**5**	**4**	**4**	**4**	**3**	**5**		**88,5**
	recycled bottles	5	4	4	4	4	5	1	5	5	5	5	2	5	1		83
open caisson	Concrete	5	1	1	1	5	5	5	2	4	3	3	2	5	5		74,5
	factor	1	1	1	0,5	2	1,5	1	1,5	2	2	2	2	2	2		

Table 7.1 MCA, floating structure

7.1.2 Outcome MCA

A timber frame with recycled barrels scores best. The motivation for scores for this option is described in this paragraph.

Building concept - criteria

Flexibility

Recycled barrels in a timber frame can be transported easily. A modular structure can be made by building timber cages, which can be connected on the construction site. By making a modular structure, it gains it demanded flexibility. *Five points are given.*

Circularity

Timber can be a circular material: it can regrow after cutting. When the timber structural elements can have a service life which configures the time the wood needs to grow back, timber can be called circular. Disregarded plastic barrels can be recycled, so it scores high for circularity. *That is why four points are given.*

Healthy

Most timber species are healthier products than concrete and steel. Concrete contains radon gas, which contains of harmful radiation. (Culot, et al, 1976) However, some timber species in timber can consist of glue, which can be harmful.

Although, barrels made out of plastic, where several resources in have been transported, can be less healthy. *That is why three points are given.*

Innovative

This product is quiet innovative. Even though some projects have been executed in this way, it is not very common for larger scale building projects. *Four points are given*

Floating performance - criteria

Rigid body

It is ought to be possible to build a rigid body with a timber frame. However, steel and concrete pontoons are ought to be stiffer. *Four points are given.*

Wide pontoon
By rigidly connecting multiple modules, it is possible to build a wide pontoon. *Five points are given.*

Additional ballast
A certain amount of empty 200-litre barrels can be used, to add extra ballast by filling them with water. *Five points are given.*

Light weighted
Since timber and HDPE both have a relatively low density (in comparison with steel and concrete) a light-weighted structure is possible to make, using a timber frame filled with plastic barrels. Although other types, EPS, bamboo and Foam are ought to be even lighter. *Four points are given.*

Location – based criteria

Manufacturable
This system provides the ability to construct a light-weighted structure, so it is relatively easy to manufacture this option. Furthermore, this system can be prefabricated, which makes it more manufacturable. *Five points are given.*

Transportable
Since this type can be executed light-weighted, it improves the ability for transportation. Modules can be executed in a relatively small module size, which improves this ability. Although, barrels are not foldable which exclude the ability to transport it in a flat pack. Yet, barrels have standardised dimensions, and can be stacked easily. *Four points are given.*

Affordable
Recycled disregarded barrels are relatively cheap, since there is a current surplus of 200L barrels. Several parties offer huge quantities of used 200L drums, for relative inexpensive prices. *Five points are given.*

Durability
The structure must gain a certain level of durability to sustain hazards that may occur. In chapter 4 several hazards have been listed.

The structure must sustain typhoons. A solid and proper timber frame, must be able to deal with strong forces due to typhoons. The submerged frame must sustain attacks which go along brackish water. A disadvantage of timber species is that it is prone for the present shipworm. This influences the score for durability negatively. However, there are ways to preserve the timber from shipworm. An advantage of a timber structure in contrast to steel and reinforced concrete, is that it is not prone to corrosion. Additionally, the quality of reinforced concrete in the area of Hagonoy is not sufficient. Cracks may occur, and carbonation will be a result of it. This influences the score for durability positively.

Plastic barrels are made of high density poly ethylene. By long exposure to sunlight HDPE may soften. (Gabriel & L. Moran, 1998) In combination with salt in the brackish water, it might get affected and loose strength. (Meyer, 1996) Although it is a negative effect on the durability, there are some good ways to deal with it. A thinkable solution is to cover the barrels from direct sunlight. Besides that, the foundation modules can be designed in a way, barrels are relatively easy to replace. *Four points are given.*

Locally produced
By building with timber and HDPE barrels, the aim of building with locally produced materials can be partially reached. Multiple plastic barrels are provided in Metro Manila. The use of local timber is nearly impossible, since a current ban on cutting. Firstly, timber out of neighbouring countries can be used, with an aim to once use local timber when the situation around structural timber is improved (chapter 11). *Three points are given.*

Sustainability

Wood works as a CO_2 buffer. In a cubic meter wood 250 kg CO_2 can be stored. In contradiction to for example steel and concrete, by production of this material there is no CO_2 emission. In addition, timber is a renewable material, so it does not contribute to exhaustion of natural resources. This makes this type of structure prestige better in the field of sustainability. Since the plastic drums are recycled, there is no need for producing new materials. The disadvantage in sustainability point of view of using plastic transport barrels is that they must be cleaned, at which harmful substances might be presence. *Four points are given.*

7.2 MCA - connection

On the basis of the same criteria, previously described connection types are analysed. Again weight factors are added in to create a fair outcome, since some criteria are more important than others.

7.2.1 Scores

A multiple criteria analysis is made to discover the best fitted connection type. All types are tested to previously stated connection criteria. Since some criteria are more important than others, criteria are weighted.

	building concept criteria	Floating performance - criteria				Location Based criteria						
	flexibility/demoutability	tension	compression	shear	restrict movements	amount of operations	self alignment	robustness in execution	durability/maintenance	sustainability	affordability	total
1 bolt/pen	**4**	**5**		**5**	**5**	**3**	**5**	**4**	**4**	**3**	**3**	**88,5**
2 cables	5	5		1	1	5	3	2	2	5	5	63,5
3 puzzle	5	5		2	3	5	5	4	4	3	3	77,5
4 male/female	**5**	**5**		**4**	**4**	**5**	**5**	**4**	**4**	**3**	**3**	**86,5**
5 hook	5	4		1	1	5	5	2	4	3	3	61,5
6 clamping	**5**	**5**		**4**	**4**	**5**	**5**	**4**	**4**	**3**	**3**	**86,5**
factor	2	3		3	3	1	1,5	2	2	1	2	

Table 7.2: MCA connection types

7.2.2 Outcome MCA

Concluded from the MCA, multiple types for a connection between foundation modules are suitable. By this, it can be stated that a bolt/pen connection, a male/female connection and a clamping connection can be a right solution. Besides these types, a combination of those types can form the right connection. A brief argumentation is elaborated:

Building concept - criteria

Flexibility

A flexible foundation can be created by demountable connections. Almost all connection types are considered to be demountable. However (Groenendijk, 2007) stated that by deformations, the demountability decreases. In addition in salt water, it expected that a steel bolt/pen connection can rust up. By using stainless steel, or use other materials which are not susceptible for rust, for example plastics, this problem can be solved. However, a bolt/pen connection scores lower than the others.

Floating performance - criteria

Rigid body

As concluded in the theory chapter the static and dynamic stability increases strongly by increasing the length and width of a structure. A large rigid floating body is less susceptible for movements by imposed loads.

Since all relative movements are undesirable, a rigid connection will be used. With rigid connections, not only the relative movements are prevented, but also overall motions are decreased, because a floating body which consists of rigidly joint elements can be approximated as a single rigid body. A rigid connection is possible as long as the internal forces stay within the limits of the strength of the floating structure.

A rigid connection can be created, when in the upper part and in the lower part of the structure tension and compression can be transferred. By placing those two transfer points at the outer edges of the structure, less forces are involved. Besides tension and compression, shear force must be able to take shear forces.

In order to create a proper rigid structure, connection may not allow many movements.

So, to rate connections on structural performance, the ability to take up forces by tension, compression, shear and restriction of movements need to be considered.

Since compression will be taken by modules itself, no scores are given for this criteria. Connections with hooks and cables are considered to not fulfil these criteria properly and scoreless compared with other types.

Location – based criteria

Manufacturable
As described a certain level of manufacturability is demanded. For this analysis several aspects of manufacturability are taken into account.

The connection between modules must be able to be executed relatively easily, in order to avoid mistakes in execution, which decreases the structural performance. As well a faster execution time reduces costs. So, the goal is to minimize the amount of operations. A higher score means a less amount of operations. It is expected that with cables and bolt/pen the largest amount of operations are needed.

By self-alignment, modules can be placed exactly at the right spot, which increases the structural performance. It must be possible to create an integrated self-alignment system in the most connections.

Affordable
A cabled or rod connection is expected to be more inexpensive compared to other connection types, since les steel can be used.

Durability
Most of the types are commonly executed in steel. By using stainless steel, or use other materials which are not susceptible for rust, for example plastics, steps into durability can be gained.

Robustness

Since the placement of the floating modules can be accompanied with bumping against each other, whether or not under influence of wind and waves, connection must be able to withstand those bumps. So the connection must be robust both during execution as during its service time. A clamping, a male/female and a bolted/pen connection are considered to be the most robust connections.

7.3 Conclusion MCA

A multiple criteria analysis concludes a best fitted types according previously listed criteria. The best fitted foundation module type is a prefabricated timber frame with recycled barrels. For connection, a bolt/pen connection, a male/female connection and a clamping connection, fits best. A combination of these types could as well be a suitable solution.


BOYSEN

Chapter 8

Scenario Analysis

Besides the MCA, a scenario analysis forms input for the design of foundation modules and connections. For this scenario analysis information of the background is used. By having insight into all possible scenarios, an overview of all possible load cases is made. Logically, the structure must withstand all possible scenarios.

In order to set up all possible scenarios, multiple configurations are made, by varying numbers of levels and connected buildings. Besides a varying configuration, the building can be in multiple states because of the expected change in water level.

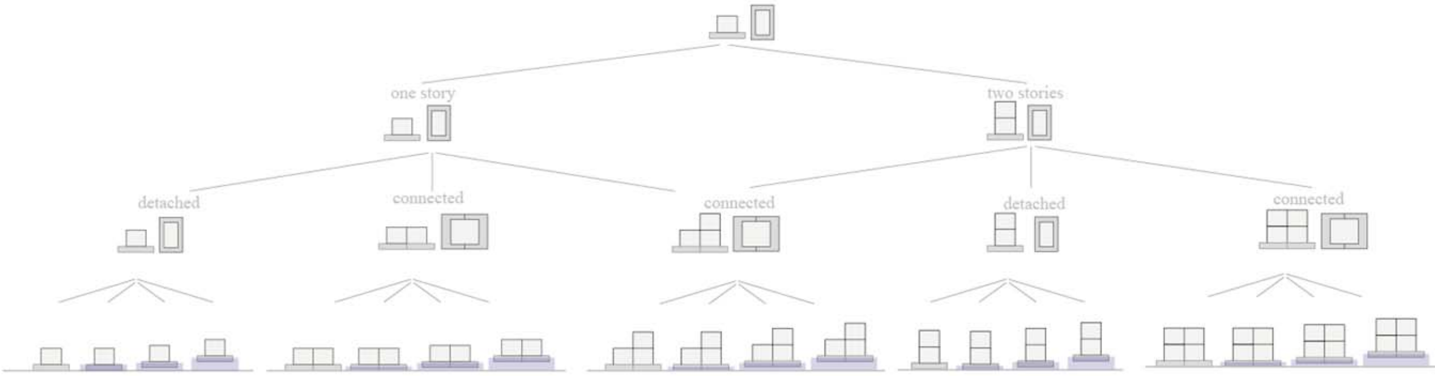


Figure 8.1: diagram of possible scenarios

8.1 Configurations by connecting and stacking

Since the flexibility and adaptability are main aspects of the design for the amphibious structure, the design can be executed as both a single detached building, and a coupled and/or stacked configuration.

Although flexibility and adaptability are important criteria, the amount of levels is limited to two. By more than two levels, it is expected that too many measurements need to be taken to ensure the floating building its stability. This assumption is validated, by means of a parametric model which is described in chapter 9.

8.1.1 - Detached single story building

A floating structure can be built as a detached building. In figure 8.2 a schematised view and plan of a single detached building on a foundation is depicted

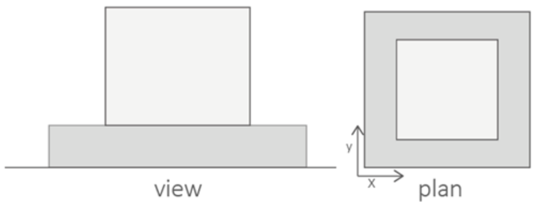


Figure 8.2 single detached building

8.1.2 - Attached single story building

The foundation must be able to carry multiple buildings. Buildings can be connected to each other or they are placed with a certain spacing. Since the structure is broadened in the x direction, it is expected that in floating position stability in this direction will increase, due the fact of size stability. (chapter 3) If the length in y-direction of the building and the foundation remains the same, the stability in this direction is decreased, since the wind load acting on the building increases and the draught d will increase. With an increasing d, the length KM will decrease and so will the metacentric height GM.

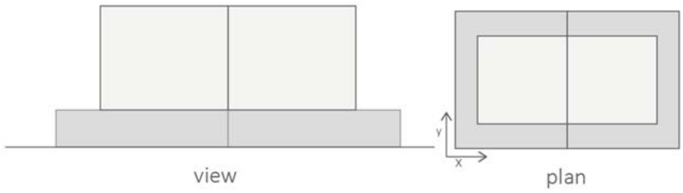


Figure 8.3: attached buildings without spacing

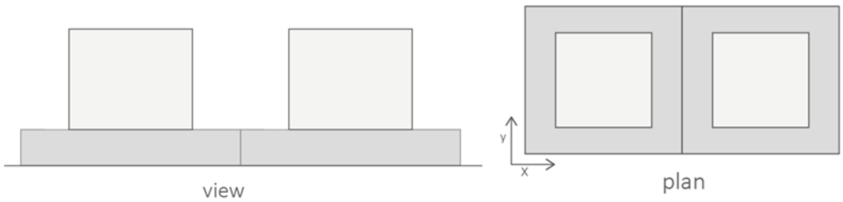


Figure 8.4: attached buildings with spacing

With an extension into two directions, the structure will be more stable, since the length b will increase and therefore MG will increase.

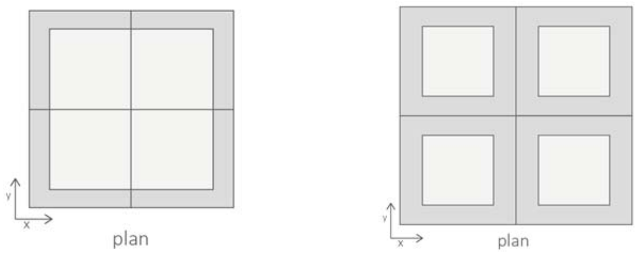


Figure 8.5: extension into two directions

8.1.3 - Attached single story - double story building

With an eccentric extension, the centre of gravity will shift. Considering the building is floating, this shift causes an external heeling moment, so that the building will tilt as discussed in chapter 3.

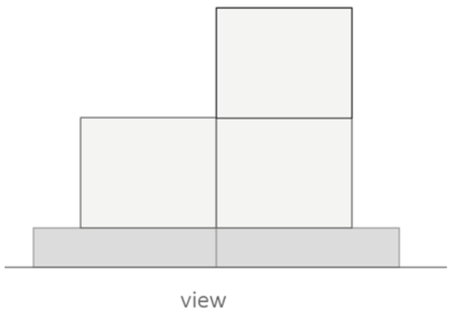


Figure 8.6: attached single story- double story building

8.1.4 - Detached double story building

With an extension in vertical direction, by stacking modules, the draught will increase in floating position, since the dead weight of the building increases. Furthermore, the building will be less stable since the centre of gravity will raise. (chapter 3)

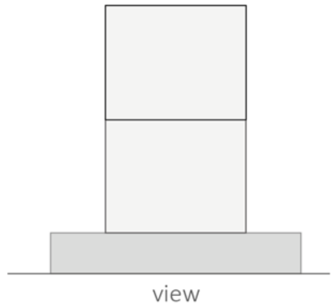


Figure 8.7: detached double story building

8.1.5 - Attached, double story building

So, an added layer on top means an increase in draught. Also for this case, it means that when the structure is broadened in one direction, it is more stable in that direction, and less stable in the opposite direction. An extension into both x and y-direction creates a more stable structure.

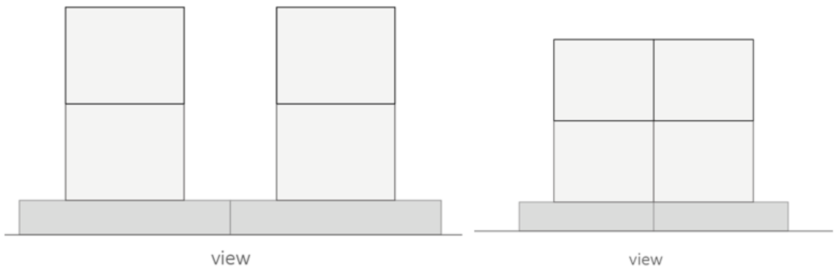


Figure 8.8: attached, double story building

8.2 Multiple water levels

Besides variations in configurations, the situation can vary by change of water level. For this variation, four characteristic situations are taken into account. A dry situation, a situation where the structure is about to float, a situation where the structure is just floating and a situation where the structure is floating are studied.

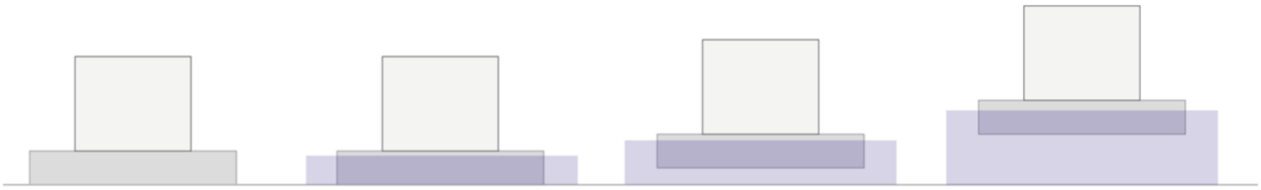


Figure 8.9: dry *about to float* *just floating* *floating*

8.2.1 - Dry

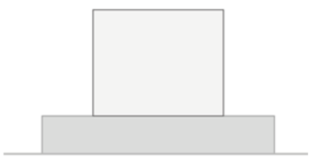


Figure 8.10: dry situation

In the thinkable situation where a certain fishpond is dried up, the underlying soil will carry the structure. This situation can be schematised as a relatively stiff plate upon an elastic foundation, with k-value of 30.000 kN/m^3. (chapter 5)

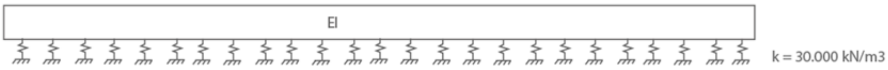


Figure 8.11: schematisation

Load cases that need to be considered are loads according code NEN-EN 1990. Obviously, loading due to snow can be neglected.

8.2.2 - About to float

Figure 8.12: about to float - situation

In the situation where the structure is about to float, the upwards pointing buoyancy force, almost reaches the gravity force. Then two elastic foundations connected in series can be schematised. For water, the subgrade modulus K=10 kN/m^3. (appendix 9) The soil has a K-value of 30.000 kN/m^3. (chapter 5)

Figure 8.13: schematisation

The equivalent spring constant can be calculated as follows:

$1/k_{eq} = 1/k_1 + 1/k_2$

$1/k_{eq} = 1/10 + 1/30000$

$K_{eq} = 27272\ kN/m^3 \approx 30000\ kN/m^3$

Because of the large difference between k1 and k_2, k_2 is a factor 3000 times as large as k_1, k_{eq} is almost equal to k_2. So this situation is approximately the same as the dry situation. Load cases that must be considered are the same as the previous situation, since the water level is very low, so forces caused by water movement can be neglected.

8.2.3 - Just floating

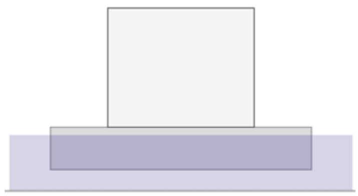


Figure 8.14: just-floating scenario

In this situation, the structure is just floating. In a stable position, when no heeling moment is working on the structure, the structure can be schematized as a floating situation. A plate resting on an elastic foundation with a Kvalue of 10 kN/m^3 forms a proper schematizing of the situation.

Figure 8.15: schematisation

When an external moment acts on the structure, the structure tends to tilt. Because of the small space between the structure and the soil, the structure will touch the soil over a certain distance.

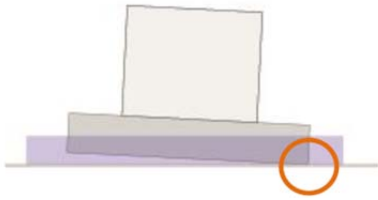


Figure 8.16: touching soil, by heeling moment

In this situation the structure can be schematized as a plate on an elastic foundation with on one side over a certain length a subsoil, with a much higher subgrade modulus, in this case with a k-value of 30.000 kN/m^3.

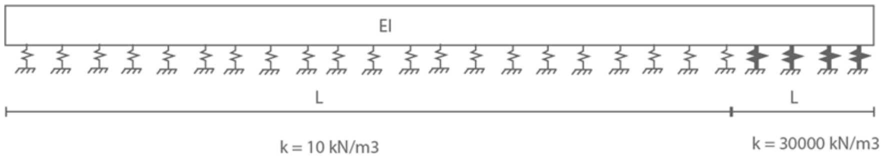


Figure 8.17: schematisation

Load cases which need to be considered according (NTA 8111) are depicted in chapter 4.

8.2.4 - Floating

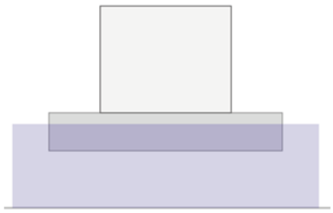


Figure 8.18: floating situation

As described, the floating situation can be schematized as a plate upon an elastic foundation with a k-value 10 kN/m^3.

Load cases which need to be considered in this situation are the same as the situation where the structure is just floating (NTA 8111). Extreme conditions as winds and waves are elaborated in chapter 5. In this part wind loads and wave loads are elaborated more into detail.

Wave loads
Resulting horizontal forces

Wave properties as calculated in chapter 4, are translated into distributed forces on the structure. Which influences both horizontal and rotational stability. Resulting horizontal forces are dependent on the ratio between the wave length and the length of the structure.

At a ratio of $L_{structure}$= 3/2 $L_{wave,}$ a maximum horizontal force due to hydrostatic pressure occurs. In this situation a cress is located on one side of the structure. On the other side a through is located.

L =3/2 L_{wave}

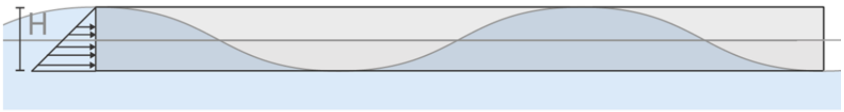


Figure 8.19: maximum resulting horizontal force

With a ratio of $L_{structure}$ = 5/4 L_{wave} this resulting horizontal force is limited.

L =5/4 L_{wave}

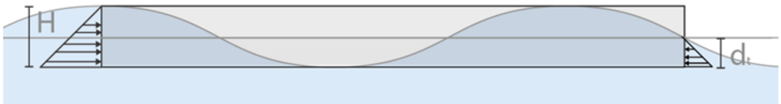


Figure 8.20: resulting horizontal force

In general, the horizontal force can be calculated by the following formula:

$$F_{horizontal} = ½ \cdot \rho \cdot g \cdot H^2 \cdot b - ½ \cdot \rho \cdot g \cdot d_t^{\,2} \cdot b$$

As stated in chapter 3 mooring piles must be able to take resulting horizontal force, in order to create a stable structure. The structural behaviour of mooring piles is checked in chapter 12.

Resulting vertical forces

Resulting vertical forces of wind generated waves at the bottom of the structure are schematised by an extra upwards pointing water pressure at the crests and a downwards pointing water pressure at the through. Extra water pressures are schematised as block loads over a length of 1/3L_{wave}.

L =3/2 L_{wave}

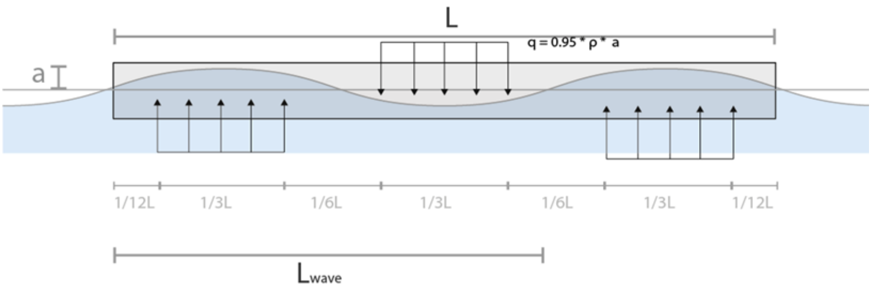


Figure 8.21: resulting vertical forces

The value of the schematised upwards and downwards pointing water pressure can be found by integrating the sine function.

The surface underneath a half period of a standard sine function is 2.

$$A = \int_0^{\pi} \sin x dx = \cos 0 - \cos \pi = 1 - -1 = 2$$

This results in a total force for one crest or one trough:

$$F_{vert} = 2 \cdot \frac{L}{2\pi}\rho g a = 0{,}32 L \rho g a$$

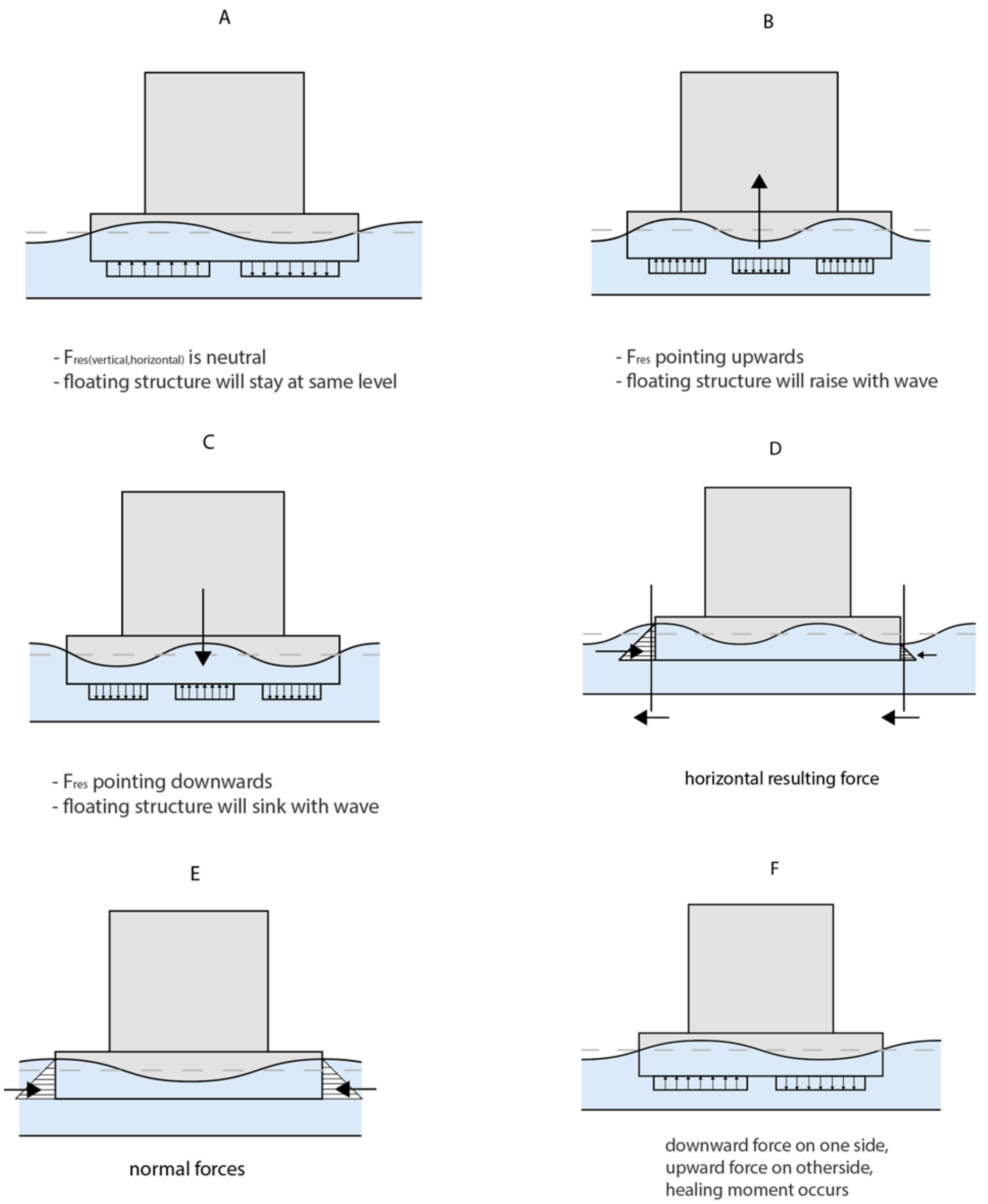
Over 1/3L the pressure is as follows:

$$p_{wave} = \frac{F_{vert}}{x} = \frac{0{,}32 L \rho g a}{\frac{1}{3} L} = 0{,}955 \rho g a$$

(Koekoek, 2010)

Possible situations

Loads by waves can act in several ways on a structure. Possible load cases are studied. Figure 8.22 shows all possible load cases that can occur by waves.



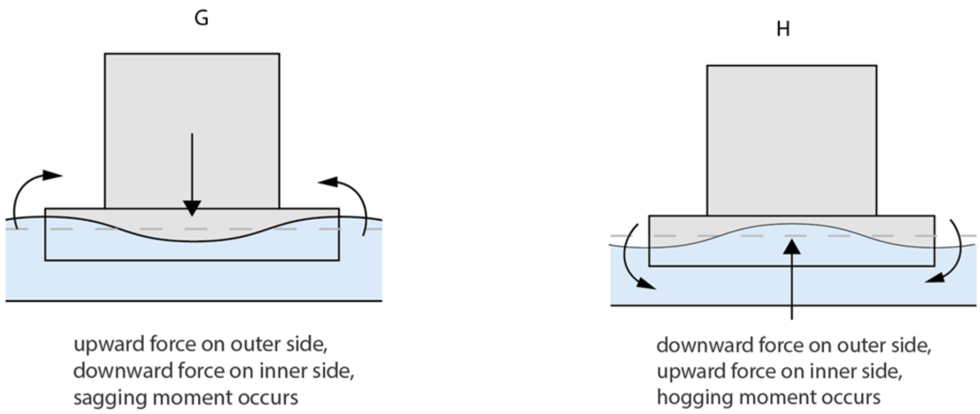


Figure 8.22: possible situations due to wave loading

Load cases that need to be considered are dependent on the ratio between the wave length and length of the structure. The following figure shows for several ratios, which cases will occur. In appendix 10 a more detailed figure is elaborated. A red surface means a downward pointing distributed force. A blue surface means an upward pointing distributed force. An entire overview is given in appendix 10.

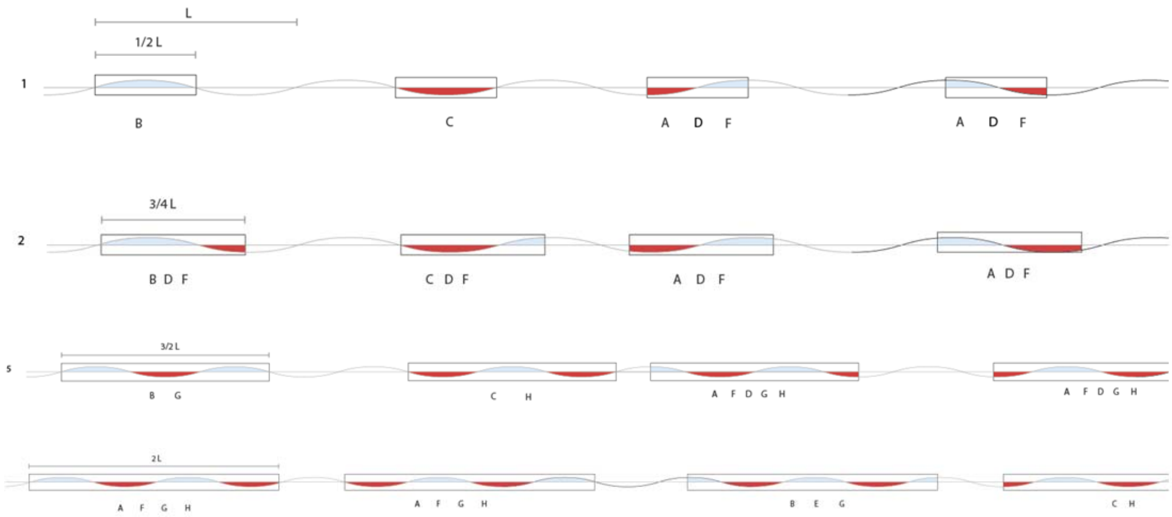


Figure 8.23: $L_{foundation}$ / $L_{wave.}$

8.3 Conclusion

Due to its demanded flexibility and its changing environment multiple scenarios can occur. Load cases by waves are dependent on the ratio between the $L_{foundation}$ / $L_{wave.}$ The amphibious structure must fulfil structural safety in each scenario. Several decisive situations need to be elaborated in order to test the structural capacity of the foundation.

It can be stated that the building must perform properly, in every scenario with all different circumstances.

Chapter 9 Parametric Models

The building concept as described in chapter 2, holds a flexible building concept. By connecting foundation modules, multiple building configurations can be built upon the amphibious structure.

In this chapter a parametric visualization and calculation model is made, with the best fitted types as described in chapter 7 as input. In the first section, a visualization model is made. In this model the foundation is adaptable in number and dimension, and can so be used for varying building configurations. By using a grasshopper plugin in Rhinoceros a parametric 3d model is created. By this model first impressions of the entire floating structure are gained. This model can be exported to calculation- or (3d)CAD software. By changing parameters multiple configurations and scenarios can be drawn fast and easily and can be rendered afterwards.

Matching with the parametric visualisation model, a calculation model is made in Microsoft Excel. This model contains all necessary calculations to give a first impression of the structural behaviour of connected floating modules. This parametric calculation model covers the floating scenario. Parameters of the visualisation model configures parameters of this calculation model.

Changes in the design of the building upon the foundation, can easily and quickly be adapted in these parametric models.

9.1 Parametric visualization model

A parametric system in grasshopper depicts in Rhinoceros an in x and y-direction-variable number of foundation modules. Dimensions of the timber structure can be changed by changing parameters in the model. As well the dimensions and numbers of the barrels can be adapted.

The number, dimensions and place of the buildings upon the structure are parametric, so multiple configurations can be modelled.

Furthermore, the water level can be changed, so multiple scenarios can be sketched. In addition, the amount and dimensions of mooring piles can be changed. In the following table, an overview of all parameters is given.

Module	**Structure**
Length in x direction, in y direction, in z direction	Amount in x direction, amount in y direction
Amount of elements per module in x direction, in y direction, in z direction	
Thickness upper plate, thickness lower plate	**Barrels**
Width and height of each structural element (x direction, y direction, z direction)	Radius barrel
Width and height of diagonals	Height barrel
Amount of modules in x direction, amount in y direction	
	Poles
Building	Depth of pole in soil
Width building, length building, height building	Radius pole
Distance between edge foundation and building in x, and y direction	Length of pole
Distance between buildings in x, and y direction	Amount of poles along edge foundation
Amount of buildings in x and y direction	
Amount of floors (in z direction)	**Waterlevel**
	Height of water level

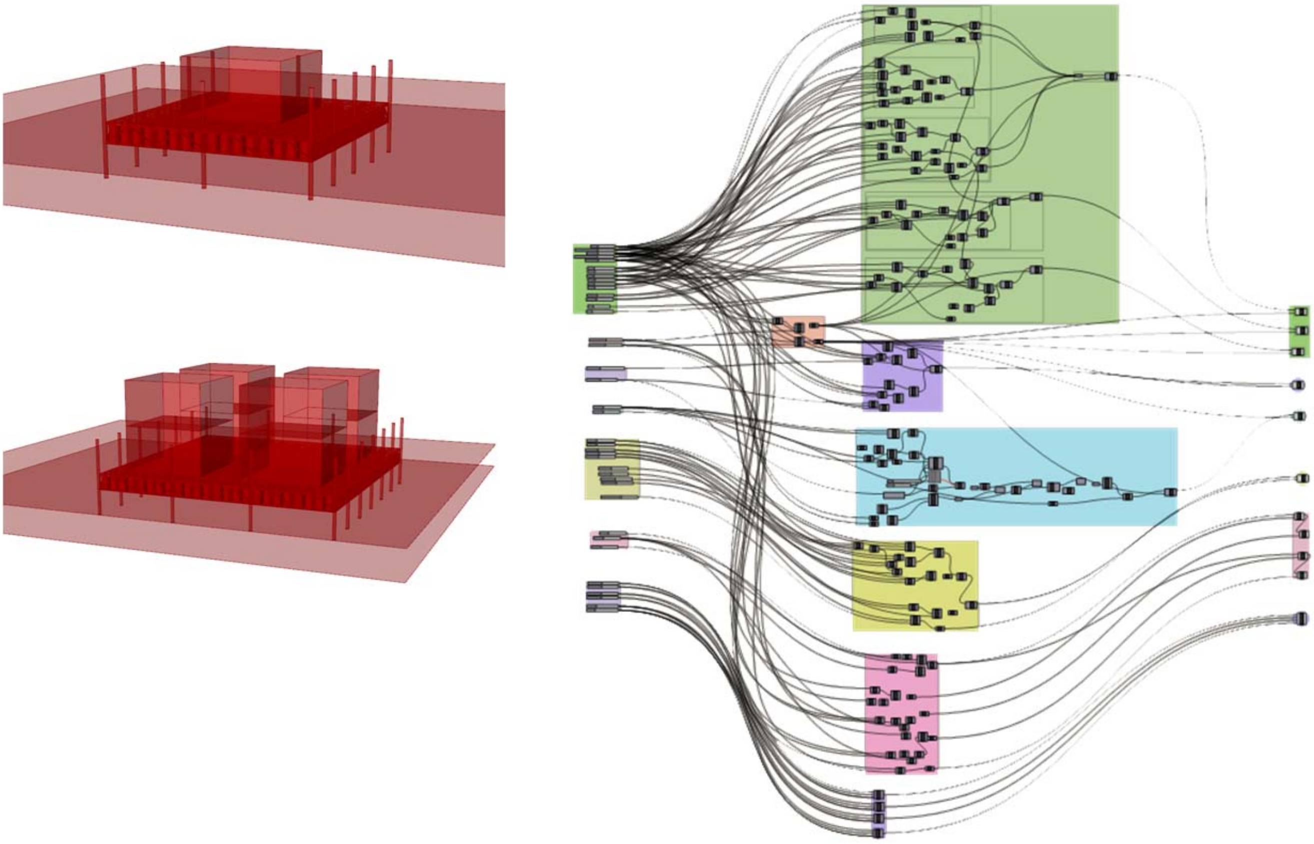


Figure 9.1: parametric grasshopper design

9.2 Calculation model

With a parametric calculation model, all important factors of floating behaviour can be calculated for all possible building configurations. Parameters, which are the input for this calculation model mainly match the parameters of the visualisation model, are listed in the following table:

Module	**Barrels**
Length in x direction, in y direction, in z direction	Radius barrel
Amount of elements per module in x direction, in y direction, in z direction	Height barrel
Thickness upper plate, thickness lower plate	Weight barrel
Width and height of each structural element (x direction, y direction, z direction)	Volume barrel
Width and height of diagonals	Barrels per module
Amount of modules connected in x- and y direction	Ways of placing modules
	Poles

Building	Amount of poles along edge foundation
Width building, length building, height building	
Distance between edge foundation and building in x, and y direction	**Load properties**
Distance between buildings in x, and y direction	Wave properties
Amount of buildings in x and y direction	Fetch
Amount of floors (in z direction)	Velocity wind
Height roof	Depth
	Wind pressure
Properties timber specie	
Density timber specie	Dead load building
Elasticity modulus timber specie	Live load building

The most important outputs from the model are described in this paragraph. Calculations are based on the NTA8111.

Firstly, the **draught** is calculated in this model. The draught is a function of the gravitation force acting vertically on the structure and the floating capacity. This model calculates the acting gravity force, and by calculating the effective area of the barrels, which gain the floating capacity, it calculates the draught. If the draught has a larger value then the height of the structure, the model shows an error.

The model calculates in two direction (both x and y) **horizontal forces**, by considering wind and wave forces, as depicted in chapter 4. By calculating the amount of structural elements, stresses due normal forces can be calculated for each structural element. As well the resulting horizontal force acting on each pole is calculated. Desired depth and radius of the poles can be calculated afterwards, and is described in chapter 12.

An important output from this model is the **metacentric height**. If the metacentric height is positive, the structure is ought to be stable (chapter 3) According the NTA 8111 the metacentric height must be larger than 0,25m.

By calculating the metacentric height and all forces which create a **heeling moment**, the tilt can be calculated, as described in chapter 3. In this model the total heeling moment is calculated according codes NTA8111 and depends on wind force, eccentric distributed force by people and the second order moment. The heeling moment causes a heeling angle and is calculated as described chapter 3. This heeling angle may not exceed 4° (NTA 8111).

In this model, Eigen periods according to heave and pitch/roll **oscillation** in both x and y direction are calculated, according the method described in chapter 3. These values are compared with the wave period.

By changing for example the building configurations by changing the number of stacked buildings, all corresponding values are calculated. Hereby, in a fast way the minimum amount of floating modules in x and y direction can be calculated, for each configuration.

In this parametric model, wind waves are not taken into account in order, since wind waves can have multiple varying influences on the structure. (chapter 8) However, acting forces by wind waves will be calculated by means of a SCIA model in chapter 11.

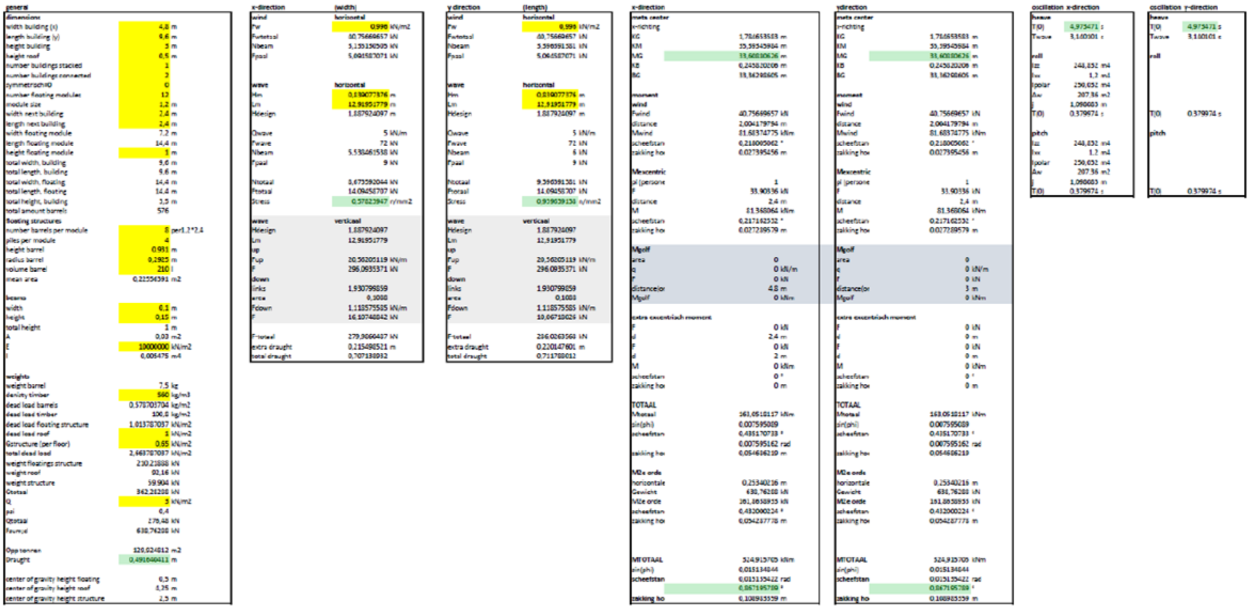


Figure 9.2: parametric calculation model. (a detail view is depicted in appendix 11)

9.3 Conclusion

By means of the parametric visualization and calculation model a first insight of the floating behavior is gained. This visualization model can be used for rendering and exportation to other CAD or calculation software. Changes in design can be adapted easily in this model.

With parametric calculation-model a first estimation of minimum amount of foundation modules is calculated, for each configuration. This output is analyzed in chapter 11, by means of SCIA and Matrix Frame.

This calculation model does not give an all-embracing calculation of needed data. Since wave forces are not taken into account in this model, a more sophisticated calculation model must be made.

The parametric models can be used to determine the baseline scenarios on which the structure must be analysed. Furthermore it provides information concerning heave, and roll and pitch oscillation and metacentric height of the structure.

Chapter 10 Final Design

Concluded from the MCA a timber cage filled with barrels forms a proper design type in order to create an amphibious foundation module, suitable for Hagonoy. Because of its dimensions and weight, the prefabricated structure can be transported to the construction site, which is a vacant fishpond in San Roque, Hagonoy.

On this construction site, demountable connections provide rigid connections between foundation modules, in order to create a stable structure.

The design of the foundation module is described in section 10.1. On the construction site, foundation modules must be connected in a proper way. The design for the connections is described in section 10.2.

10.1 Design – amphibious foundation module

For the design of the amphibious structure the design approach as described in chapter 6 is used. After a concept design, drawings and a physical model have been made. Hereinafter the design is analysed on structural behaviour and checked whether it can fulfil the criteria. Output of this analysis, is the input for improvements of the design.

Design → Drawings/Physical model → analysing by criteria/structural behaviour

The final design is described. Detailed drawings are depicted in appendices – technical drawings.

10.1.1 Structural principle

A prefabricated foundation module is designed. This module consists of a timber frame which holds a certain amount of recycled 200L barrels in place. In order to create a large foundation platform, prefabricated foundation modules must be connected on the construction site. A rigid foundation must be designed (theory), so the foundation module itself must be rigid, and so must be the connection between modules. To create this rigid behaviour, a timber braced frame is designed. Timber beams are connected by stainless steel plates on each point where structural elements come together.

10.1.2 Material

Main benefits of timber are find in the field of sustainability, and comparative cost-effectiveness. However, some challenges among using timber for an amphibious structure in the Philippines are found, in which the presence of shipworm, and the current situation in the Philippines among a ban on logging and trade of timber, are the most important. These aspects are briefly discussed, and the most suitable timber specie is given.

Sustainability

Wood works as a CO_2 buffer. In a cubic meter rough sawn timber, 250 kg CO_2 can be stored. In contradiction to for example steel and concrete, by production of this material there is no CO_2 emission. In addition, timber is a renewable material, under so it does not contribute to exhaustion of natural resources, which makes it a circular product. (APU, 2003)

Situation Philippines

There is officially a nationwide ban on logging wood, because it is believed by current government that logging makes areas more prone to landslides and flooding. The ban on logging leads to the situation where no contracts will be granted for cutting natural forest anywhere in the Philippines. (McGeown, 2011) The ban on logging does not mean no forests are logged. The level of sustainability and fair trade timber is questionable, and therefore it is advised not to buy timber from the Philippines, when it is not officially certified.

Furthermore, a due to relative underdeveloped transportation in the Philippines, transport duration and cost are relatively high. Resulting in relatively high prices, in comparison with other Southeast Asian countries, such as Malaysia and Vietnam.

However several FSC certified timber species are commonly available in the Philippines. A broad research, done by Joran van Schaik, advises the use of Eucalyptus Grandis as most suitable structural timber, due to its strength, workability, durability and sustainability. Eucalyptus Grandis is used as structural timber in the design for the amphibious structure.

10.1.3 Dimensions

Manufacturability and transportability are important inputs to determine ideal dimensions. Small modules can be executed relatively light-weighted and are easier to transport and easier to move on the construction site. However, larger modules, can be coupled with less connections. Less connections mean a decrease in proceedings at the construction site, and a decrease in material which has a positive influence on the price.

To solve this contradiction, modules need to be constructed as large as possible, but still be manageable to be transported to and moved on the construction site. The material that give the object the floating capacity are 200L barrels. This plastic barrel, made out of HDPE weights 7.5 kg, and has the dimensions as depicted in figure 10.1

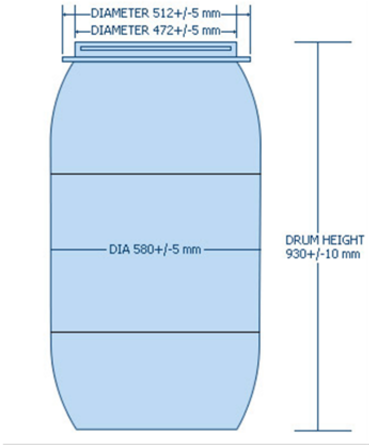


Figure 10.1: plastic 200L barrel

By building a module that consists of eight barrels with a surrounded timber structure, a module of around 1,2m by 2,4m by 1m can be built. These dimensions configure with the upper building.

Foundation modules of this size have an expected weight of around 200 kg and are thereby still able to be transported and moved. Precise weight of the foundation module can be calculated with the parametric calculation model as described in the previous chapter.

10.1.4 Construction order

In this paragraph all building steps are elaborated. In these description of building steps, design considerations are given.

1 Timber cage

Firstly, three timber trusses will be built by connecting timber beams with stainless steel plates. The outer two trusses are strengthened by diagonal beams. The three trusses are connected by perpendicular beams and steel plates. Again the edges are strengthened by diagonal beams.

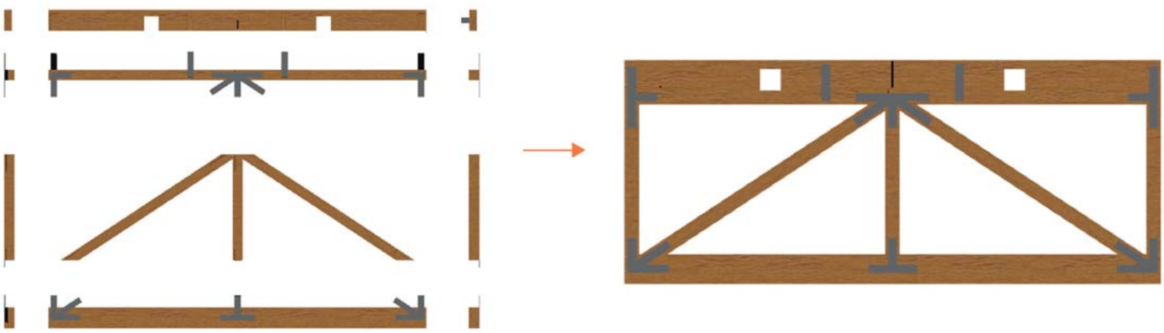


Figure10.2: creating timber trusses

Upon the upper beam an extra beam layer is connected with steel plates. This beam is 12 mm thinner on both sides, than the one beneath. This extra layer ensures a space for connections between modules and for piping.

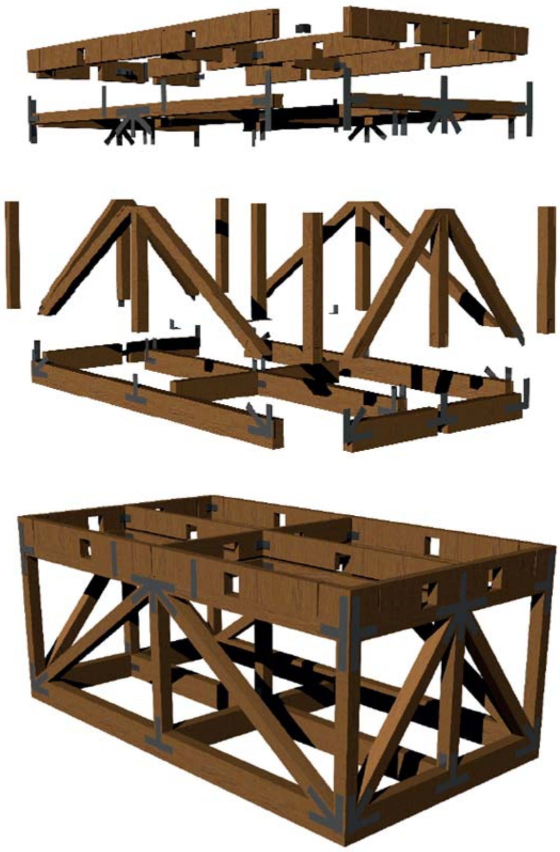


Figure 10.3: creating a timber cage with steel connections

2. Timber planks to secure barrels.

After the timber cage is built, timber planks are nailed on the cage for securing the later placed plastic barrels. First at the bottom of the cage timber planks will be mounted. Thereafter, at the sides of the cage timber planks are placed. The planks are placed on the inside of the cage, in order to ensure the barrels to remain their position.

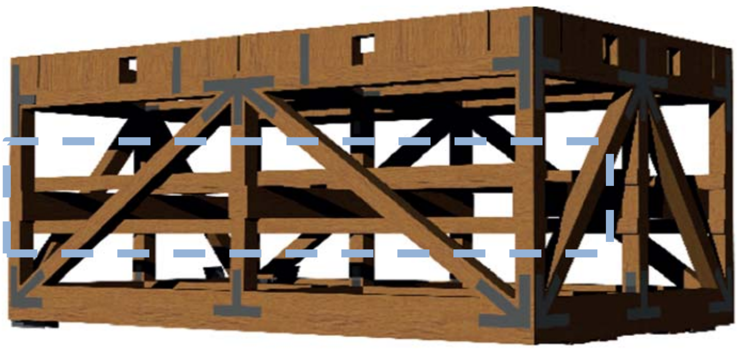


Figure 10.4: timber planks

3. Placing barrels

After step 2, barrels are placed in the right position. The cage is divided in four equal parts. In each part, two barrels can be placed. By placing two barrels in one division, barrels are able to be replaced after execution. This is elaborated more into detail in later in this chapter.

Figure 10.5: timber cage with barrels

4.Top plates

After the barrels are placed, the cage can be closed by mounting a top plate. These top plates obstruct barrels from uplifting in floating position. Now, each two barrels are surrounded with structural elements to hold all barrels in place. Since the upper beam is thinner than the under laying beam, an edge is created to connect the top plate with. Above each barrel a single top plate is mounted, in order to create the ability to replace barrels.

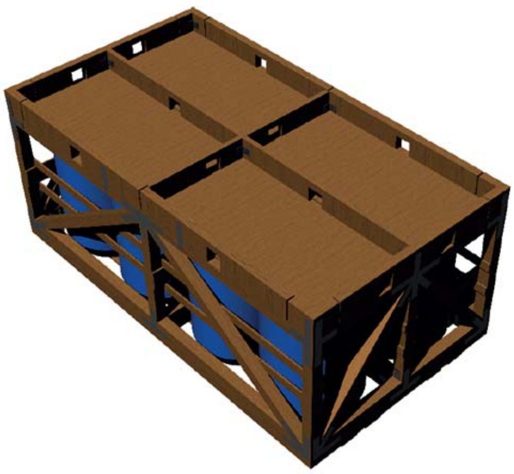


Figure 10.6: module with top plate

At this point, the prefabrication process is completed. Now the foundation modules can be transported to the construction site, in order to be connected. This process is explained in the next section. After connecting modules, an extra layer is placed on top. These layers close the entire cage, and thereby a proper floor is installed. This layer perfectly fits in between the upper layer of the beam structure.

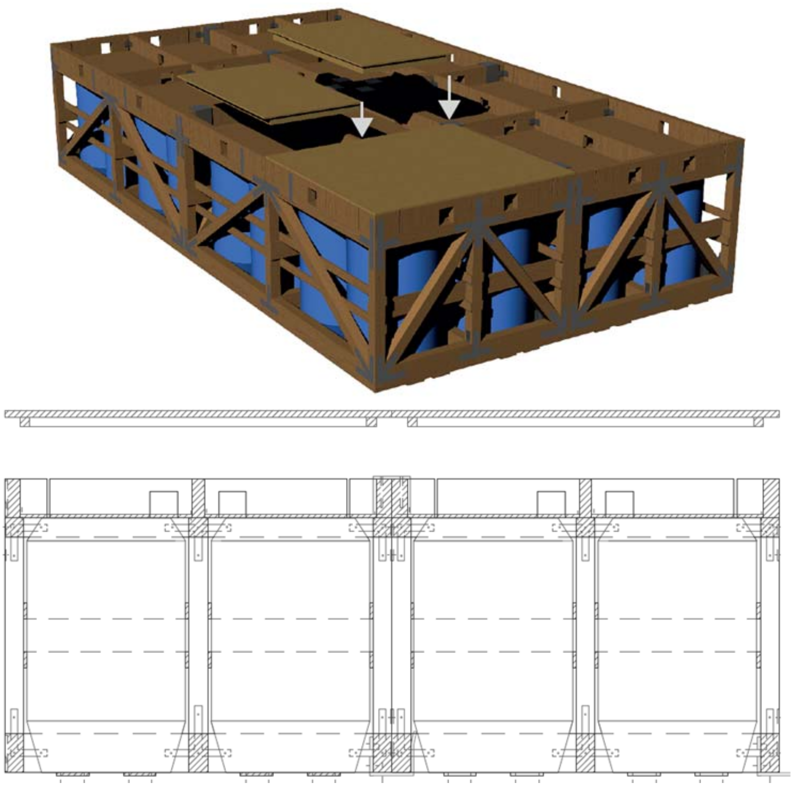


Figure 10.7: placing top layer

10.1.5 Preservation floating module

In order to enlarge the service time of the foundation module, preservation measurements must be taken on both the timber structure and the barrels.

10.1.5.1 Wood preservation

The presence of shipworm forms a serious tread for the timber structure. Already in 1730 the entire Dutch coast form Zeeland to West-Friesland, was seriously affected by damage due to shipworm on timber elements of quays, lock gates and dikes. As well wooden ships were attacked by these organisms, which contributed to the spread all over the world. Several measurements against shipworm attacks stem from that time. However, nowadays timber structures still struggle with the presence of shipworms. Several possible measurements can be taken, to preserve the timber from shipworm. In the following diagram several options are given. Thereafter options are elaborated and rated.

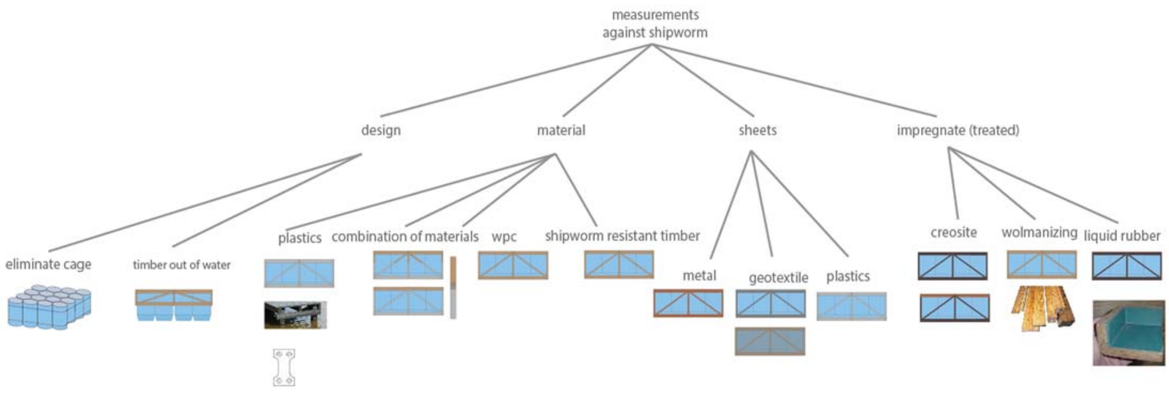


Figure 10.8: diagram shipworm prevention

Impregnation

First measurements of shipworm prevention have been taken by Chinese, Egyptian and Roman seafarers, where they used chemical repellent layers. In Europe, a layer of tar or creosote has been used as shipworm protection. Creosote is an effective way of protection, which can be gained out distillation of coal tar. However, creosote has two major disadvantages. Firstly, the layer must be replaced every year. Secondly, it is a very eco-unfriendly, toxic and carcinogenic product. Because of these reasons, creosote is prohibited in many countries. Alternative measurements, as anti-fouling paints, are prohibited since 2008, because of disruptions of hormone function of many marine organism. (Kerckhof, 2008)

It can be stated, that these protection measurements are not suitable, since mostly sustainability criteria are not met.

Design-measurements

Several design-measurements or changes in the design can be taken in order to keep the structure as much as possible above the water level. First it can be reviewed whether the timber cage is really needed. It might be a solution to bind barrels to each other. The advantage which is achieved (no decay of structural elements), however, leads to a number of disadvantages. The structural performance drops significantly, since the barrels, by lack of a timber structure, need to take bending moments, shear forces en normal forces, which is unfavourable. Furthermore it is harder to make a connection between the building and its foundation, as well as the connection between floating modules, and connection with mooring piles.

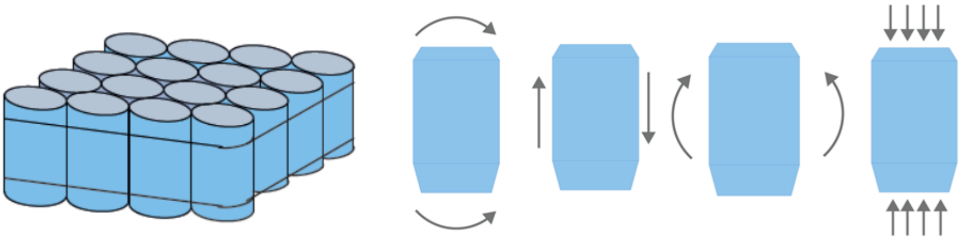
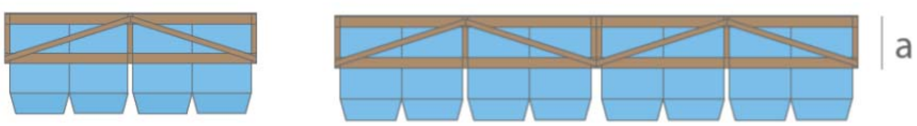


Figure 10.9: barrels without cage

Another adjustment in the design in order to prevent the timber from shipworm attacks, is to shorten the height of the timber frame. The timber can be kept dry in most scenarios, so shipworm cannot affect the structure.

However, several disadvantages come along with this solution. The length *a*, over which bending moments must be transmitted, is shorter than in the situation in which the timber structure is built over the entire height of the barrel. The bending moment results in a tension or compression force in the timber structural elements. For a positive bending moment, a tension force in the bottom beam and a compression force in the upper beam. For a negative moment it is the other way around. When the distance of the acting forces decreases, the tension and compression forces increase.

Another disadvantage is that the barrels are not entirely enclosed. This can result in the situation where barrels will slip loose under brutal forces, by typhoons. When the water level is very low, the building will rest upon those barrels. As stated before, the barrels cannot take that large forces as a timber frame can do. Furthermore, when the water level is inclining, barrels come loose from the frame by adhesion of the soil.



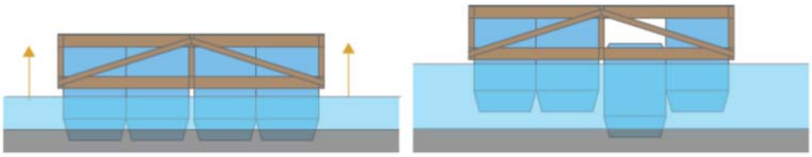


Figure 10.10: shortened timber cage

Materials
Another solution can be found in the field of material. By building with a shipworm-resistant timber, or a combination of materials, this problem might be solved.

Composite
(Wesin, et al, 2008) tested a fully bio-derived wood plastic composite (WPC). Decay resistance of WPC in soil and in seawater is tested both in laboratory and infield tests. In the marine field test, the WPC from unmodified wood were severely attacked by shipworm, whereas the WPCs from modified wood were sound. This fully bio-derived modified wood plastic composite can be a fitted solution to avoid shipworm attacks. The lower structural elements, which are submerged most of the time can be built out of this material. Upper structural elements, which are never submerged at all, can be executed in a different timber specie.

Nowadays, several factories in the Philippines are able to produce WPC. However, the plastic used for this composite is an oil-based material, which does not fit the sustainability criteria. WPC, with bio-derived plastics, is not yet available in the Philippines.

Figure 10.11: WPC submerged structure

Timber species
Several timber species are resistant to shipworm attacks. On the Belgium shore-line, several tropical hardwood species are being used, of which is known that they are more difficult to be pierced by shipworm. However, this material was still attacked at several places by the shipworm Teredo Navalis. (Kerckhof, 2008)

Class	Marine Boarders
D	Basralocus, demerara greenheart
M	Afrormosia, Azobe, Biliniga, Sapeli, teak

Figure 10.12: Natural durability against marine boarders. (NEN-EN 350-2)

The natural resistance against shipworm of timber species, suitable for applications in salt and brackish water, varies widely. Many timber species owe their resistance not only to a high silica content, but also their content of alkaloids and other toxic substances. These substances may leach out in the long run. The basralocus, Demerara greenheart, jarrah and teak are without impregnation, applicable in salt water and brackish water. (CentrumHout, 2013)

Again, submerged structural elements can be executed in these timber species. However, those timber species, nowadays are not present in the south-east Asia area. Jarrah (eucalyptus marginata) grows in southwest of Western Australia, Basralocus grows mainly in Suriname and West Africa. (CentrumHout, 2013)So by building with this specie, the locally-produced criterion is not met. Teak however, does grow in the area. It is relatively expensive to use FSC teak, so for affordability reasons, this timber specie is not applicable.

Sheets
Sheets can withhold the shipworm from entering the timber elements. This measurement is firstly executed at wooden ships. Double layered wooden ships were built, so after shipworm attack, only the external layer needed to be replaced. (Hoppe, 2002)

Metal sheets
Chinese, Egyptian and Roman seafarers, already used cupper or lead sheets to protect their ships. Also in the 18th century ships were equipped with a cupper or lead layer. It creates a proper protection against shipworm. Since this was relatively expensive, marine structures such as seawalls could not be protected in this way.

Even though metal sheets form a proper protection, it is not a good solution, since it does not meet several criteria. First of all it is relatively expensive. Furthermore, the dead load of the foundation will increase significantly, so it does not meet all theory-criteria. (Hoppe, 2002)

Plastic sheets
In the USA, timber piles are protected with plastic foils, which give a proper protection. Plastics are oil-based materials, and do not fulfil sustainability criteria. It can be an interesting study in how to use recycled plastics, for example PET bottles, and to create plastic sheets with it in a sustainable way. (Hoppe, 2002)

EPDM sheet/fishpond liner
EPDM is being used as a medium for water resistance in construction projects for roofing membranes geo-membranes, pond liners and many other applications. Fishpond line is often made from EPDM. In some cases HDPE is being used. Some companies claim to deliver sustainable, eco-friendly EPDM fishpond liner. By wrapping all structural elements with fishpond liner or another EPDM sheet material, shipworm cannot attack the timber structure. Fishpond liner is being produced in the Philippines by several providers. However, eco-friendly fishpond liner or other EPDM products, are not being produced in the Philippines.

Geotextile
Another way of protecting the structure against shipworm is by adding a geotextile around structural elements. Geotextile is a collective noun for differing materials; from very thin, but water resistance foils, to wide meshed geo-grids. Textiles are being used in road- and waterworks, the building industry and in agro-technic projects. Geotextile can be divided in woven and non-woven geotextile. (Brinks & Bottenberg, 2012)

A patent from 1978 describes the use of geotextile in order to protect structures against shipworm. By surrounding the structure with a nonwoven fabric having an effective pore size less than 200 microns, wooden structures can be protected against shipworm. Nonwoven fabrics of non-cellulosic organic or inorganic fibres are suitable. A self-bonded nonwoven fabric of polypropylene fibres is preferred. The fabric has high tensile and tear strengths, good puncture resistance, and a small effective pore size. The method may be used on new structures or old ones that are already infested with marine wood-borers. (Patridge, 1978)

However, polypropylene is not sufficiently eco-friendly, because of the petroleum-based source, and non-biodegradable polymer matrix. By using natural fibres with polymers based on renewable resources, an environmental friendly product can be made. Biodiverse embedded renewable recourse based biopolymers, green bio-composites are being developed. (Mohanty, et al, 2002)

Bio-based geotextile
Besides woven and nonwoven polypropylene or polyester geotextile, also many kinds of bio-based geotextiles do exist. Geotextiles can be made of coconuts, straw, jute, or cellulose in combinations, or in combination with bio-foil. The natural fibre extracted from the husk of coconut is called coir. Coir is the fibrous material found between the hard,

internal shell and the outer coat of a coconut. Among vegetable fibres, coir has one of the highest concentrations of lignin, which makes it stronger, but less flexible than cotton fibres. Coir fibre has a good resistance to microbial actions and salt water damage. Coir has a relatively high silica content, which is ideal for shipworm protection. The method of making coir is environmentally friendly and CO_2 neutral. The residual material of the coconut is used in its entirety. Glue and chemical additives are not needed for productions. (FOA, 2016)

The coir industry is fully developed only in India and Sri Lanka, but economically important in Brazil, Indonesia, the Philippines and Vietnam. Coconuts are typically grown by small-scale farmers, who use local mills for fibre extraction. Since coconut husks are waste products, the material is relatively inexpensive. Furthermore, it forms an extra source of income for these small-scale farmers in developing countries. (Raman, et al, 2006)

Figure 10.13: coir sheets

Instead of using coconut, as well cotton fibres, for example from recycled clothing can be used to protect timber against shipworm, since cotton is a material with a relatively high content silicon. In a same way rice hulls can be used. Rice hulls have the highest silica content of all.

Conclusion – shipworm prevention

Multiple measurements have been explained and evaluated. Since coir-fibre meets most of the stated criteria, it forms the best fitted solution. Because of a high silica content, it will not be attacked by shipworm. Due to a high level of affordability, sustainability, healthy and the ability of local production, this measurement is very suitable.

Structural timber elements which are expected to be submerged most of the time can be wrapped with a coir foil, before elements will be connected to each other with stainless steel plates. However, the use of coir against as shipworm protection has not been tested. It is recommended to test multiple options, since (recycled) cotton and rice hulls can be a good solution to. (FOA, 2016)

10.1.5.2 Barrels preservation

Not only timber structural elements must be preserved. As well measurements must be taken in order to extend the service time of plastic barrels. Barrels can soften under direct sunlight in combination with salt-containing brackish water. (Berlepsch et al, 1988) The design of the foundation-modules is made in a way, barrels can be easily replaced, in case of leak barrels. Leak barrels can be detected by drawing a line at the height of the water level. When it is noticed that the line after a certain time period is decreased, it can be concluded that either a heavier dead load is gained, by for example more or heavier furniture, or a certain amount of barrels are damaged and need to be checked and replaced.

Since barrels are placed by two in a subdivision of the cage, each barrel is reachable, even when structural elements are placed on top of a barrel. The following figures show how replacement of barrels can be done.

Covers above a barrels can be demounted. Hereafter (damaged) barrels can be removed. New barrels can be placed, and the structure can be closed again. In a floating position, it is quiet heavy (max force of 2 kN. (200l water)) to push a barrel back. This can be solved by filling a barrel with water before placing, and pumping water out of a barrel after placing.

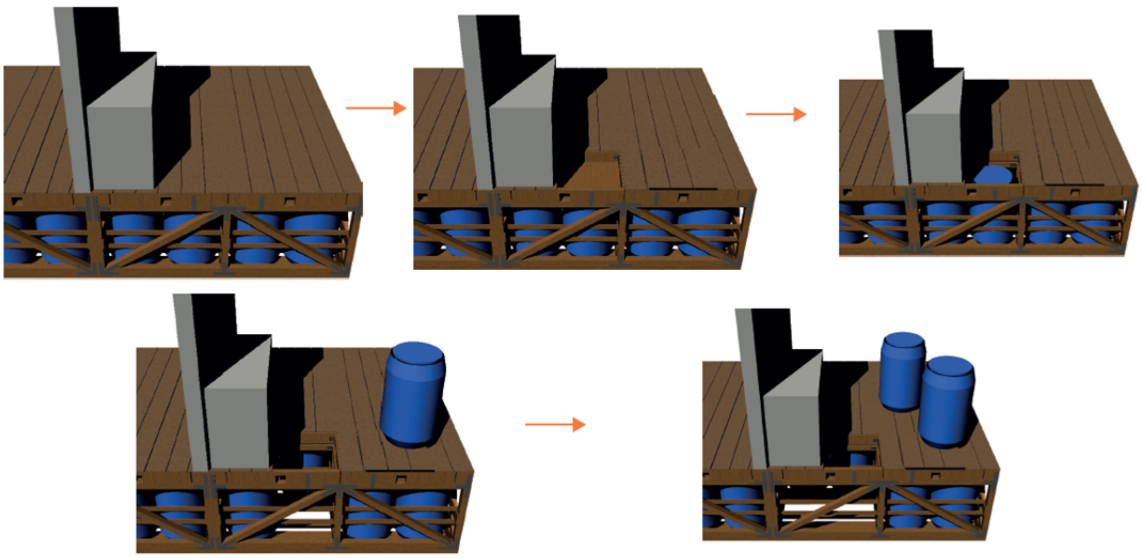
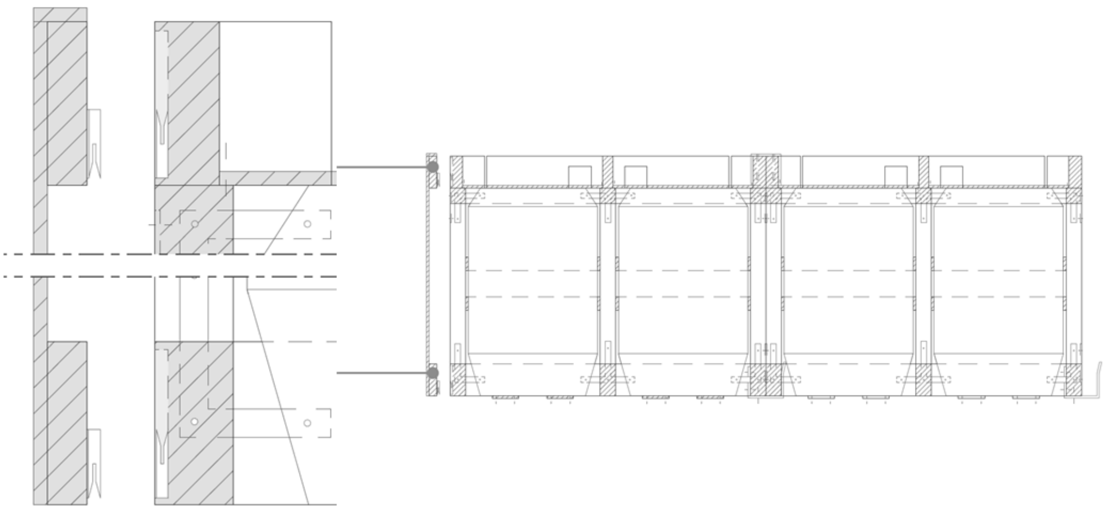
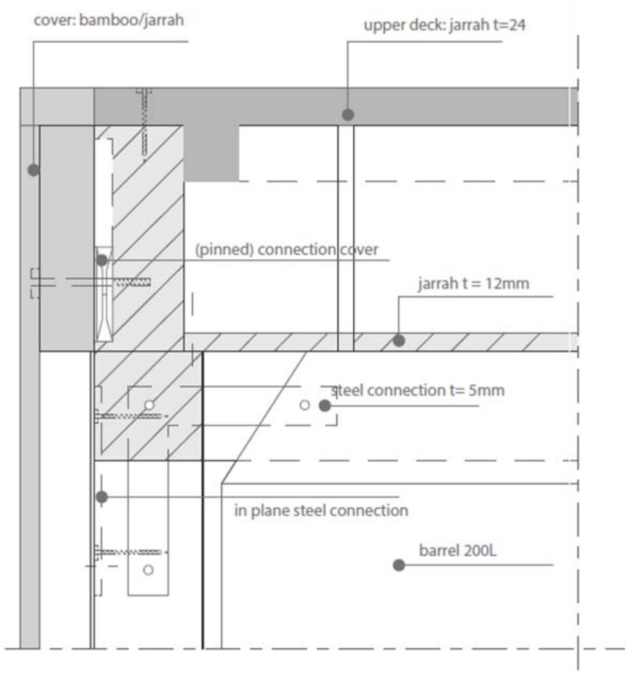


Figure 10.14: replacement barrels

By covering barrels from sunlight a longer service time can be gained. Prefabricated covers can easily be added on the construction site, by hanging the covers on the side of a module as depicted. By adding a pin in the upper connection, the cover will remain its place. (appendix II – technical drawings) The material of this covers may be of inferior quality than the structural timber, since it can be replaced very easily. For example simple bamboo or coco-lumber planks nailed on a coco-lumber frame can be used. It will degrade much faster, but because of its simple replacement and its relative low price it can be a good solution.





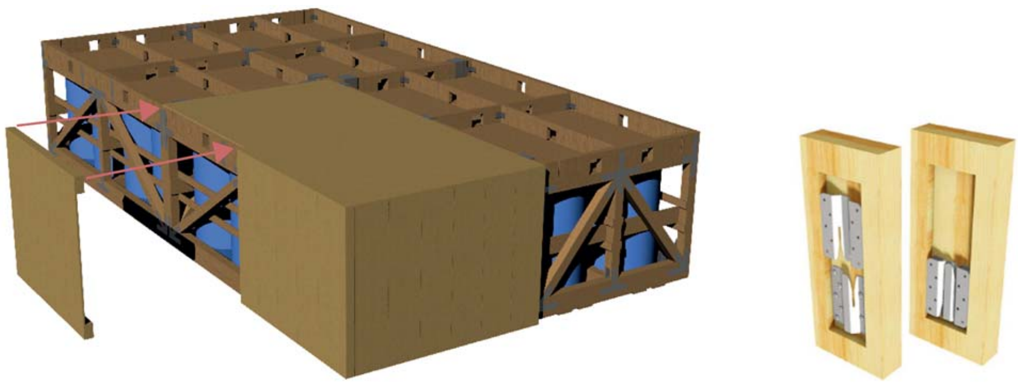


Figure 10.15: covers

10.2: Design connection

In order to create a decent foundation, modules must be connected on the construction site.

In this part a proper connection according previously criteria is described. The solution lays in the field of best types concluded from the MCA.

To design a proper connection, the design approach as described in chapter 6 is used.

Design → Drawings/Physical model → analysis by criteria/structural behaviour

By this iterative process, lessons can be gained, after drawing/building and evaluating a design, until the design fulfils the criteria in a proper way. In this thesis the final design is elaborated. Design of alternatives are depicted in appendix 16.

Multiple foundation modules are prefabricated and are transported to the construction site, which in this case is a fishpond. On these fishponds the modules must be connected simple, properly and rigidly in both x and y direction. Two connections must ensure a rigid connection. One connection is placed in the bottom and one on the top of each module. It is not obligatory that both connections have the same structural behaviour. With designing a connection in a way, that a fixation point is not needed for the bottom connection, a simpler connection can be created. In contrast to alternatives (appendix 16) and in contrast to connection of the floating pavilion Rotterdam as described in chapter 5, no long threaded rods are needed, in order to fix the bottom connection. When bolts or pens are eliminated in the bottom layer, the connection will not be influenced by rust, and will remain its ability to be disconnected.

10.2.1 Bottom connection

The design of the bottom connection is made in a way that only tension and compression can be taken. Compression can be taken by the foundation modules itself, since modules are able to be compressed together. By creating a U-shaped connection, modules can be connected on the bottom side of the modules. The U-shaped connection can be mounted to the lower beam of the timber cage in the factory, before it is transported to the construction site.

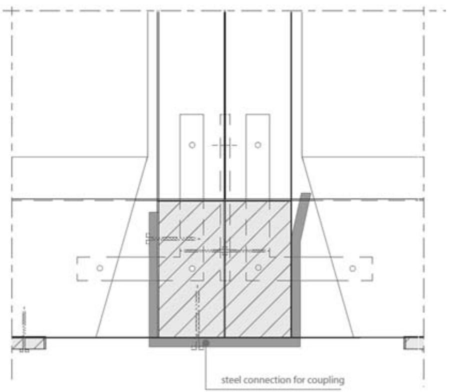
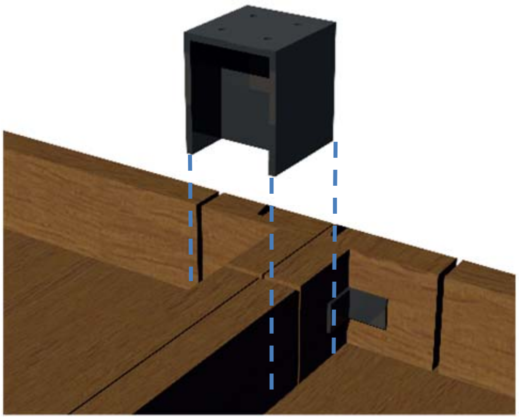


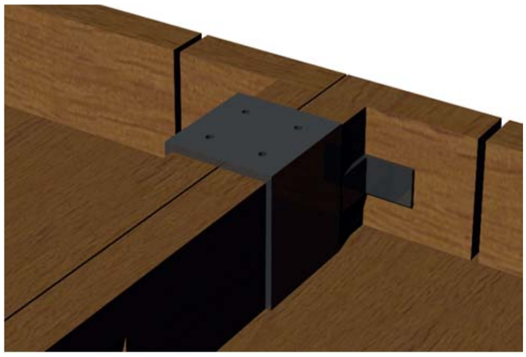
Figure 10.16: bottom connection

Figure 10.17: bottom connection

10.2.2 Upper connection

After the bottom of the foundation modules are connected, the upper connection can be placed. The upper connection is able to take tension, compression and shear forces. After connecting the lower connection, a clamping steel connector is placed over the upper beams of two modules. By its shape it can resist, shear force and tension force. By small openings in the upper beams, the steel connector can be placed in one way, and it makes sure that modules are placed in the right position. After placing the connector, it must be screwed to both upper beams in order to take shear forces.





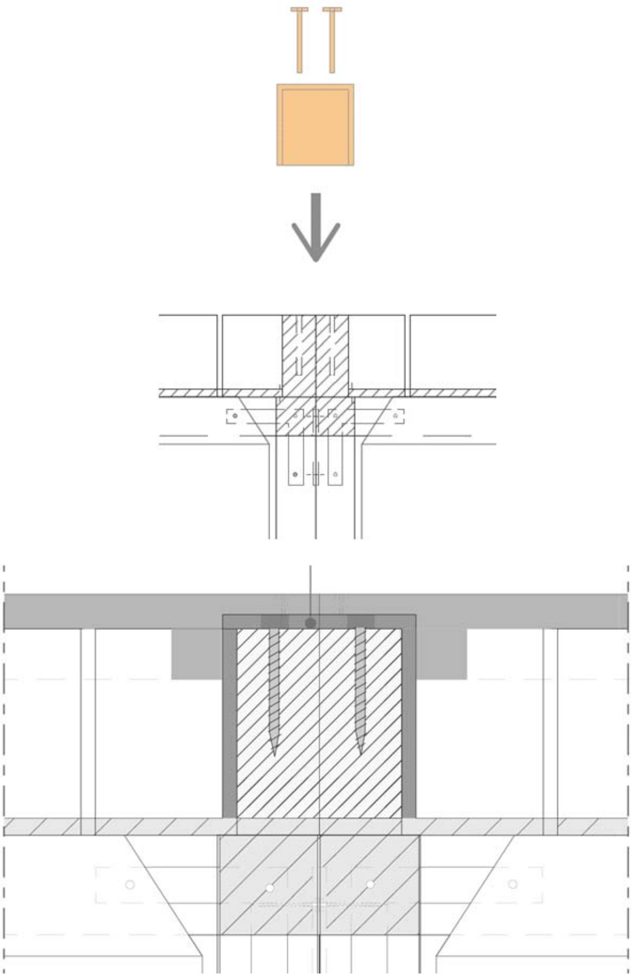
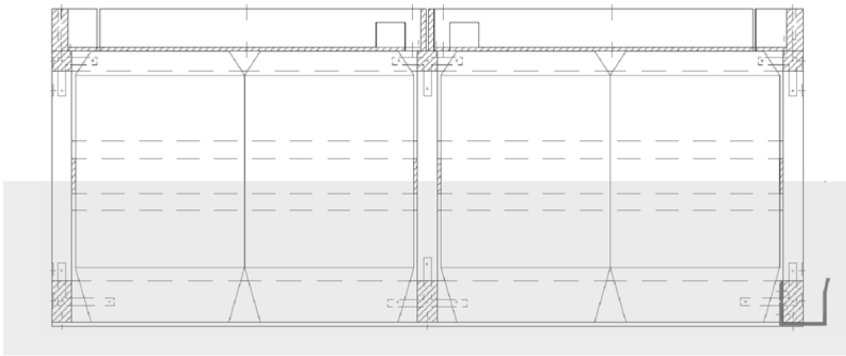


Figure 10.18: upper connection,

In order to connect the centre part of the foundation module, two smaller connections are placed (Appendix II: technical drawings)

10.2.3 Building steps

Step 1: A U-shaped connection can be connected on the timber module in the factory. The module can be transported to the fishpond.



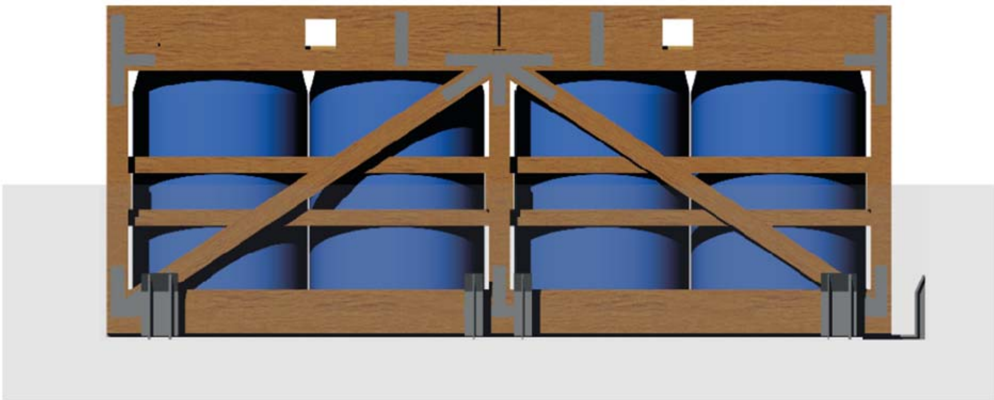


Figure 10.19: module with bottom connection

Step 2a: A second module is brought to a position next to the existing module. By filling some barrels with water, or by simply placing some sand bags on top, the second module will have a bigger draught then the first module. In *appendix II, technical drawings,* more detailed drawings are depicted.

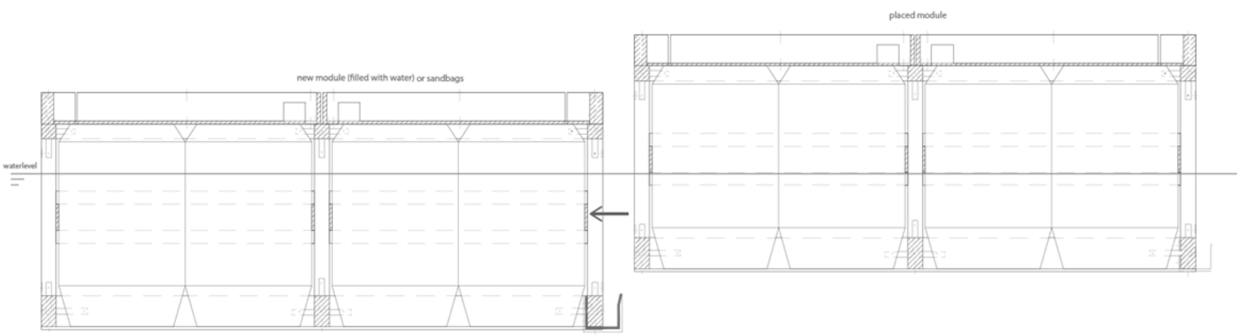


Figure 10.20: placing modules

Step 3a: By pumping water out of the barrels, or by removing sandbags, the module will lift and will be connected to the first module. In order to create a more robust connection, a rubber layer can be placed on the U-shaped profile to protect the connection and the timber structure wrapped in coir foil.

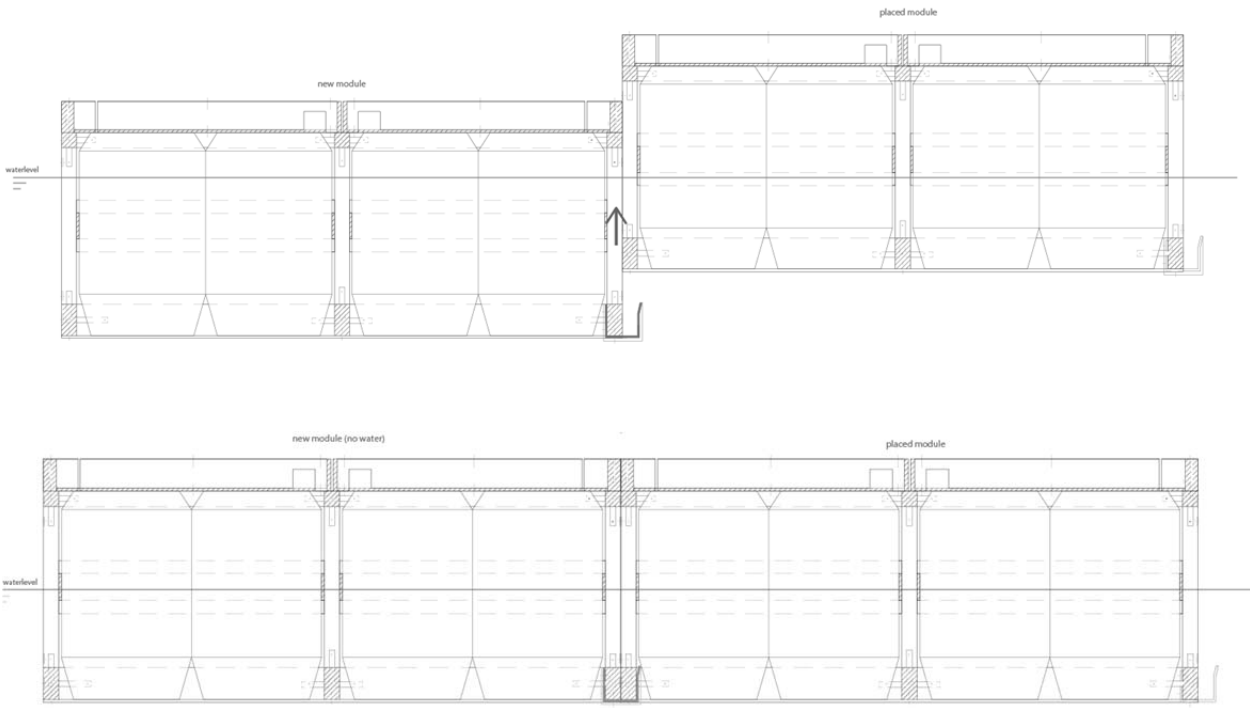
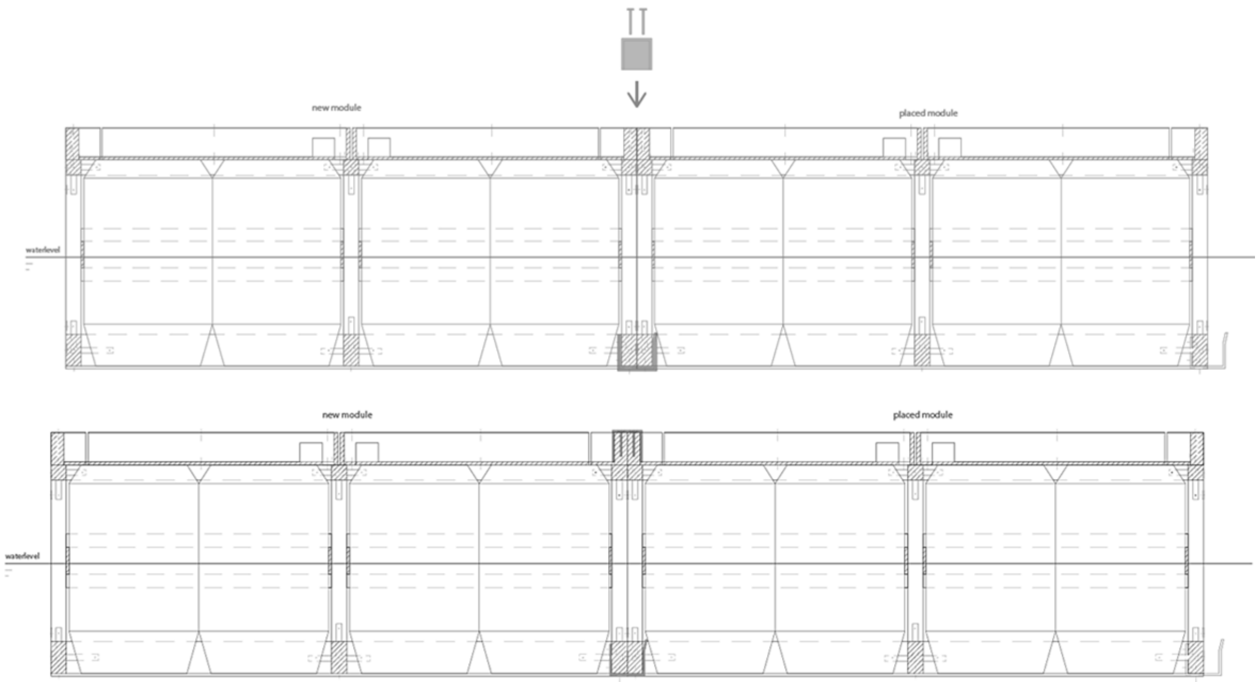


Figure 10.21: coupled modules

Step 2b: An alternative way of placing modules is to not load a second module. Then one module must be pulled over the other in order to fit in the bottom U-shaped connection.

Step 4: Now, the upper connection can be clamped around the upper beams, in order to create the rigid structure. The upper connection must be screwed into both modules.



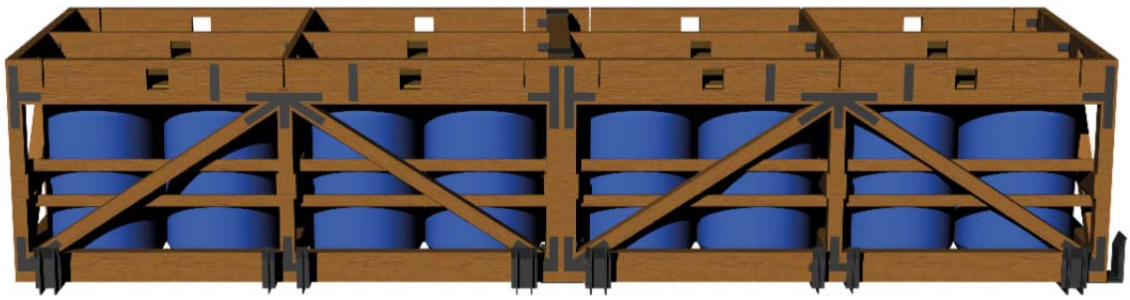


Figure 10.22: connecting upper connection

Step 6: After this connection is fixed, modules can be coupled in the other direction. This process is exact similar to the connection in the described direction. In *appendix II:* drawings of connections in the other direction are shown.

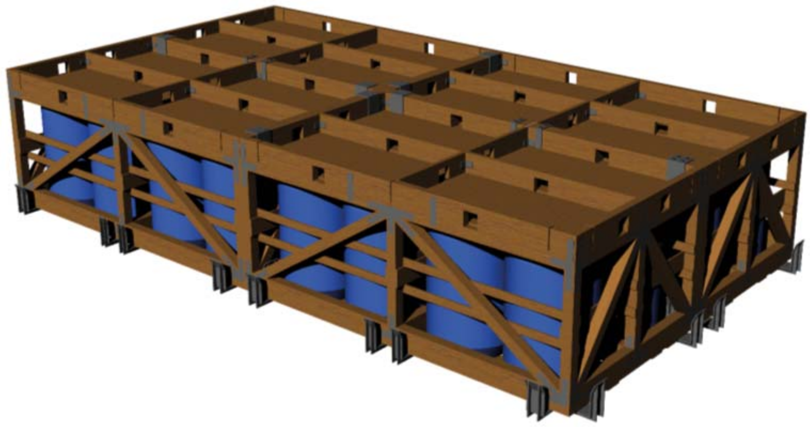


Figure 10.23: coupled modules

Step 7: After the desired amount of modules is connected, the upper plate can be placed. All technical drawings of this placement are attached in appendices II: technical drawings.

10.3 Conclusion

A design for a timber modular structure, filled with barrels is made. This prefabricated design fits building concept -criteria, floating behaviour-criteria, and local-depended criteria in a proper way.

Several measurements are taken for increasing the service life of the foundation modules. Shipworm-protection measurements are never tested, so in order to build this design, tests must be done. Tests can be executed relatively easily by building a small timber element, wrapped in coco fibre, cotton and rice husks and measure the decay over time.

By a relative simple rigid connection system, modules can be connected relatively easily. Modules fit only in one way, so less mistakes during execution are expected. In addition, just a small number of operations is needed. By self-alignment modules can be placed relative precisely.

With this design a proper amphibious foundation can be built, with the goal to contribute to an uplift of the quality of living for inhabitants of Hagonoy, by means of low tech engineering solutions.

Figure 10.24: coupled foundation modules

Chapter 11 Design - Analyses

In this chapter, two case-studies are done, in order to analyse the structural behaviour of the amphibious modular structure.

In the first section two case studies are tested with the parametric calculation model, and with a Matrix Frame model. Outcomes of these calculations are compared. To analyse the structure in all scenarios and to add the influences of waves, a SCIA model is used. This is elaborated in section 2. In the third section structural checks of both the foundation module and the connections are made, with output of the SCIA model. In the fourth section an analysis of the cost of both cases is made. The first case is a foundation with a single building upon it. The second case is a foundation with a configuration of eight buildings on top. In this way as well a small as a large foundation is tested. In addition, these configuration are expected to be built mostly.

11.1 – Parametric model and Matrix Frame

In this section two case studies are analysed; a single building, and a configuration of connected and stacked buildings.

11.1.2 - Case: single building, 9600x9600mm foundation

The first case study is a foundation with a single building. This single building has a length of 4,8m, a width of 4,8 m and a height of 2,7, and a hipped roof with a height of 1,0m. By using the calculating model, it can be concluded that a single building of 4,8x4,8m^2 needs a foundation of 9,6x9,6m^2. In this foundation fits 4 by 8 (=32) foundation modules of 1,2x2,4m^2.

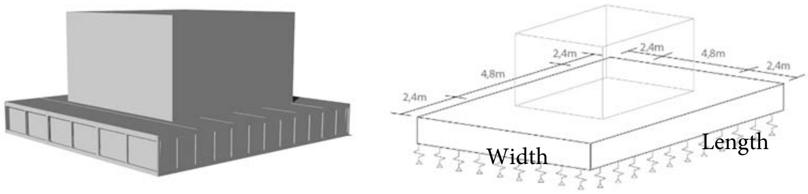


Figure 11.1: single building on amphibious foundation

Output parametric model

The parametric calculation model gives the following output:

Draught = 0,314 m (under self-weight and vertically acting live loads)
Heeling angle = 1,93 ° (under self-weight, vertically acting live loads, eccentric live loads, wind loads, second order effect)
Depth at edge A = 0,152m
Depth at edge B = 0,475 m

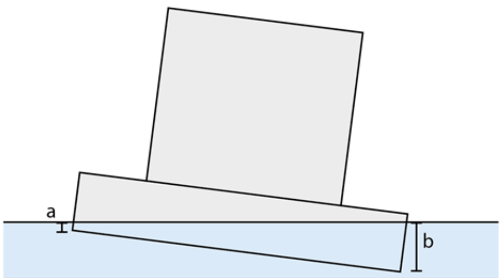


Figure 11.2: tilt

Input Matrix frame

For the Matrix frame model, the structure is schematized as a beam on an elastic foundation.

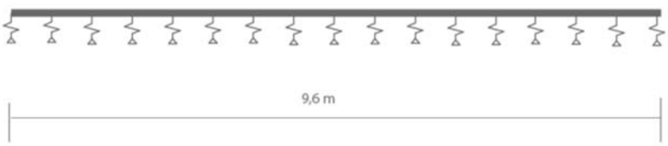


Figure 11.3: schematisation elastic foundation

A calculation for the subgrade reaction modulus K is made. Since there is a certain volume between barrels, where water can flow freely, a certain restriction for the K value must be made. The total area of barrels is calculated. By dividing this by the total area of the floating structure and multiply by $10 kN/m^3$ the new K-value is calculated. Since in this schematized situation a 2d plate is converted to a 1d beam, the K value must by multiplied with the width of the foundation.

K = (mean) area barrels / total area * $10 kN/m^3$
$K = 57{,}74/(9{,}6 * 9{,}6) *10 = 6{,}26 kN/m^3$
$K = 6{,}26 * 9{,}6 = 60{,}15 kN/m^2$

Tension must be eliminated in the Matrixframe model, since the elastic foundation only works on the structure when the foundation is loaded by compression. One can imagine that when a structure will (partly) raise above water level over a certain length L, water does not give any tension nor compression reacting forces in L.

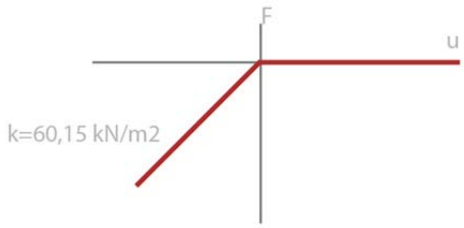


Figure 11.4: modelled spring constant

The structure is schematized as a beam with length L= 9,6m. The EI of the structure comes out of material properties (D40, $E=11000N/mm^2$), and the shape of the structure. Since the structure consists of multiple elements in width, the I of each structural elements is multiplied by the amount of structural elements. Each foundation module consists of three timber trusses with a second moment of area of $I=4435788838 mm^4$. $I = 3 \times 4 \times I_{single} = 5{,}32 \times 10^{10} mm^4$.

The following load cases are checked.

The values of the specific loads, are calculated in the parametric calculation model.

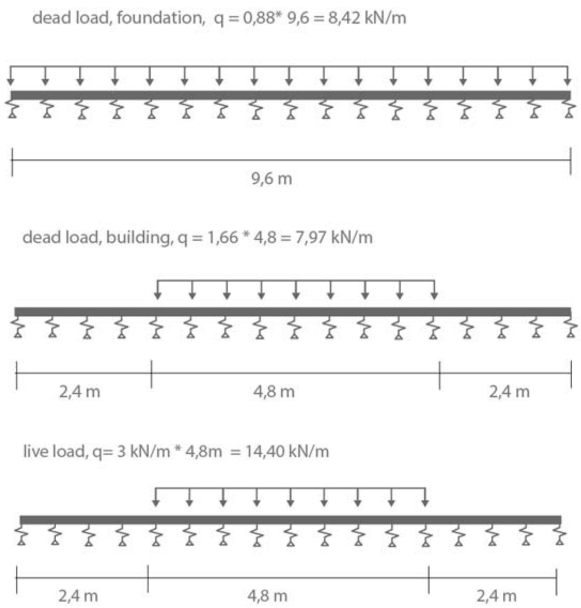


Figure 11.5: load-cases draught

Output Matrixframe

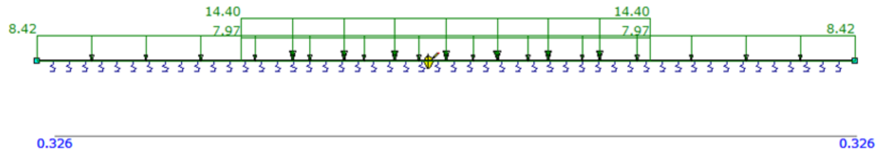


Figure 11.6: matrix frame output

Draught

According to Matrixframe, the draught of this structure configures the draught of the parametric calculation model (0.326 m)

By adding heeling moments, caused by wind, eccentric loading and the second order moment, the foundation will heel under a certain angle. Moments caused by wind and, second order are schematized as a couple of forces acting in opposite direction, acting on the location of the structural facades of the building. The eccentric loading is schematized as a distributed loading over the half of the length of the building.

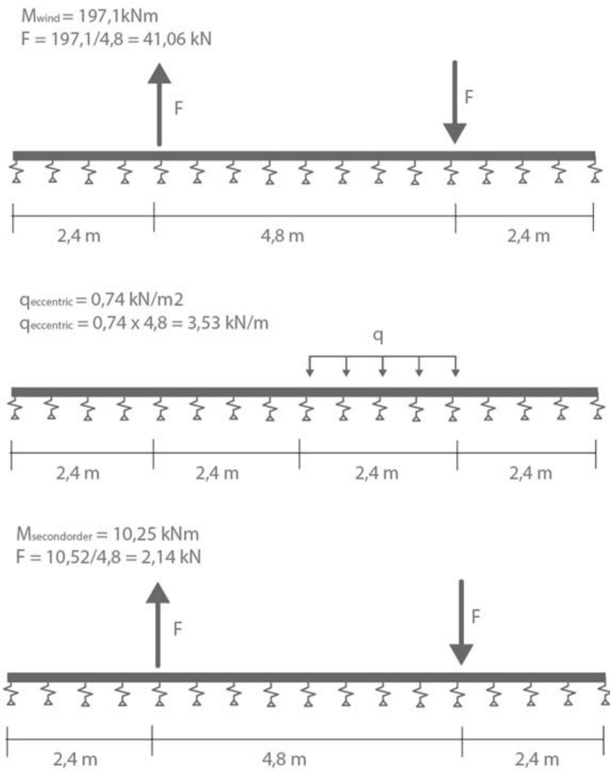


Figure 11.7 loadcases, heeling

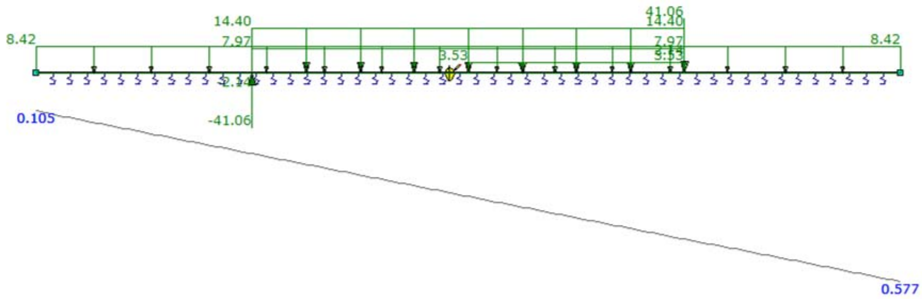


Figure 11.8: matrixframe output

Although the heeling moment equals the heeling moment used in the parametric model, the Matrix Frame model results in a different heeling angle (2,81^{0}) and in different displacements. Reasons for this difference is the way of schematizing the eccentric load by people. Furthermore, at the parametric calculation model, in the calculation of the tilt, water that can move freely between barrels is not taken into account, which makes the Matrix Frame model a more precise method. This heeling angle is checked with SCIA in the section 11.2.

11.1.3 Case 2: 2x2x2 buildings, 14400x14400mm foundation

Now a foundation is tested, on which eight buildings are placed as depicted:

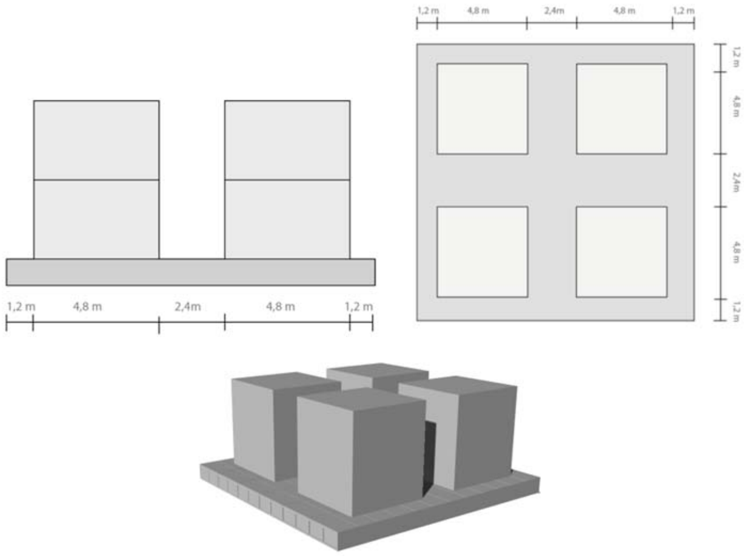


Figure 11.9: configuration of 8 buildings on foundation

By using the calculating model, it can be concluded that this configuration of buildings needs a 14,4 meter wide structure, when the buildings are placed with a spacing of 2,4m. For this foundation 6x12=72 floating modules are needed.

The calculation model gives the following output:

Draught = 0,651 m (under self-weight and vertically acting live loads)
Heeling angle = 3,12 ° (under self-weight, vertically acting live loads, eccentric live loads, wind loads, second order effect)

Depth at edge A = 0,26 m
Depth at edge B = 1,04 m

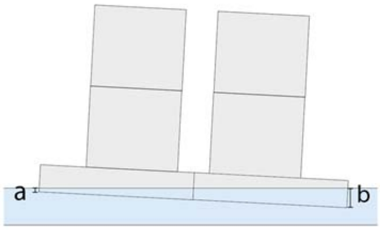


Figure 11.10: tilt

Input matrixframe

The structure is schematized as a beam with length L=14,4m. The EI of the structure comes out of material properties (E=11.000N/mm^2), and the shape of the structure. Since the structure consists of multiple elements in width, the I of each structural elements is multiplied by the amount of structural elements. Each foundation module consists of three timber trusses with a second moment of area of I=4435788838 mm^4.   I = 3 x 6 x I_{single} = 7,98 x 10^{10} mm^4.

For this situation the K value is as follows:

K = (mean) area barrels / total area * 10 kN/m3
K = 57,74/(9,6*9,6) *10 = 6,26 kN/m^3
K = 6,26 * 14,4 = 90,22 kN/m2

The following load cases are tested:

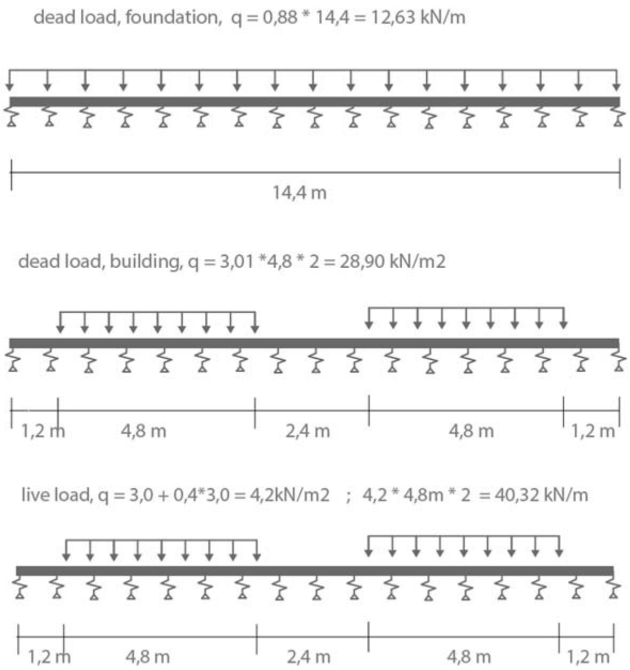


Figure 11.11: load cases, draught

Output Matrixframe:

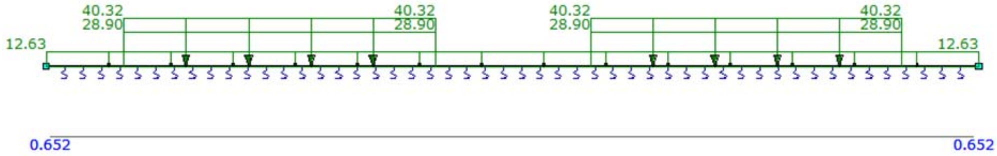


Figure 11.12: matrixframe output

The draught calculated by using Matrix frame, configures the draught calculated in the parametric calculation model. (0,652m)

Since buildings, are connected on each other again, the heeling moments can be schematized as a couple of forces acting on the location of the structural façade.

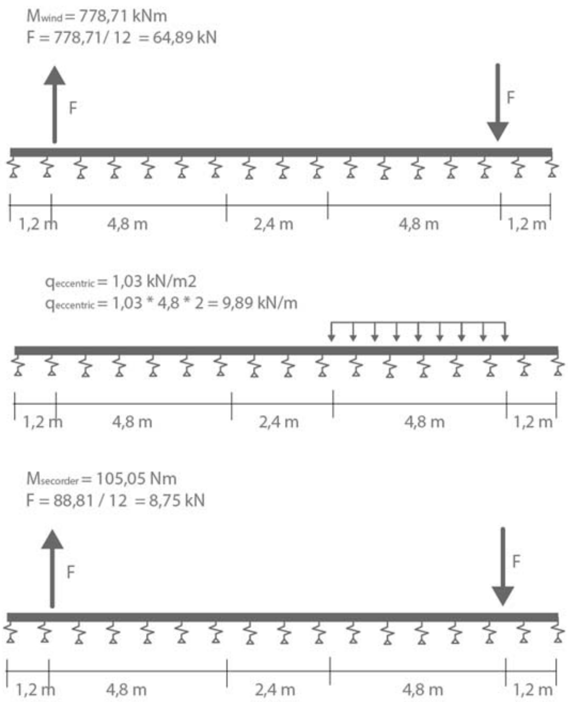


Figure 11.13: load cases heeling

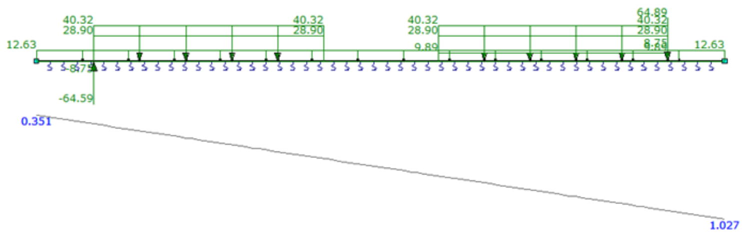


Figure 11.14: matrix frame, heeling

Again these deflection due to a heeling moment do not equal the values calculated in the parametric calculation model.

11.1.4 Conclusion Matrixframe

The parametric calculation model is tested for two cases. In both cases the tilt due to the heeling moment, calculated with Matrix Frame, does not configure the results from the parametric calculation model. In addition, the effect of waves is not taken into account, and this model counts only for the floating-scenario.

11.2 SCIA model

In this section a SCIA model is made in order to get a detailed overview of the structural behaviour of the foundation. In this model, all forces acting on the structure are modelled. Each scenario - dry, just floating and floating – is schematized. Since the almost-floating-scenario is by approximation similar to the dry-scenario, this scenario is neglected. This SCIA model calculates, displacements, maximum bending moments and shear forces. This forms the structural requirements, which the structure must fulfil. Both the connections, between modules, as the module itself, must be able to deal with those maximum forces. A similar case study is done in this SCIA model. First a single building is tested. Hereafter, the configuration with eight buildings is tested.

11.2.1 - Case 1: single building

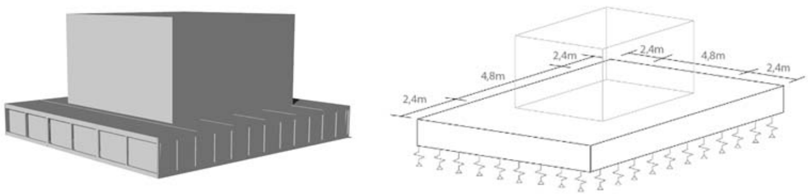


Figure 11.15: single building on amphibious foundation

11.2.1.1 Input Scia

The foundation is modelled as a ribbed plate, with in one direction beams placed with a spacing 0.6m, and in the other direction beams placed on a distance of 1.2m.

Beams are modelled as straight timber ribs with dimensions of 100mmx1000mm.

The timber covering plate has a thickness of 24mm and is connected to the beams in two direction.

All elements have material properties of the timber specie eucalyptus, which is D40.

The foundation is restricted in two corner points. In one, the foundation is restricted in x and y direction, in the other corner point only a restriction in the x direction is added in order to create a stable structure.

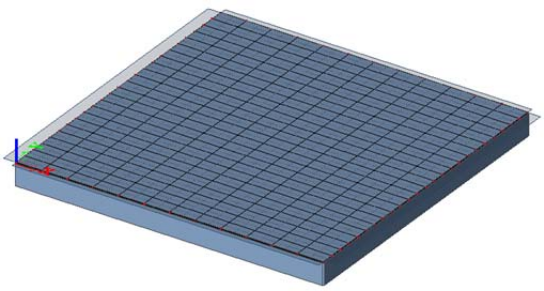


Figure 11.16: modelled foundation

Elastic foundation

In order to model water, an elastic foundation has been modelled. Since tension must be eliminated, a non-linear foundation with a K-value of 6,26 kN/m^3 is modelled. A test is made in order to check the presence of the tension elimination. (appendix 12)

In the dry situation, the same schematizing is used, but the K-value is changed to 30.000 kN/m^3. To schematize a foundation for the just-floating-scenario, an elastic line-support with a K-value of 30.000 kN/m^2 is modelled on the side of the structure that deflects the most.

Figure 11.17: just floating scenario

Loads

All loads act on the building in the weakest direction. In this direction the spacing between structural models is 1,2m.

The **dead load** of the foundation) and **dead loads of the building(s)** are moddeled as distributed forces on the structure. (Appendix 14) Scia model is not considering any modelled self-weight of structures.

A **live load** is distributed over the location of the building.

A **wind load** causes a heeling moment. This heeling moment is modelled as a couple of an upwards distributed line force at the location of the structural façade, and a downwards distributed line force at the other structural façade.

As stated previously, an **eccentric load** must be taken in consideration. The most unfavourable situation is applied.

As well the **second order moment** is modelled as a couple of an upwards pointing and downwards pointing line load at the location of the structural facades.

For a single building, with foundation of 9,6mx9,6m, the wavelength is approximately equal to the length of the foundation. Characteristic values of wind waves are calculated in chapter 8. These wind waves result in distributed loads, which have a value of 4,78 kN/m^2

$$P = 0.955 * 1,599 * 0,5 * 6,26 = 4,78 \text{ kN/m}^2$$

In appendix 14 all load cases are depicted.

Combination

In order to calculate non-linear calculation, non-linear load combinations must be modelled in SCIA. The following load combinations are tested, according NTA8111:

Combi 1: draught
Combi 2: tilt, wind, eccentric, second order
Combi 3: tilt, wind, eccentric, second order, wave 1.1
Combi 4: tilt, wind, eccentric, second order, wave 1.2
Combi 5: tilt, wind, eccentric, second order, wave 1.3
Combi 6: tilt, wind, eccentric, second order, wave 1.4

For the floating situation and just-floating situation, each combination is tested. For the dry situation, only combinations one and two are modelled

11.2.1.2 Output SCIA – Case 1

The most important SCIA output is depicted and explained. In appendix 15 all Scia output is depicted.

Floating – scenario

Load Combination 1: Draught The maximum deflection Uz is -326,4 mm, and the minimum deflection is -327 mm. This configures with values, calculated in the parametric calculation model and in the Matrix frame model.

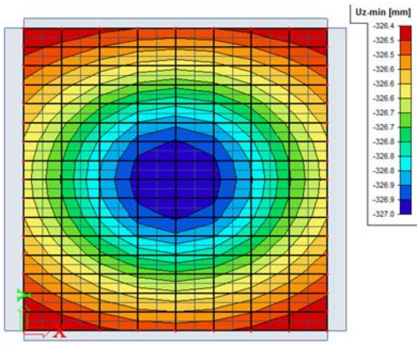


Figure 11.18: U_z Draught

Combination 2 : tilt, wind, eccentric, second order

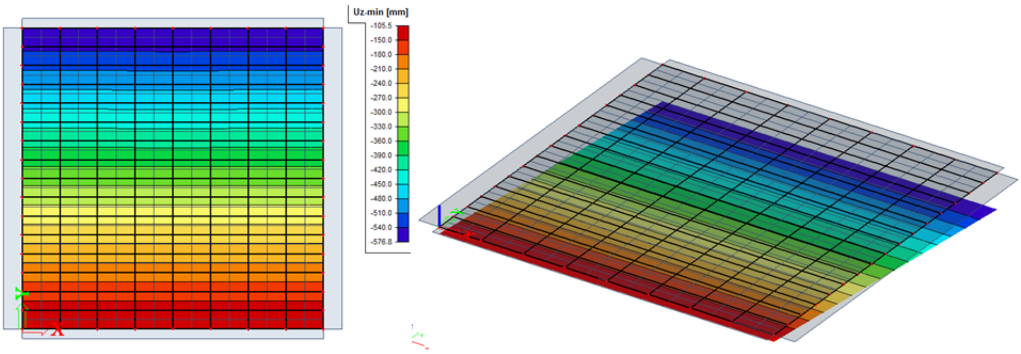


Figure 11.19: U_z, combination 2

The deflection due load combination 2 is -105,5 mm on one side and -567,8 mm on the other side. These values configure with the previously calculated values in Matrix Frame.

Combination 3 : tilt, wind, eccentric, second order, wave 1.1

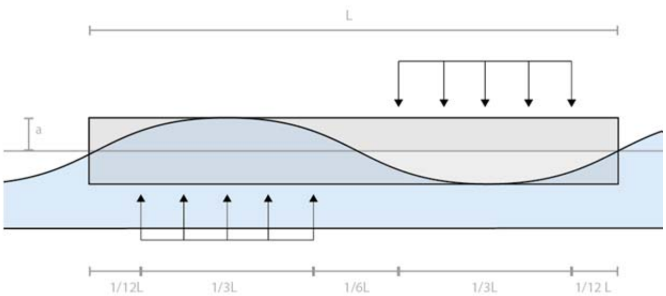


Figure 11.20: wave 1.1

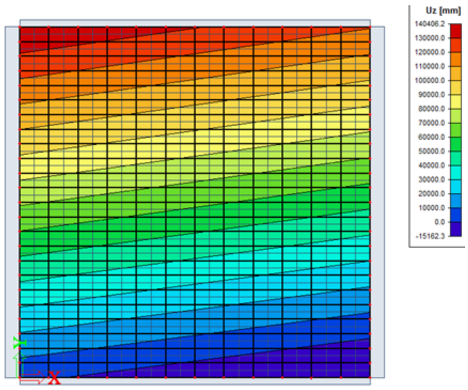


Figure 11.21: Uz combination 3

Due combination 3, an enormous deflection is calculated by SCIA. However, this is not a representative value, it can be concluded that the deflection is too high to provide a liveable situation:

Although its initial stability (the metacentric height = 22,26 m), this structure tilts too much at wave loading. This expected deflection is caused by fact that the length of the structure equals the wave length. For this short length, the foundation has the tendency to move very easily along with the waves. In the parametric calculation model, the Eigen period of heave, and pitch oscillation are calculated; 4,06s (heave) and 0,381 s (pitch/roll). For pitch and roll oscillation this is significantly less than the wave period (3,14s) so the structure is susceptible for oscillation, as concluded in chapter 3.4.6.

The high deflection calculated with SCIA is not a representative value. Since tension is eliminated, the part of the structure on which an upward loading is acting, deflects in positive direction. In this model this part of the structure raises above water level. In this model, wave loading is still acting on the structure. In reality, due to the shape of the wave, the buoyancy force will decrease, when the structure raises. In order to create a more realistic schematization, a model is needed in which parts of the elastic foundation can be translated. The best schematization would be a sinusoidal elastic foundation, upon which the foundation rests. As depicted in figure 11.22.

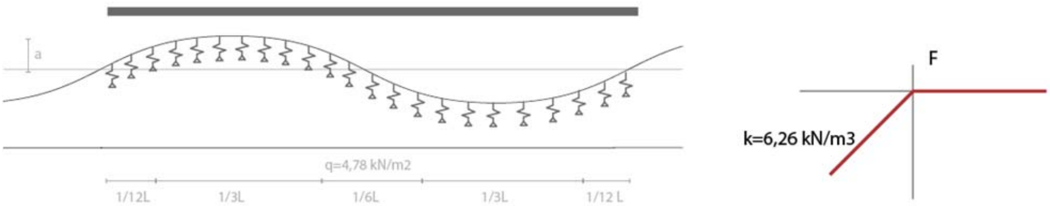


Figure 11.22: translation elastic foundation

This sinusoidal translation of the elastic foundation can be simplified, in a same way as distributed forces due to waves were simplified into block loads.

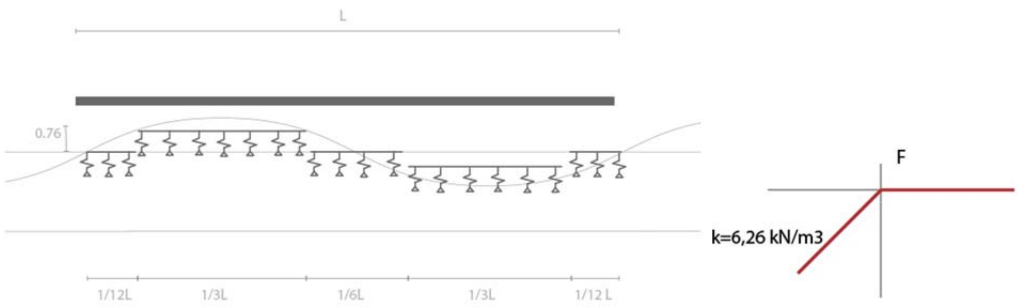


Figure 11.23: schematization

This translation can be gained in SCIA by modelling the non-linear elastic foundation as depicted in figure 11.24. In this situation a crest is acting in part 2, and a through is acting on part 4. The foundation of part 2, works on the structure immediately at a deflection of U=0m. Part 1, 3, and 5, work after a deflection of U=- 0,76 m. The elastic foundation in part 4, works after a deflection of U=-1,52m. The value U=0,76 m is derived by applying the distributed force of 4,78 kN/m3 on the elastic foundation with a Kvalue=6,26 kN/m^3.

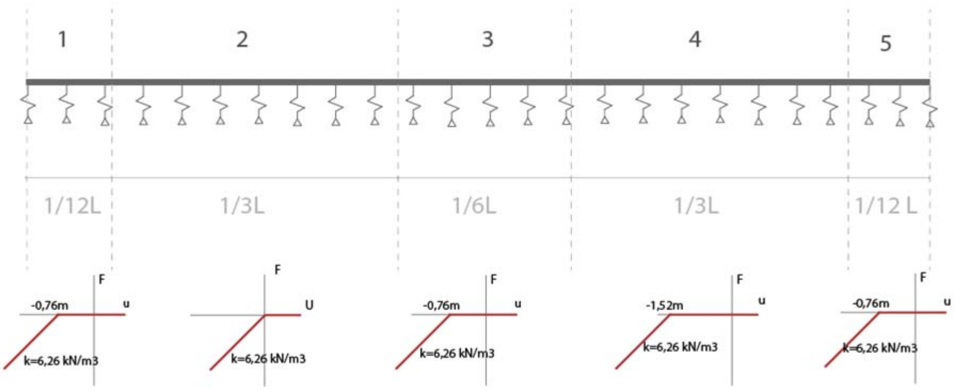


Figure 11.24: schematisation wave

11.2.1.4 Extension

In order to create a more stable structure, the foundation as described in case study 1, is enlarged. The dimensions of this foundation are 12 m x 12m. A building of 4,8m x 4,8m is placed in the centre of this foundation.

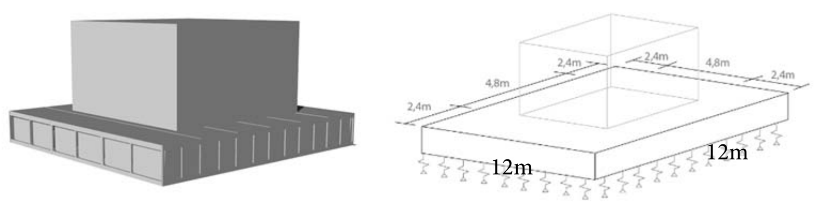


Figure 11.25: single building on amphibious foundation

All previous described load cases act on this structure. Since the wave length – foundation length ratio is changed, other wave load cases are considered. A wave is schematized in a similar way as depicted in figure 11.26.

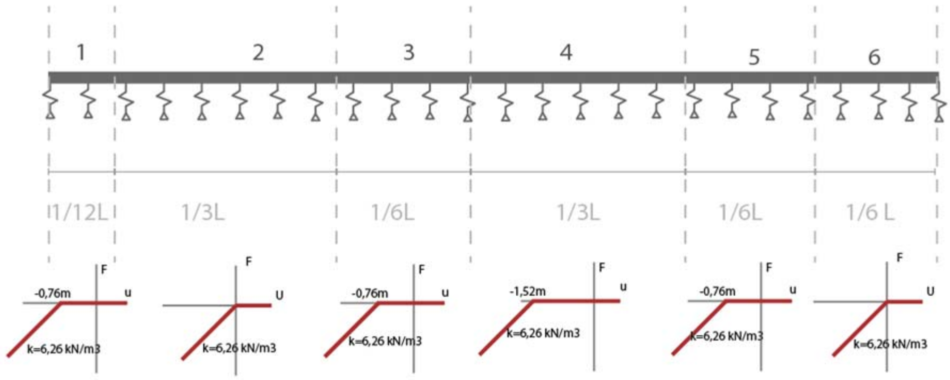


Figure 11.26: schematisation wave

SCIA output

All output is depicted in appendix 15. The most important values are depicted in this section.

Floating

First the draught is calculated and checked with the values calculated with the parametric calculation model. The minimum deflection of -257,7mm and maximum deflection of -259,4 mm are equal to the values out of the parametric calculation model.

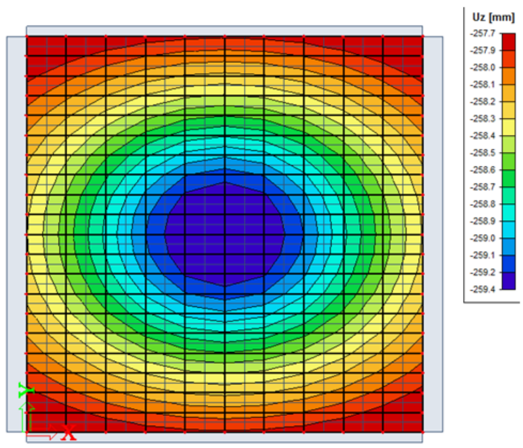


Figure 11.27: draught

Now the most unfavourable situation is load combination 3. The maximal deflection in this situation is: -1092 mm on one side and -338 mm on the other side. Which gives an heeling angle of $3{,}6^0$, which is an acceptable deflection according NTA8111.

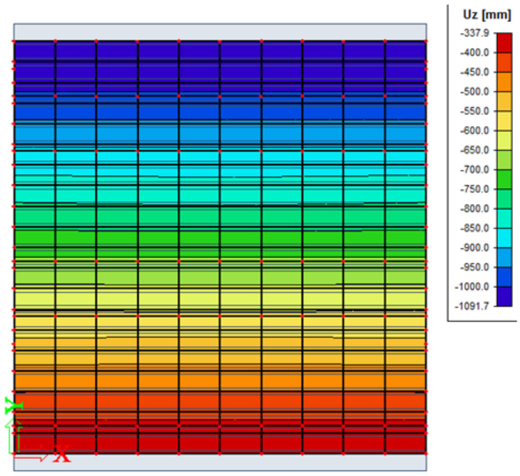


Figure 11.28: Uz, combination 3

Just Floating - scenario

In order to calculate the just-floating-scenario, a non-linear elastic line support with a K-value of 30.000 kN/m^3 is added on the most deflected side. In this schematisation, the structure only touches the soil on the outer edge. In this case, this situation leads to the largest bending moment M and shear force V; 41,66 kNm and 18,95 kN.

In this schematisation, block loads due to waves are schematised. Waves are derived with a water depth of 2,5m. However, this schematization results in overestimated bending moments, and internal forces, since with this deflection, and this water level, the ground is expected not to be touched on one side. In lower water, forces of waves decrease, and the tilting behavior decreases. By means of an iterative process the exact water depth at which the structure is expected to touch the soil. In this thesis this schematization is used. In further research a more detailed calculation can be made, in order to calculate precise forces and moments.

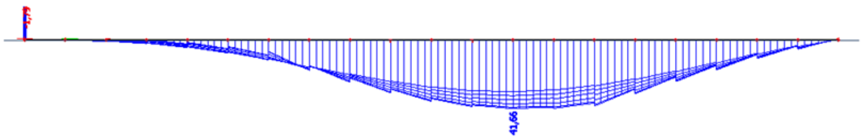


Figure 11.29: maximum M

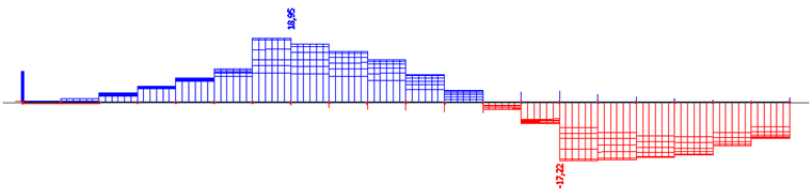


Figure 11.30: maximum shear force V

Dry

The dry situation is schematized as a structure on non-linear elastic soil with a K-value of 30.000 kN/m^3. In this situation load combinations with waves are eliminated. This gives relatively small deflections, bending moment and shear force.

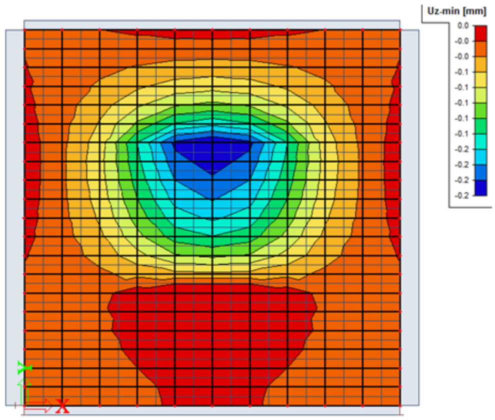


Figure 11.31: draught, dry

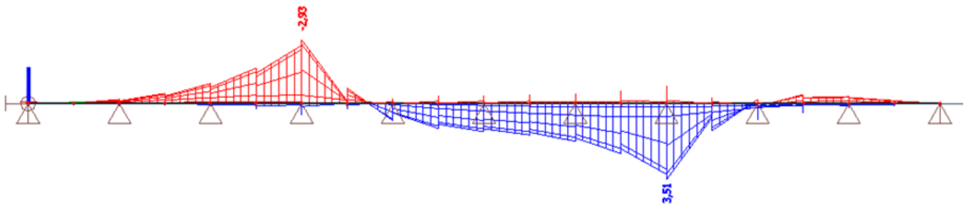


Figure 11.32: M, dry

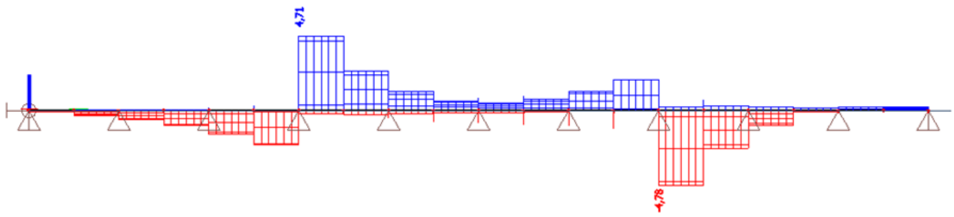


Figure 11.33: V, dry

Conclusion single building

By making a foundation of 9,6 x 9,6m to support a building of 4,8mx4,8m the deflection exceeds the maximum permitted heeling enormously, since the length of the foundation configures the length of the wave. In order to create a more stable structure an extension is made in x and y direction. A foundation of 12mx12m is modeled in order to check whether this extension gives the structure enough stability, in floating position. For these dimensions an acceptable heeling angle is achieved.

11.2.2 Case 2: 2x2x2 buildings, 14400x14400mm foundation

Structure

In this situation a configuration of eight buildings is placed on the foundation. Two stories of four buildings with dimension of 4.8m x 4.8m are placed with a spacing of 2,4m from each other. Between the edge of the foundation and the façade a distance of 1,2 m is created.

The foundation is again modelled as a ribbed plate, with in one direction beams placed with a spacing 1.2m, and in the other direction beams placed on a distance of 2.4m.

Apart from the dimensions of the foundation, other input is the same as for the previous case.

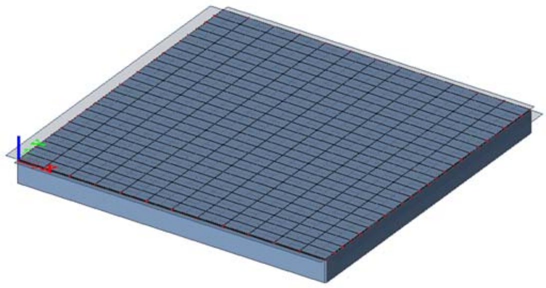


Figure 11.34: modelled foundation

Loads

Since the buildings upon the foundation are structurally connected in two directions, the heeling moment due wind and second order is modelled as a line load pointing upwards at the outer façade of the buildings and as a line load pointing downwards at the other façade.

Multiple wave situation can be calculated. For this structure a wave length of 9,6 m and a length of 11,52 m are modelled in order to find the extreme situation. Waves are modelled as block loads.

The load combinations as described in appendix 14 have been calculated, with a non-linear calculation in order eliminate tension.

Combi 1: draught:	BG1, BG2, BG3
Combi 2: tilt, wind, eccentric, second order:	BG1, BG2, BG3, BG4, BG5, BG6
Combi 3: tilt, wind, eccentric, second order, wave 1.1:	BG1, BG2, BG3, BG4, BG5, BG6, BG7
Combi 4: tilt, wind, eccentric, second order, wave 1.2:	BG1, BG2, BG3, BG4, BG5, BG6, BG8
Combi 5: tilt, wind, eccentric, second order, wave 1.3:	BG1, BG2, BG3, BG4, BG5, BG6, BG9
Combi 6: tilt, wind, eccentric, second order, wave 1.4:	BG1, BG2, BG3, BG4, BG5, BG6, BG10
Combi 7: tilt, wind, eccentric, second order, wave 2.1:	BG1, BG2, BG3, BG4, BG5, BG6, BG11
Combi 8: tilt, wind, eccentric, second order, wave 2.2:	BG1, BG2, BG3, BG4, BG5, BG6, BG12
Combi 9: tilt, wind, eccentric, second order, wave 2.3:	BG1, BG2, BG3, BG4, BG5, BG6, BG13
Combi 10: tilt, wind, eccentric, second order, wave 2.4:	BG1, BG2, BG3, BG4, BG5, BG6, BG14
Combi 11: tilt, wind, eccentric, second order, wave 2.5:	BG1, BG2, BG3, BG4, BG5, BG6, BG15
Combi 12: tilt, wind, eccentric, second order, wave 2.6:	BG1, BG2, BG3, BG4, BG5, BG6, BG16

Floating

First the draught (deflection due to load combination 1) is calculated. These values (651,7 mm and 652,8 mm) configures with the draught calculated in the parametric model and with Matrixframe.

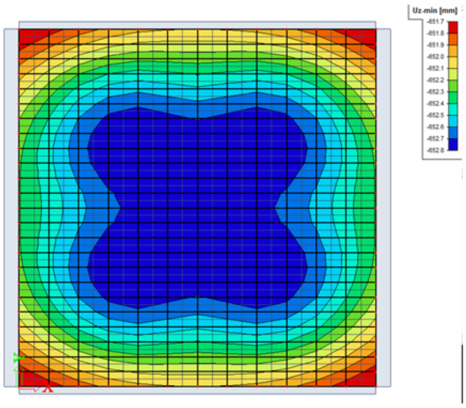


Figure 11.35: draught

The maximum deflection occurs when the structure is loaded by load combination 2.1. In this situation the deflection is -21,4mm on one side and -1146,7 mm on the other side. This means a heeling angel of 4,46 °.

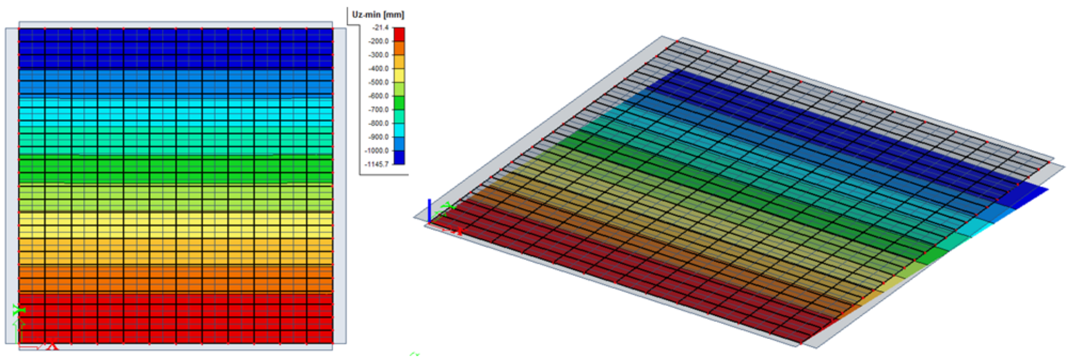


Figure 11.36: U_z, combination 2.1

Under a three-second wind gust the deflection increases to 5,0 ^{0}

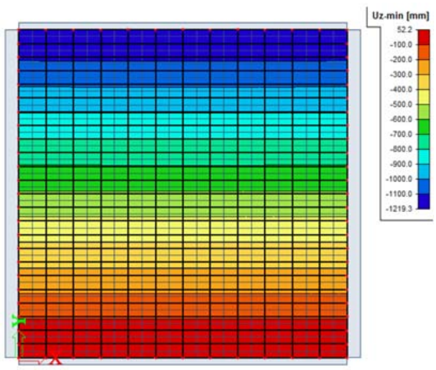


Figure 11.37: U_z, combination 2.1- 3 seconds wind gust

In this situation the tilt exceeds the maximum allowed tilt of 4°. (NTA8111) The oscillation period for both heave, and pitch are smaller than the wave period, so expected is that this heeling angle of 4,46^{0} under a 10-minute average wind gust, and a 5,0^{o} under a 3-second wind gust will be obtained. In these building codes (NTA8111) tilt due to typhoon winds are not taken into consideration.

However, in this situation the damping behavior of this structure is not taken into account. A rigid connection is often not fully rigid due to the small occurring deflections in connections. These deflections lead to a decrease of the heeling angle. (chapter 3.7) Extra foundation modules can be added in order to decrease the tilt. However, this leads to increased costs. This tilt of 5,0° due to the strongest typhoon is expected to occur about once a year. Consequently this exceedance is ought to be acceptable.

In this scenario a maximum negative bending moment occurs, due to a hogging moment (wave 2.4) In this situation M=-30,07 kNm

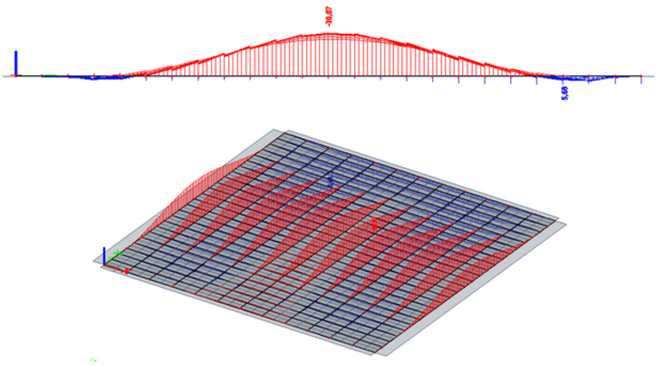


Figure 11.38: M_y

Dry

For the dry situation an elastic foundation with a k-value of 30.000 kN/m^3 is modelled. The structure experiences relatively low deflection (-0,2mm), bending moments (2,25 kNm) and shear forces (3,71kN) in this situation.

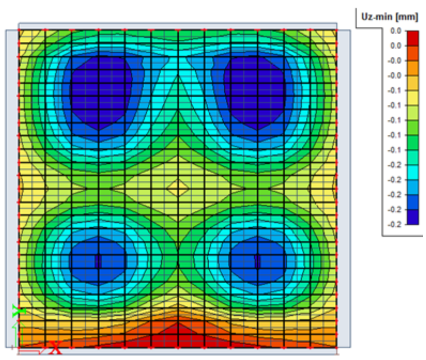


Figure 11.39: Uz, dry

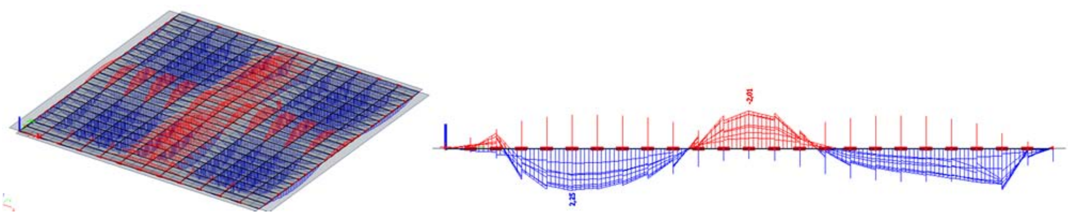


Figure 11.40: M_y, dry

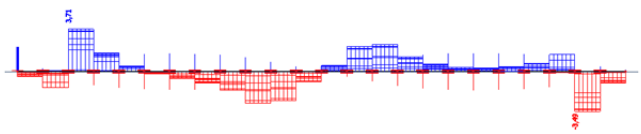


Figure 11.41: V_z: dry

Just floating

The just floating situation touches the ground at one side of the foundation, so an elastic line support with a subgrade modulus of 30.000 kN/m^2 is modelled.

The most unfavourable situations are depicted below. The maximum bending moment occurs under load combination 2.1 and has a value of 67.74 kNm.

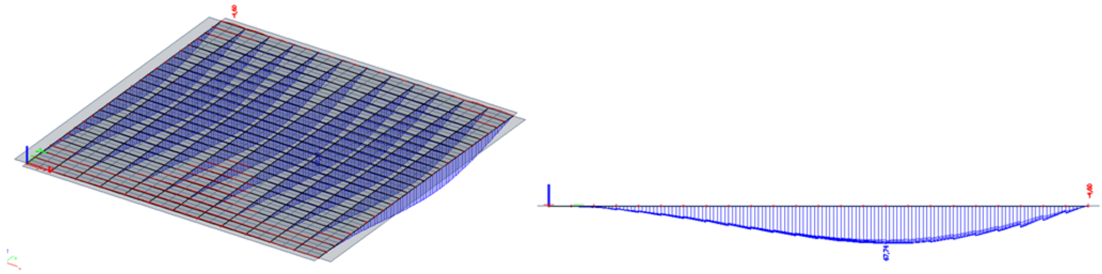


Figure 11.42: Maximum M, combi 2.1

The largest shear force occurs under load combination 2,6 and has a value of -29,11 kN.

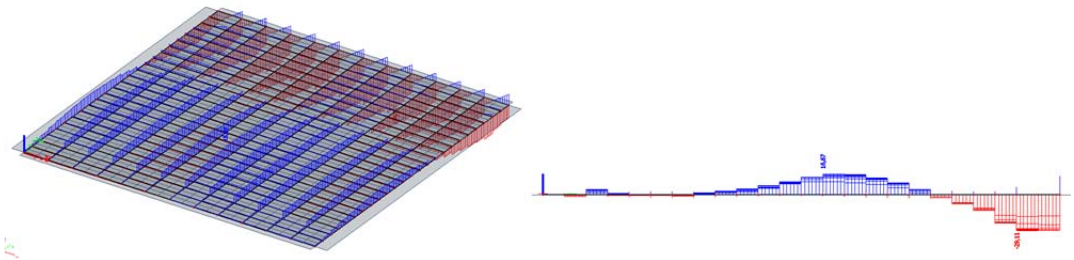


Figure 11.43: Maximum shear force

In this schematization, block loads due to waves are schematised. For the same reason as described in paragraph 11.2.1 an overestimation has been made.

Conclusions case 2x2x2 buildings, 14400x14400mm foundation

In this configuration the length and width of the foundation, is significant longer than the wave length. Hereby a much more stable structure is created. However, this structure gives the largest bending moments and shear forces, when it touches the soil on one side.

11.2. Conclusion SCIA Model

The largest deflections occur at the smallest foundation, mainly due to wave loads. These deflections can be lowered by extending the foundation. So the ability of extensions, in the design of the amphibious structure is a large advantage.

The way of schematizing wave loads as distributed block loads works for structures that are significantly larger than the wavelength. For smaller structure this schematisation works not optimally. A better schematisation can be gained by translating the elastic foundation in z-direction.

All scenarios have been studied for two cases. The highest internal forces occur in the configurations with eight buildings on top, in a just floating situation.

The maximum bending moment in a truss is **67,74 kNm**

The maximum negative bending in a truss is -**30,07 kNm**

The maximum shear force in a truss is **-29,11 kN**

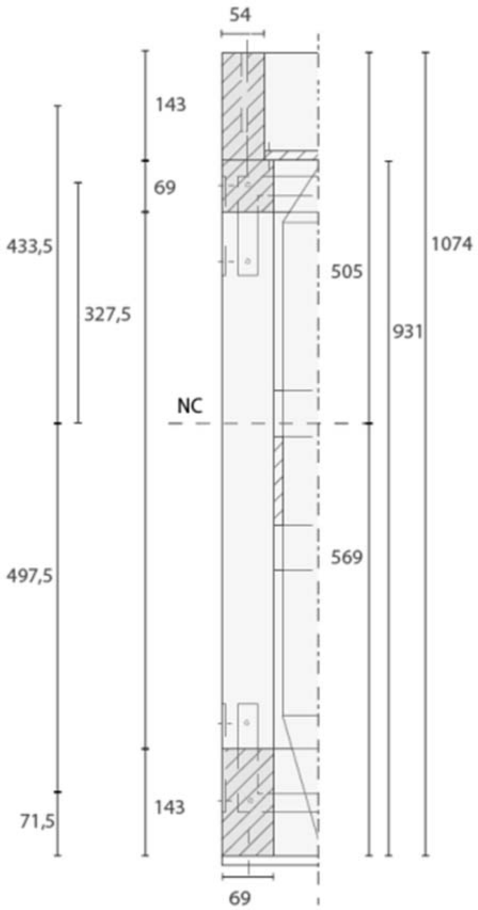
These values are the most important values to base dimensions of the timber modular foundation and the connection between the modules on, in order to design a rigid foundation. All configurations which are equal or smaller than a 14,4x14,4 m2 foundation can be executed in these dimensions.

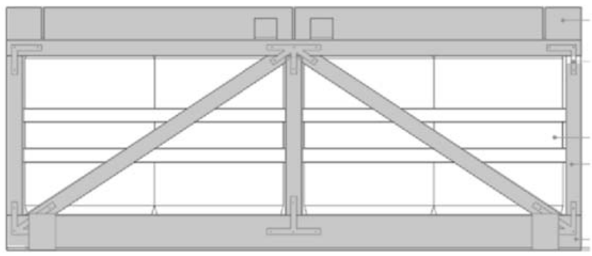
11.3 Structural analysis

In order to design a rigid structure, the foundation modules and the connections must withstand the previously calculated loads. In the first paragraph the timber structure of the modular foundation is checked. Secondly, the structural behaviour of the connections is checked.

11.3.1 Structural check - timber structure

The maximum forces that can occur, and the structure must withstand, are a positive bending moment of 67,74 kNm, a negative bending moment of-30,07 kNm, and a maximum shear force of 29,11 kN. Besides those values, normal forces can act on the structure, by horizontal forces caused by wind and by wind waves. For the configurations with eight buildings upon the foundation the total horizontal force due to wind and waves is 172,93 kN. This force is distributed over six modules in width, with each three timber trusses. The total horizontal force is then 9,57 kN per truss. These horizontal forces are calculated with the parametric calculation model.





The section of the timber frame has the dimensions as depicted.

$I = 4435788838\ mm^4$

$A = 22350\ mm^2$

The design strength values of the timber specie Eucalyptus grandis (D40) :

$K_{mod} = 0,7$

$\gamma_{m.} = 1,1$

$f_{t;k}= 24\ N/mm^2$ $\quad f_{t;d} = 0,7 \times 24 / 1,1 = 15,27\ N/mm^2$

$f_{c;k}= 26\ N/mm^2$ $\quad f_{c;d} = 0,7 \times 26 / 1,1 = 16,55\ N/mm^2$

$f_{v;k} = 3,8\ N/mm^2$ $\quad f_{v;d} = 0,7 \times 3,8 / 1,1 = 2,41\ N/mm^2$

Figure 11.42: section timber structure

The bending moment causes tension in the lower beam of the truss and compression in the upper beams. The maximum tension stress in this structure due to bending moment is calculated:

$$\sigma_t = (M * s) / I = 67,74*10^6 * 569 / 4435788838 = 8,69\ N/mm^2$$

The maximum compression stress in this structure due to bending moment is calculated:

σ_c = (M * s) / I = 67,74*10^6 * -505 / 4435788838 = -7,71 N/mm^2

The normal forces causes compression stress in both the upper beam as the lower beam.

σ_n = N/A = -9,57*10^3 / 22350 =-0,43 N/mm^2

The total maximum tension stress is:

σ_t = 8,68 – 0,43 = 8,25 N/mm^2

The total maximum compression stress is:

σ_c = -7,71 – 0,43 = -8,14 N/mm^2

The maximum shear force in the section:

τ_{max}= (3·V) / (2·A)

τ_{max} = (3·29110) / (2·22350) = 1,95 N/mm^2

Verification:

Tension: UC = 8,25 /15,27 = 0,54 < 1

Compression UC = 8,14 / 16,55 = 0,49 < 1

Shear: UC = 1,95 / 2,41 = 0,81 < 1

Since the lower beam is under compression, it is tested for buckling. The maximum compression force in the lower beam is 76,11 kN:

F=M/a
F= 67,74 / 0,89 = 76,11 kN

Buckling:

F_{max} = π^2 EI/ l^2 (l_c = 2400)

I = 16814190 mm^4

F_{max} = 317 kN > 76 kN

Normal force due to shear force acts on the diagonals:

N = 45,47 kN (goniometric)

σ_c = 45,47 * 10^3 / (69*69) = 9,55 N/mm^2

UC = 9,55 / 16,55 = 0,58

Check for buckling.

F_{max} = π^2 EI/ l^2 (l_c = 1560)

I = 1888926 mm^4

F_{max} = 84 kN > 45,47 kN

Additionally a connection between timber elements of the module itself is analysed, in order to create an insight in dimensions of these connections. For this calculation a corner joint has been calculated, since in this joint a maximum tension force of 76,11 kN can occur.

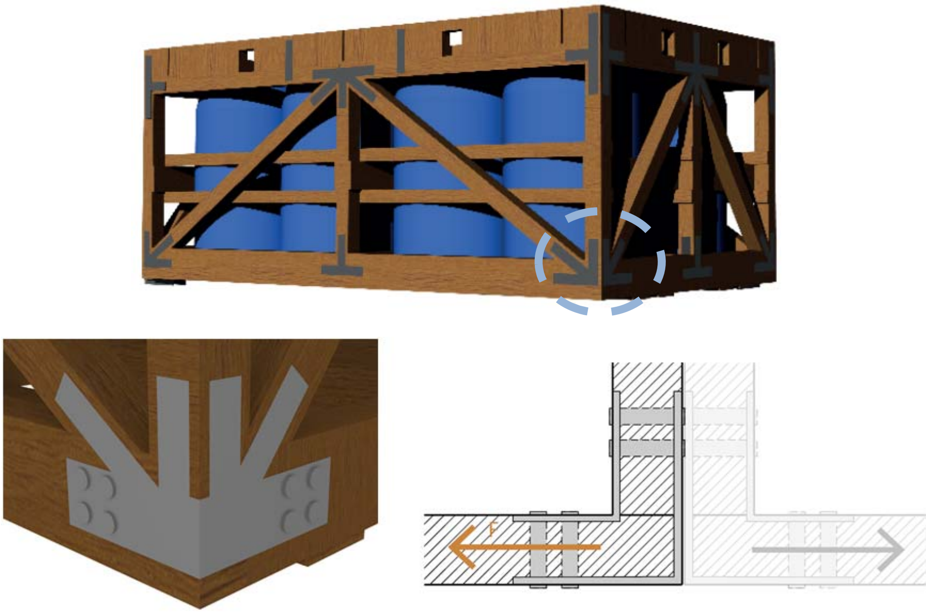


Figure 11.44: connection between timber beams

On both the inside and the outside of the structure a stainless steel plate is mounted with four stainless steel bolts.

F = 76,11 kN

Single strip : 60 * 6 = 360 mm^2

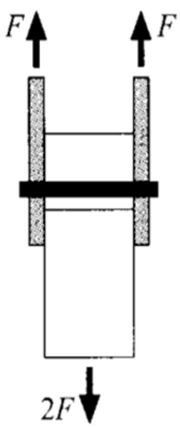
Hole for screw = 14 * 6 * 2 = 168 mm^2

Two strips: 2* (360 – 168) = 384

Effective area = 432 mm^2

76,11*10^3 / 384 = 198 N/mm^2

Two fail mechanism, which can occur are tested:



1)

$R_d = f_{hd}\ t_1\ d$

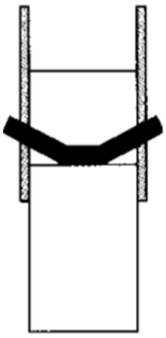
$f_{h,d} = 0{,}082\ (1\text{-}0{,}01\ d) * \rho_k * k_{mod} / \gamma_M = 0{,}082\ (1\text{-}\ 0{,}14) * 590 * 0{,}7 / 1{,}1 = 26{,}47$ N/mm^2

t_1 = 69 mm

d = 14 mm

R_d = 26,47 * 69 * 14 = 25,57 kN

Four dowels: $R_{d,total}$ = 4* 22,32 kN = 89,76 kN > 76,11 kN



2)

$R_d = 1{,}1 * \sqrt{(2\ M_{y,d}\ f_{h,d}\ d)}$

$M_{y,k} = 0{,}8\ f_{u,k}\ d^3/6 = 0{,}8 * 400 * 14^3/6 = 146347$ N/mm

$M_{y,d} = 146347 / \gamma_M = 133042$ Nmm

$R_d = 2 * 1{,}1 \sqrt{(2 * 133042 * 26{,}47 * 14)} = 21{,}8$ kN

$R_{d,total} = 21{,}8 * 4 = 87{,}38$ kN > 76,11 kN

Figure 11.45: fail mechanisms

Hereby it is proved that the structure is able to withstand the maximum occurring moments, normal forces, and shear forces. A reduction in dimensions can be gained, since dimensions are based on the previous described over estimated schematisation. A reduction in price can be gained, and a reduction in weight can be gained to create a lighter and more manufacturable structure. However, the actual behaviour of waves in typhoon areas is not predicted precisely, nor is the performance of the coir foil around structural elements, so for now a certain over dimensioning is recommended.

11.3.2 Structural check - connection

In order to design a proper rigid connection, the structural behaviour of the connection between foundation modules is calculated. The connection must be tested for a maximum bending moment of 67,74 kNm and a maximum shear force of 29,11 kN.

Both connections (upper and lower one) must be able to take tension and compression in order to take a positive and a negative bending moment. Compression is taken by the module itself. Connections between modules take tension forces.

Lower connection

A bending moment of 67,74 kNm leads to a maximal tension force of 76,11 kN. This forces lead by eccentricity to a moment in the connection.

$$M=F*a = 76{,}11 * 0{,}0715 = 5{,}44 \text{ kNm}$$

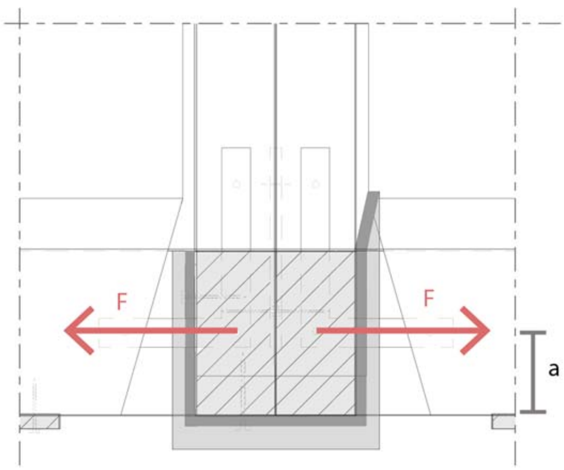


Figure 11.46: lower connection

In order to give the U-shaped profile its strength, two reinforcement strips are added. Perpendicular placed steel plates are added in order to raise the second moment of area I from 5120 mm^4 to 1382400 mm^4. In contradiction to the upper connection, the extra steel plates are placed on the outside, since an inside plate makes the placement of the modules more complex and less robust. By placing two plates instead of one, shorter plates can be used, which is preferred because of the presence of barrels. Figures 11.47-11.50 show the profile, its dimensions and its properties.

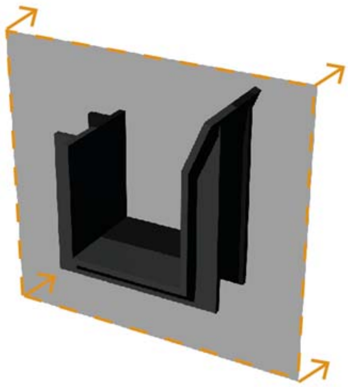


Figure 11.47: section 1

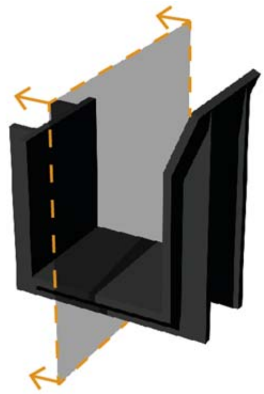


Figure 11.48: section 2

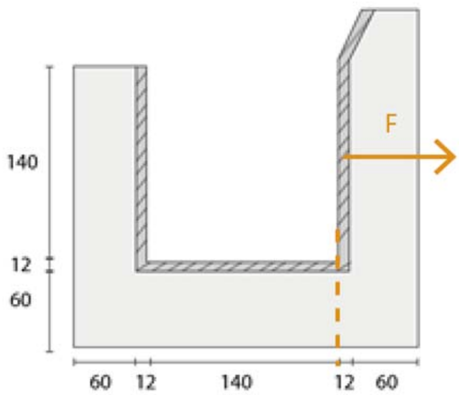


Figure 11.49: section 1

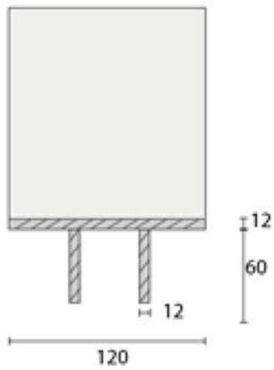


Figure 11.50: section 2

In order to check the capacity a check for bending is made:

I=1382400 mm^4 (right section)

A= 2880 mm^2

The normative calculation is as follows:

$\sigma = M * z / I = 5{,}44 * 10^6 * 60{,}89 / 1382400 = 196\ N/mm^2$

UC=196/235 = 0,83

Upper connection

The upper connection must be able to take shear force, tension and compression forces.

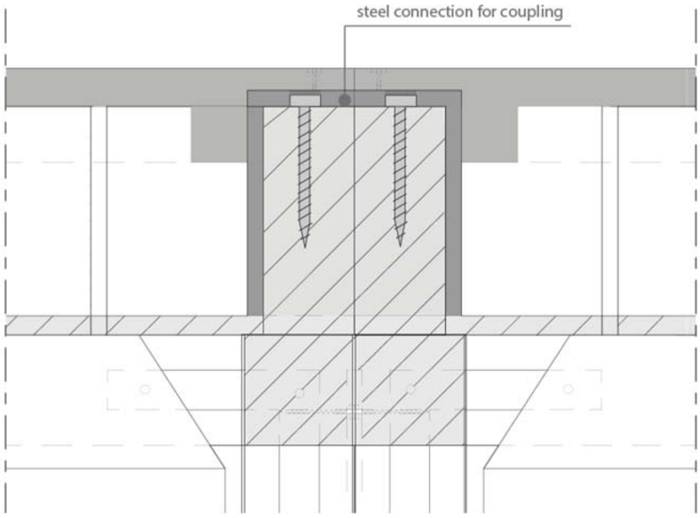


Figure 11.51: upper connection

The upper connection has a T-profile in section (figure11.53, 11.55) The following figure shows the profile, its dimensions and its properties.

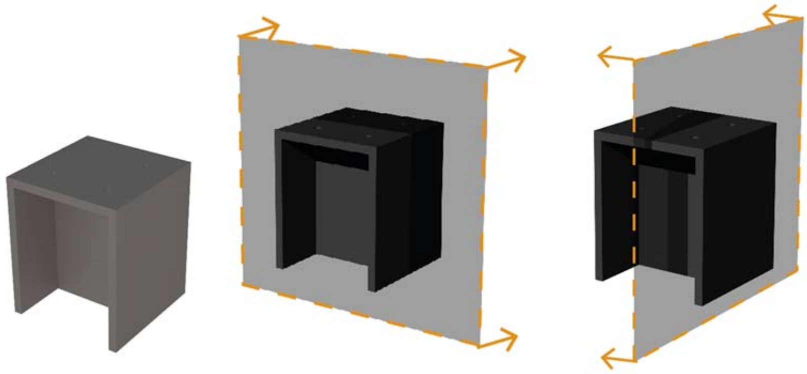


Figure 11.52: section 1 *Figure 11.53: section 2*

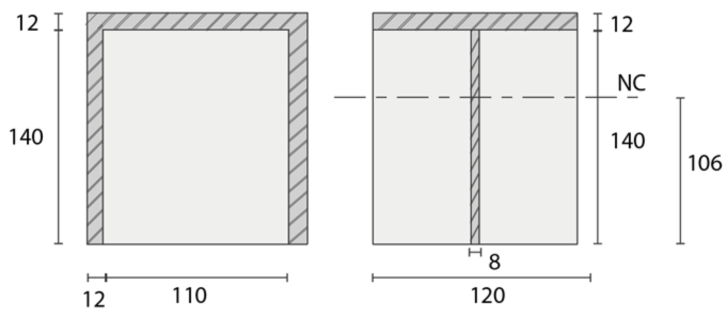


Figure 11.54: section 1 *Figure 11.55: section 2*

Maximum forces leads by eccentricity to a moment in the connection. The maximum tension in the connection of 33,79 kN is due to a bending moment of-30,07 kNm

F=M/a

F= 30,07/ 0,89 = 33,79 kN

Tension causes by its eccentricity a moment of

$M=F*a = 33{,}79 * 0{,}106 = 3{,}58$ kNm

$I= 4929997$ mm^4 (right section)

$A= 2464$ mm^4

$\sigma = M * z / I = 3{,}58 *10^6 * 106 / 4929997 = 77$ N/mm^2

UC=77 /235 = 0,33

Shear force

Shear force will be taken only by the upper connection:
The area of the connection that will take the shear force has a value of A=2464 mm^2

$\tau = V/A = 29{,}11*10^3/ 2464 =13{,}84$ N/mm^2

UC=13,84/234= 0,06

In addition shear force causes a moment of 29,11 * 0,055 = 1,60 kNm

$\sigma = M * z / I = 1{,}60 *10^6 * 106 / 4929997 = 34{,}4$ N/mm^2

UC = 34,4/235 = 0,15.

Screws

The upper connection is screwed to the upper beam in order to take the shear force. The (stainless steel) screws are only needed to take shear force, since in tension and compression screws will not have any influences.

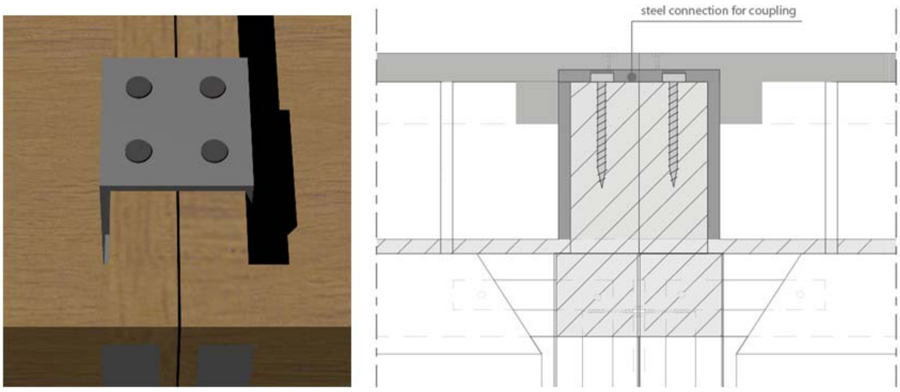


Figure 11.56: screws upper connection

$R_d = f_{3,d} (l_{ef} – d)$

$f_{3,d} = k_{mod}\, f_{3,k} / \gamma_m$

$f_{3,k} = (1{,}5 + 0{,}6\, d) \sqrt{(\rho_k)}$

d= the screw diameter = 10 mm

l_{eff} = is the threaded length in mm in the member receiving the screw = 120 mm

ρ_k = the characteristic density = 590 kg/m^3

$f_{3,k}$ =219 N/mm^2

$f_{3,d}$ = 140 N/mm^2

R_d = 15,4 kN

By connecting the steel plate with two screws per beam a shear force of 30,8 kN can be taken.

UC = 29,11/30,8 = 0,94 < 1

Hereby it is proved that the connections are able to withstand the maximum occurring moments, normal forces, and shear forces.

11.4 Cost analysis

The affordability determines if the modular foundation and so the entire building can be built on large scale. Since the target group is the low income class the building needs to be relatively cheap. The local parameters concerning affordability are discussed, followed by certain price assumptions. The affordability is estimated and options for optimisation are mentioned.

As mentioned previously, the target cost price of the entire building is $6700.

In order to estimate the cost of the total building, the cost of all factors involving the building costs should be known. Several cost estimations have been made. Three main factors influence the total cost of the building: material prices, labour prices and transport prices. Cost assumptions concerning these factors are discussed.

11.4.1 Estimation costs

Material price

The largest percentage of the total cost of the building is the material cost. Material prices in the Philippines are generally cheaper than in the Netherlands. From certain characteristic materials the local prices in Hagonoy have been collected.

Structural timber

Eucalyptus Grandis is used as structural timber. The cost of machining rough logs into sawn timber is $100/m^3, which results in a total cost of $330/m^3 for sawn Eucalyptus Grandis timber. In order to allow some price differences and to calculate a conservative total cost, the cost of sawn Eucalyptus Grandis timber is estimated to be $500/m^3.

Plastic 200L barrels

Several parties in the manila bay area offer new and recycled 200 L barrels. The cost of barrels is currently around $7,-
.

Connections

The connections which are taken into account in this calculation, are both connections between timber structural elements to build the foundation modules, and connections to connect modules to each other. Connections are estimated at $10,-.

Labour price

The building needs to be manufactured. This is done by local construction workers, either in the factory or on-site. For the total price calculations the amount of hours needed for manufacturing is estimated and multiplied with the cost of a skilled worker. The cost of labour in significantly lower than the cost of material.

Cost of transportation

Raw materials and prefabricated elements need to be transported, either to the factory for manufacturing or to the site for assembling. The transportation cost is estimated to be 5% of the material cost.

11.4.3 Cost estimation

structural		$ 261,85	
module	columns	$ 15,96	
	upper beams x	$ 20,57	
	upper beams y	$ 9,74	
	lower beams x	$ 13,71	
	lower beams y	$ 13,71	
	upper plate	$ 6,91	
	upper plate 2	$ 13,82	
	planks bottom	$ 1,37	
	planks x	$ 1,37	
	planks y	$ 1,37	
	steel plates	$ 24,00	
	barrels	$ 40,00	
	preserve timber	$ 40,00	
connection	lower connection	$ 50,00	
	upper connection	$ 50,00	
side cover	side cover x	$ 13,20	
	side cover y	$ 26,40	
fabrication		$ 67,50	
		$ 299,35	
in project			
2*2*2			
	total	$21.553,29	
		$ 2.694,16	per building
1*1*1			
	total	$14.967,56	
		$14.967,56	per building

A first cost-estimation of the upper laying building is made. A single building costs approximately $4700,- and a double costs $4250,-. So in a project of eight buildings, the total price is calculated to be around $7000,- per building.

11.4.4 Conclusion

For both two cases, the total costs are estimated. A project of a single building is considered to be not feasible, since the price of the foundation exceeds the target price extremely.

In a project of a configuration of eight buildings (2x2x2), the price for a floating structure per building is $ 2.700,-. This can be considered as a substantial part of the total target price. It can be stated that several optimizations or concession must be made in order to create a realisable project.

Possible optimizations are described in *chapter 14 - recommendations*.

Chapter 12 Design - Integration

In this chapter, the integration of the amphibious modular foundation is elaborated. An integrated design covers multiple design solutions. In the first section an integrated water management system is explained.

The second section describes how extra ballast can be added. In the third section, the design and calculation of mooring piles is given. In the fourth section connections with the building and the modular foundation is given. The last section is shown how the modular foundation is accessible.

12.1 Water management

The main cause of the ground subsidence is the excessive groundwater extraction. (Van 't Veldt, 2015). By changing the source of water harvesting, the pressure the demand for groundwater extraction decreases.

The climate of the country is divided into two main seasons: the wet season and the dry season. The wet season or rainy season is considered to start in June and to end in November. (PAGASA, 2015) To contribute to lowering the demand for groundwater, during the rainy season rainwater can be harvest in order to use water for showering, washing and to flush toilets, or even to use as drinking water. Logically, in order to make use of rainwater it needs to be filtered. A limited amount of barrels can be used as storage for filtered water.

Besides water harvesting, improvements in waste water management can be taken by designing an amphibious foundation. Due to ground subsidence sewer pipes are disconnected, which causes a polluted habitat. By making use of helophyte filters, which can be planted in barrels, water can be purified, before it is drained. Natural water purification relies on the self-purification processes of water, soil and plants. This wastewater purification technique uses no extra artificial energy supply or other necessary substances. Waste water can be drained to helophyte filters. The water infiltrates through the soil in which the helophytes are planted. Helophytes create a good environment for bacteria that actually purify the waste water. (Ridder, 1996)

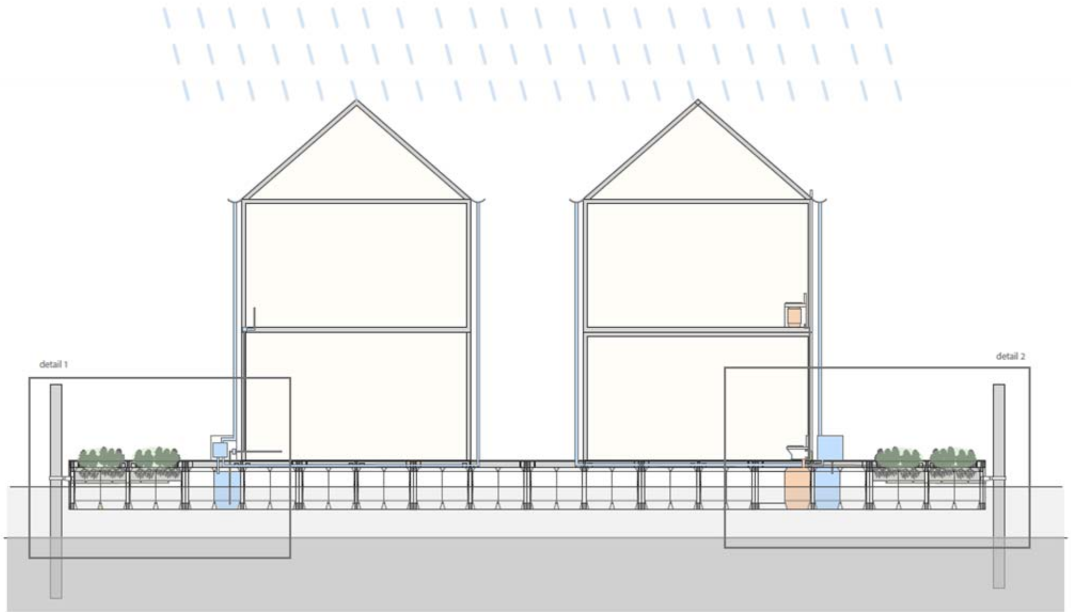


Figure 12.1: watermanagement

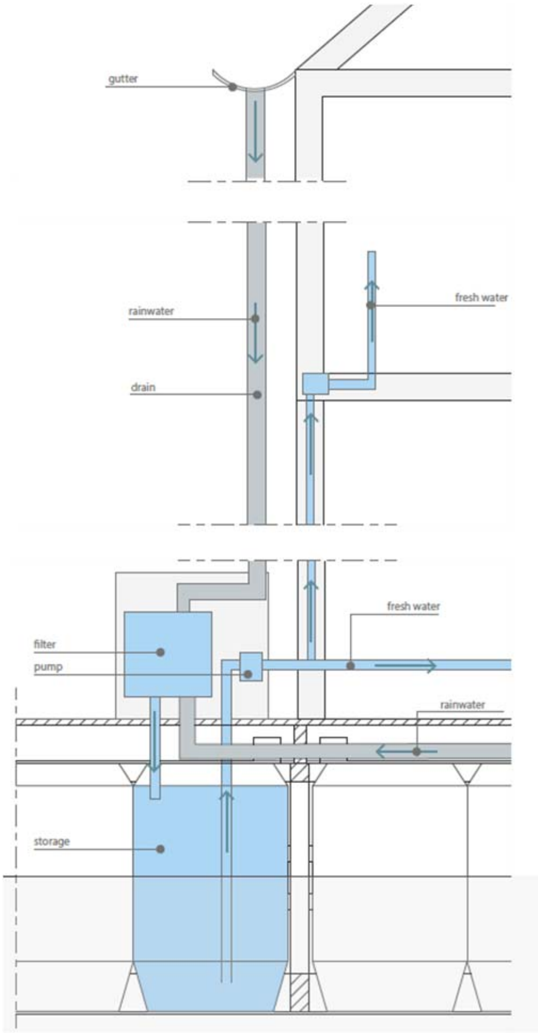


Figure 12.2: water management, detail 1

By making use of composting toilets, little to no wastewater is produced. Human excreta can be mixed with coconut coir to facilitate aerobic processing and liquid absorption. The human excreta can be stored in an underlying barrel. Since barrels can easily be removed, they can be emptied, cleaned and replaced. Composting toilets produce a compost that may be used for horticultural or agricultural soil enrichment in the area. By connecting a natural ventilation duct, the degradation process in the toilet is predominantly aerobic and it vents odorous gases. Urine can be drained through pipes to the helophyte filter system.

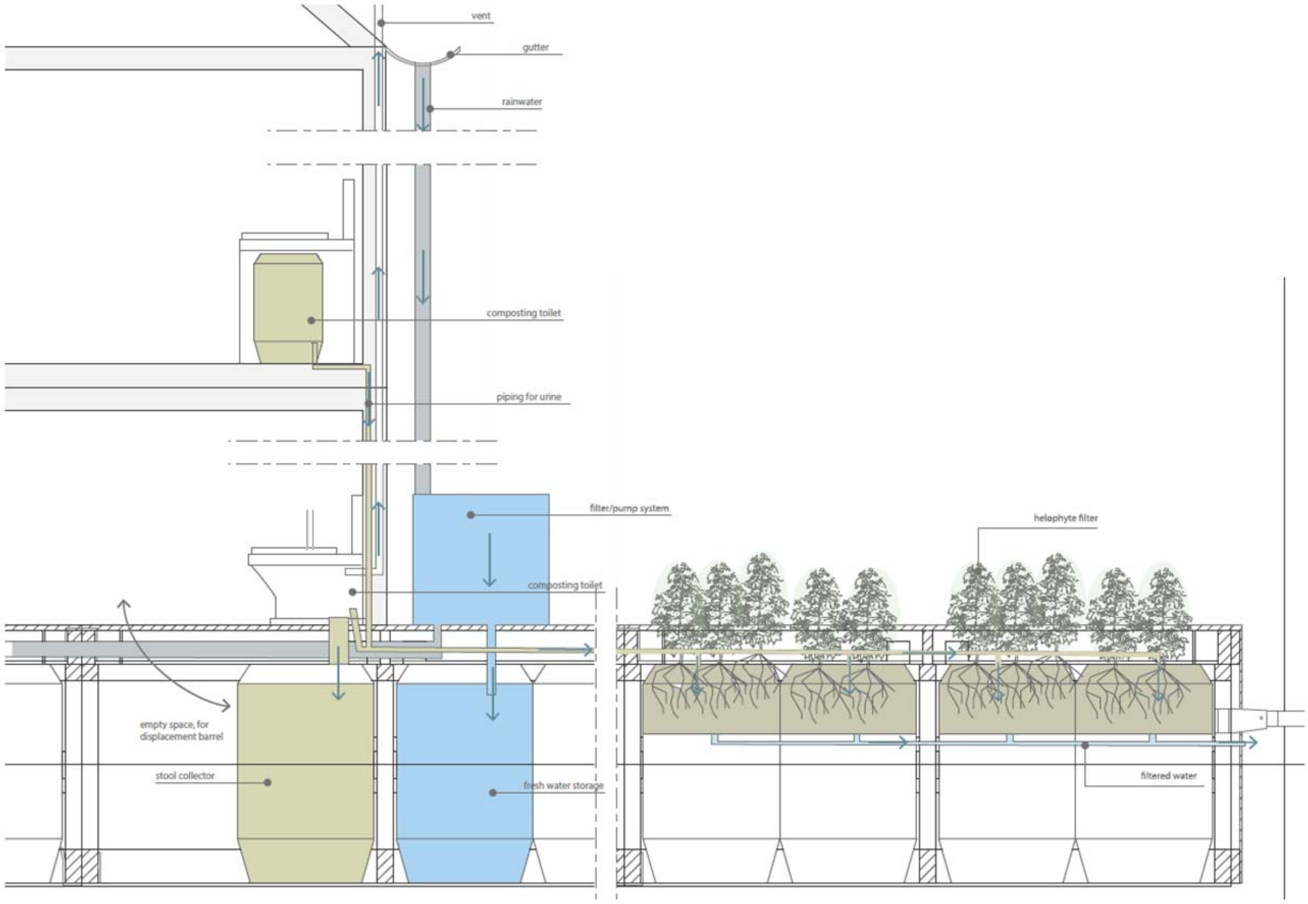
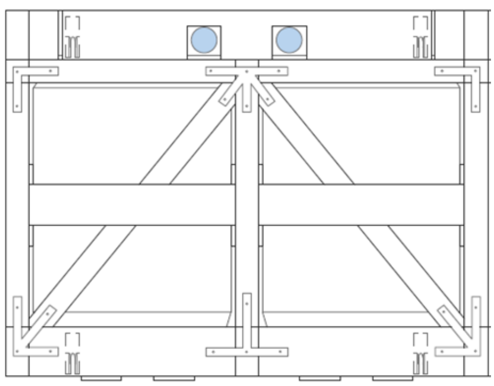


Figure 12.3: water management detail 2

As previously mentioned, an extra beam layer is added to the amphibious foundation modules. This creates extra space for pipelines and cables. By creating openings in the layer, pipelines can be connected from one module to another, or can be placed after modules are connected.



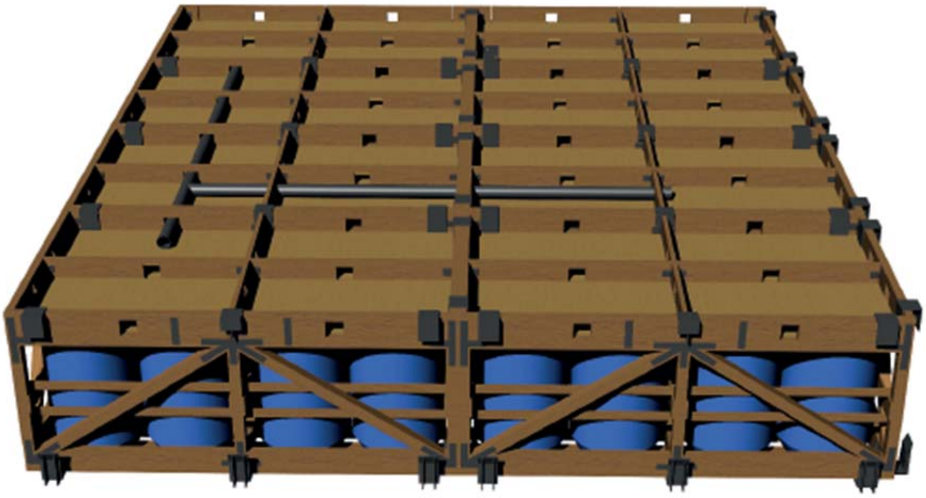


Figure 12.4: integrated piping system

12.1.2 Additional ballast

The barrels in the foundation modules, give the ability to create extra ballast in case of eccentric loading by for example heavy furniture, of eccentric placed buildings. By filling a certain amount of barrels with water, buildings can be straightened. As well oscillation periods for heave and roll and pitch can be raised, by adding extra ballast. Though this measurements straightens the foundations, less floating capability will be gained. So instead of filling barrels with water, extra foundation modules can be added on the heavier loaded side.

12.2 Mooring piles

Mooring piles must give the structure restriction from surge and sway, and the same time provide the structure the ability to heave freely. When mooring piles restrict the modular foundation for roll and pitch movement, large moments occur in this piles. For these reasons a hinged connection which can move freely in z-direction must be created.

12.2.1 Design mooring piles

Several options for the design of mooring piles are studied. Bamboo piles give a suitable solution.

A bamboo stem is from origin relatively straight, which creates the ability to slide smoothly along the pole. However, bamboo stems cannot sustain against shipworm. Especially the softer inner side of bamboo stems is susceptible to be attacked by shipworm. A large advantage of bamboo is that it grows relatively fast. Bambusa blumeana, is the most common bamboo specie in the Philippines. This specie grows around 15 cm per 24 hours. It grows to a 5 cm-20cm diameter with a length maximum length of 20m. During the first growing season this bamboo specie is grown to their full length and the second year it fully strengthened. (Alcala, 1992)

Bamboo bundles

A native method to improve structural behaviour of soils, is bundling bamboo piles and hammering them into the soil. The most common way is creating a bundle of 5 or 7 bamboo piles (called bamboo cluster), by tying them together. With a small local drop hammer bamboo piles can be hammered in the soft soil. (Rujikiatmamjorn et al, 2005) In this design bundled bamboo stems are used as mooring piles.

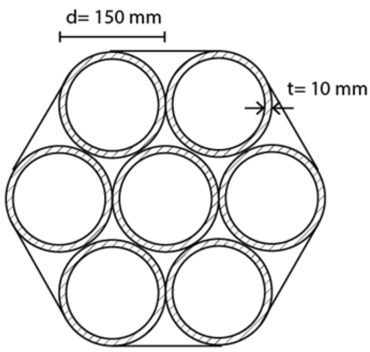


Figure 12.5: bundled bamboo

By planting a bamboo stem on the construction site, mooring piles can immediately be replaced after they are damaged by shipworm. The dikes of the fishponds can be an interesting place to let these bamboo piles grow. In this way mooring piles fulfill most of the criteria. Bamboo can be cut and placed in the ground on the construction site. No further transport is needed. Clearly, it is locally produced, and moreover, it is expected to be inexpensive, which makes it very affordable.

12.2.2 Calculation mooring piles

To create mooring piles with a second moment of area which is large enough, bambusa blumenea piles are bundled together, with a salt water resistant material. Seven stems with a diameter of 15 cm and a wall thickness of 1 cm can be clustered and hammered or pushed in the soft soil. It is important to make sure the bamboo piles will not float up, by its upwards pointing buoyancy force. An extra weight can be placed on bamboo piles in order to create an equilibrium.

The following properties are calculated:

E= (18-20 GPa) (Meier, 2016)
A_{single} = 4398 mm^2
A_{bundle} = 30788 mm^2
$I_{singlebamboo}$= 10831 E+03 mm^4
I_{bundle}: 75814485 mm^4
$W_{singlebamboo}$ = 144409 mm^3
W_{bundle} = 1010863 mm^4

In Matrixframe a model is made in order to calculate the pile deflection under horizontal loading by wind and waves. In the parametric calculation model a total horizontal force due to both wind and waves of 172,32 kN is calculated for the case where a configuration of eight buildings is placed on a 14,4m x 14,4m foundation. Twelve mooring piles give the structure its horizontal stability. This means that a horizontal force of 14.36 kN acts on a single pile. The method of calculating $K_{horizontal}$ is given in part II- chapter 1.5. By filling in this calculation, for each specific layer the horizontal K-value is calculated. Appendix 6. This is modelled as a vertical elastic line support. Tension is not eliminated, since the soil can act on both sides on the pile. As stated previously, the upper layer is expected to be added in order to strengthen the soil, and is not taken into account in this calculation. The properties of the second layer of soil are extrapolated over the first layer.

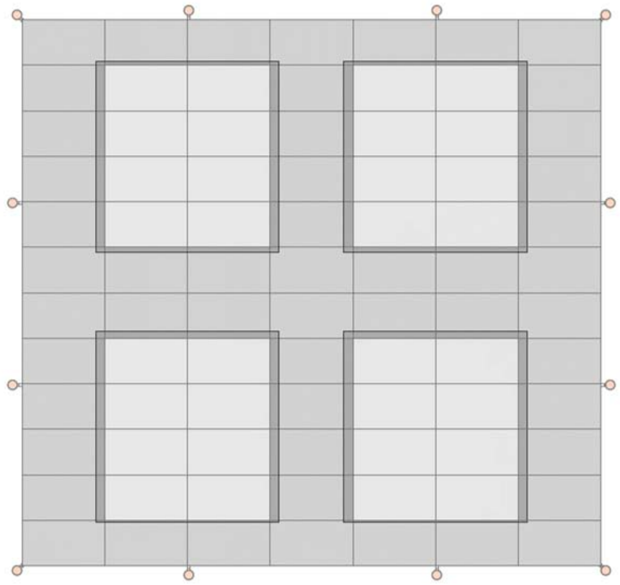


Figure 12.6: Situation: position mooring piles

Matrixframe

Several pile lengths are tested in order to calculate the desired depth of the pile. In figure 12.7 is shown that placing the pile at a depth of 4 m provides already enough horizontal stability to the structure. The total deflection of the upper part of the pile is 54 mm. By hammering the pile deeper, the horizontal the deflection does not decrease that much. In this situation the maximum bending moment is 40.4 kNm. The maximum shear force is 14.4 kN. This results in a maximum bending stress of 39,97 N/mm^2, and a maximum shear stress 3,27 N/mm^2. These stresses can be taken by the bundled piles, max bending strength of most bamboo species varies between 50 and 150 N/mm^2. The maximum shear strength of most bamboo species varies between 4 and 12 N/mm^2. (Meier, 2016)

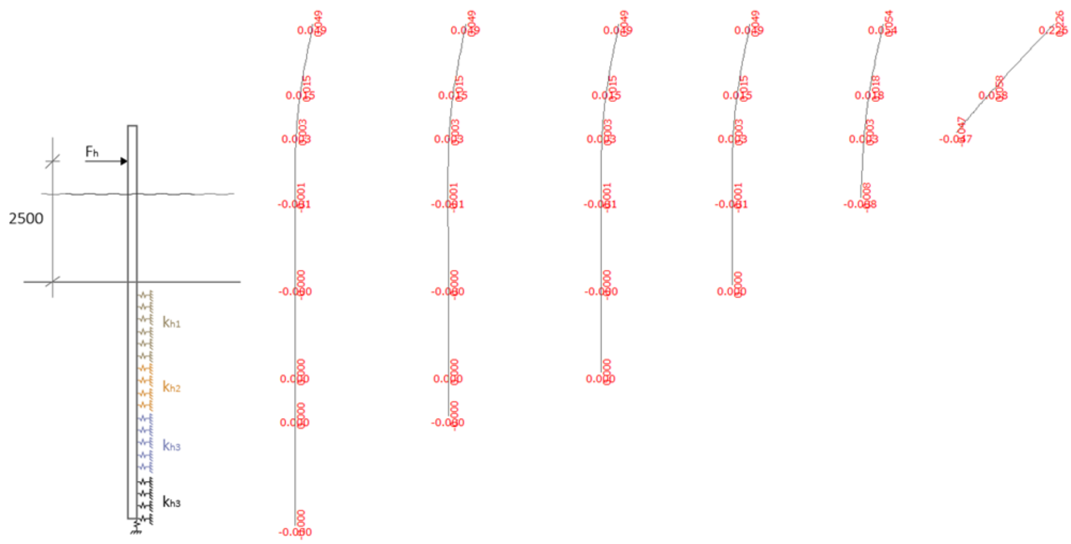


Figure 12.7: Matrixframe model

The maximum displacement of the soil is 18 mm, and the deflection of the pile itself is 107 mm. Since the horizontal force caused by waves and wind is cyclic some additional calculations are made to calculate the pile displacement.

The effect of cyclic loading is expressed in an additional displacement. (CUR228, 2010)

$$y_c = y_s + y_{50} \cdot C_1 \cdot \log N$$

in which:

y_c total displacement due to cyclic and static load;

y_{50} displacement due to static load;

C_1 empirically determined constant

N number of load cycles

With N=10000, the total soil displacement is 61,2 mm.

12.2.3 Connection mooring piles

In order to prevent large bending moments in the pile, a hinged connection, which is able to slide freely in vertical direction must be created. By building a steel ring around the bamboo bundles, and connect this steel ring with a steel plate on the structure this hinged connection can be created. The mooring piles does not influence the structure form roll and pitch movements. However, it can create some damping, by friction between the mooring piles and the ring connection. In *appendix – technical drawings* all drawings of these connections, are depicted.

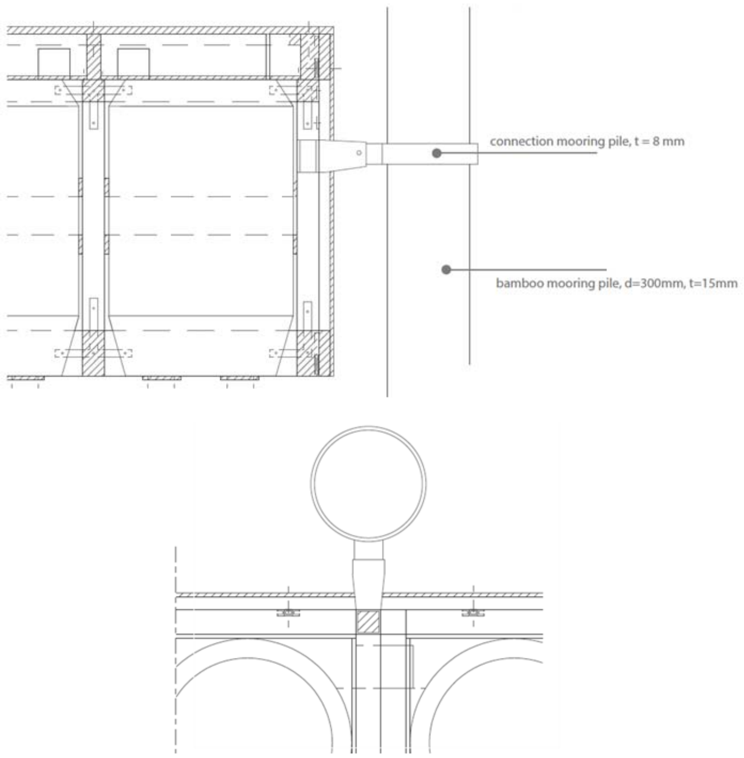


Figure 12.8: connection mooring piles

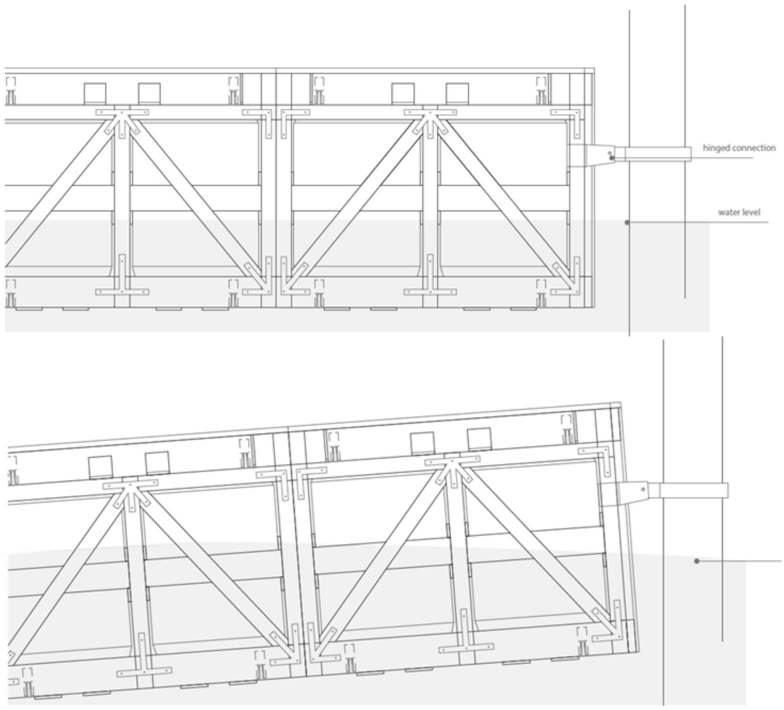


Figure 12.9: hinged connection mooring piles

12.3 Connection with building

As well a connection with the building upon the amphibious foundation can be integrated in this system. By mounting a steel connection on the upper beam, structural elements of the building can be connected to the foundation. Since the building provides its own stability, a hinged connection can be bade. An example of how the building can be connected to the foundation is depicted on figure 12.10.

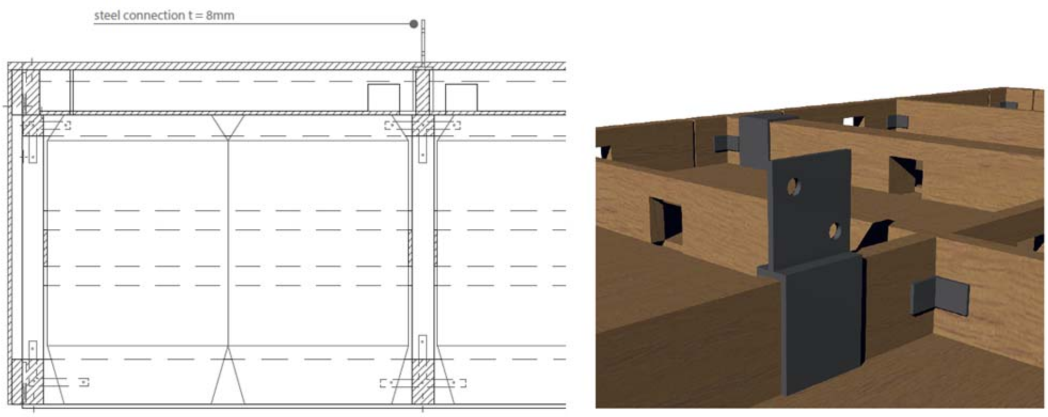


Figure 12.10: connection building

The connection with the building can be integrated with the connection between modules by adding a vertical plate on top of the connection. This is depicted in 12.11.

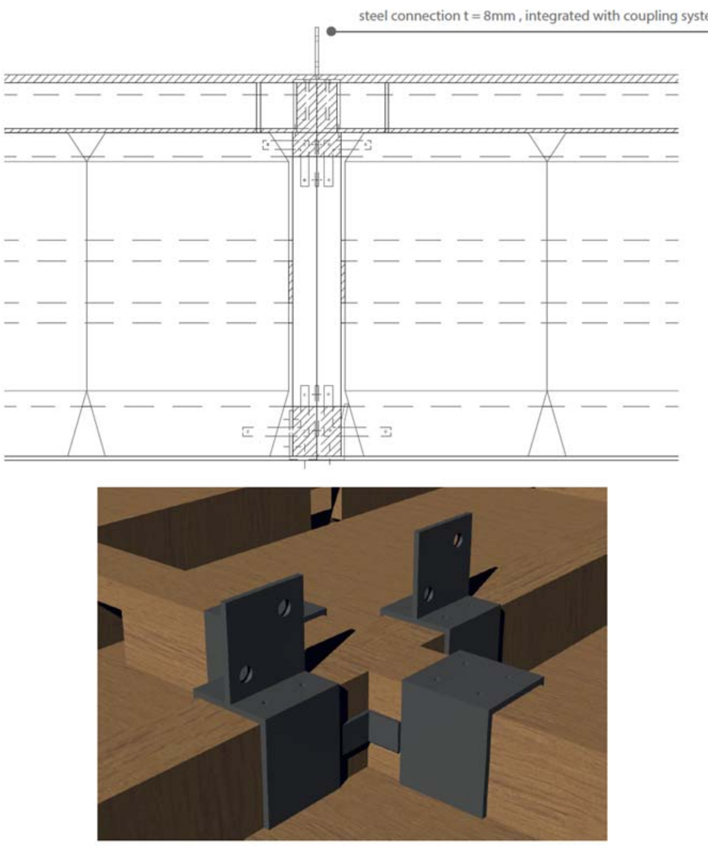
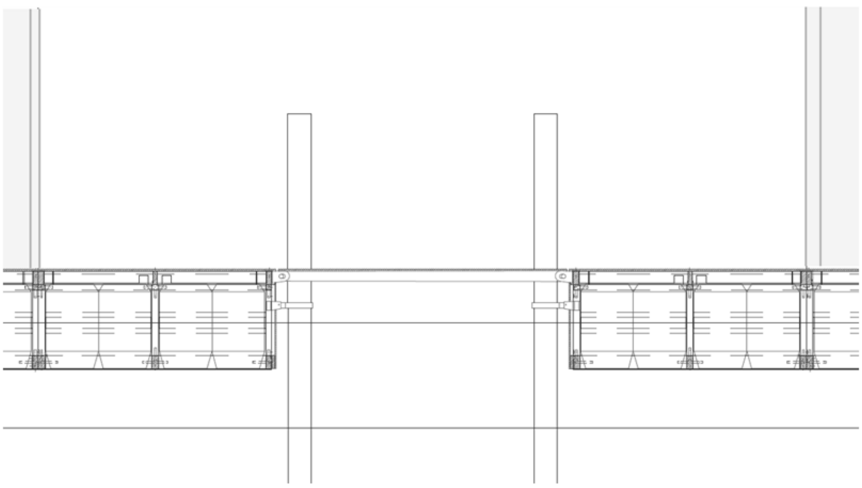


Figure 12.11: integrated connection

12.4 Quay model

When multiple foundations with buildings are placed together, a neighbourhood is created. A bridge between foundations creates the ability to move from one to the other.

The structures have a certain spacing between each other, so the connections can be designed in a way that the structures are able to move independently in vertical direction. These connections do not have to transfer any forces between modules. Only the self-weight of the bridge and loading by people must be taken by the bridges and its connections. So the connection can be dimensioned relatively lightly. A bridge with on each side a hinge and some space for translation can give a proper connection between two foundations.



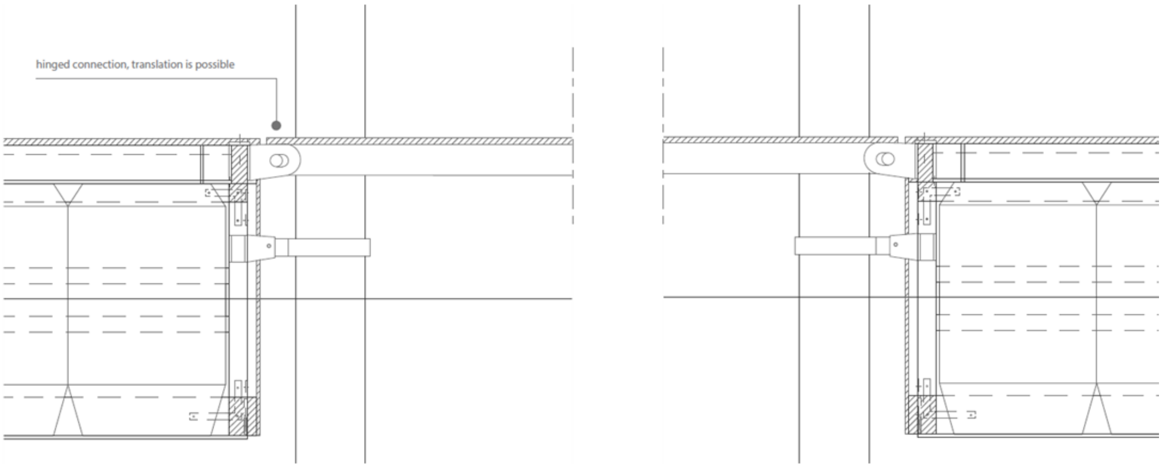


Figure 12.12: hinged bridge between foundations

As well, a connection from a foundation to the quay is designed. This is again a hinged connection so the bridge from the foundation to the quay does not influence the deflection of the foundation.

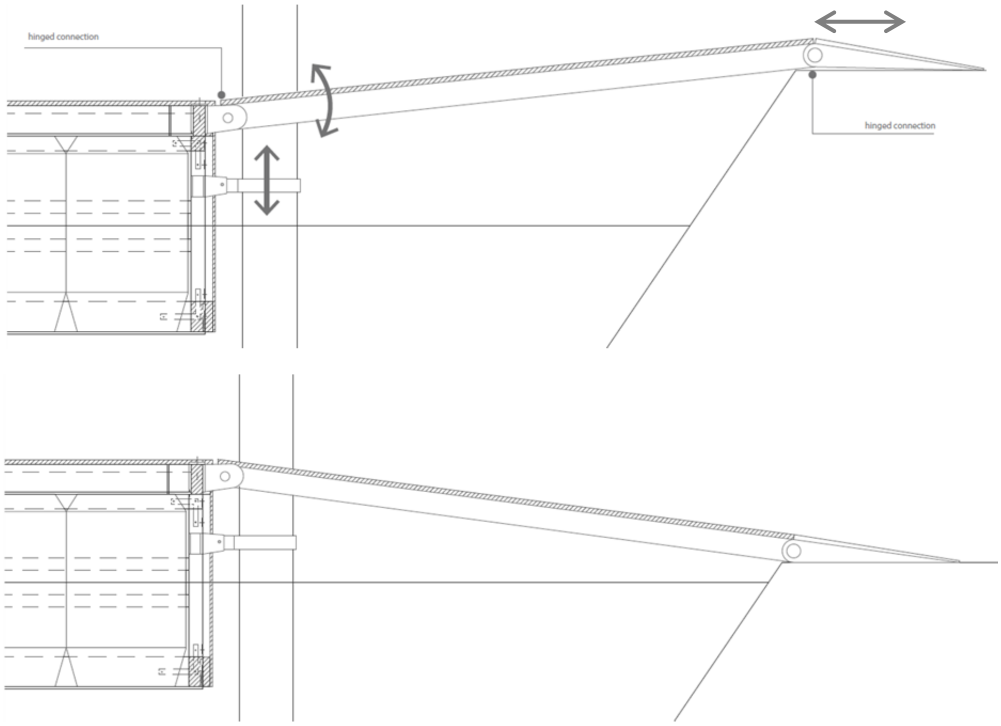
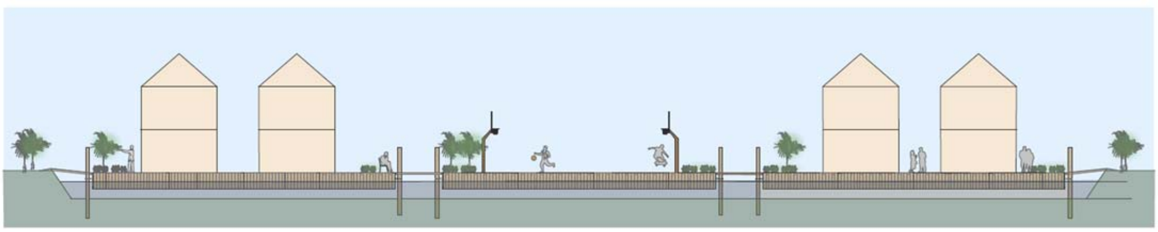


Figure 12.13: connection quay

Livelihood

Since multiple foundations can be connected to each other a neighbourhood can be developed. Besides functioning as foundation for housing projects, these foundations can create open space for gardening of sports. Hereby a greener and healthier area can be created. Vacant foundations can function as a basketball court or city garden.



Chapter 13 Conclusions

In this paragraph the research questions as stated in the introduction are answered in order determine whether the research objective is reached. Every research question is separately answered, which results in an overall conclusion.

The goal of this thesis is to:

__Design__ a __prefabricated modular amphibious structure__ that is applicable in and adjusted to a __flood__ and __typhoon__ prone area; __Hagonoy__, Philippines.

In order to determine whether the research objective is reached, the research questions are answered.

First research questions lead to similarities/lessons and differences between Western/Dutch building aspects and Filipino aspects. These similarities and differences lead to a list of design criteria. In research questions concerning the design for both the foundation modules and the design of connections between modules those criteria are taken as basis.

Modular, circular building concept

What are the main objectives of a modular and circular building concept? How can these objectives help solving housing problems identified in Hagonoy?

Criteria which play a major role for a modular and circular building concepts are listed. These main criteria as described in chapter 2, which are fully integrated into Finch Buildings' concept, do count for both the Netherlands and the Philippines. Being, flexibility/modularity, circularity, healthy, and affordability.

Flexibility is gained in the Netherlands by creating a modular building concept. In the Netherlands flexibility provides the ability to adapt buildings in function and location. For a modular amphibious structure in the Philippines, flexibility ensures the ability to expand and re-use foundation elements.

The benefits of prefabricating a modular building structure counts both for building in the Netherlands as for building in the Philippines. Prefabrication has a positive influence on the construction time, quality, sustainability, adaptability and the affordability. (MBI, 2015).

Floating behaviour

What is the general theory behind floating behaviour and how can floating behaviour be improved?

General improvements of floating behaviour are listed (floating behaviour criteria). The main conclusion is that in order to improve stability, a rigid structure which is significantly longer than the wave length must be designed. This design for both the foundation module and the connection provides this ability. By designing a modular foundation, extensions can easily be made by adding and connecting extra foundation modules.

Location

What are the most important location-based requirements, which the structure must fulfil? What are possible scenario's in which the structure must be able to function?

In addition to similarities between building in the Netherlands and the Philippines, differences have been detected, during the field research, being: (1) extreme climate conditions, (2) lack of proper infrastructure, (3) labour attitude and costs, and (4) available proper building material (appendix 2). These aspects has led to a number of location based criteria. (Appencis 2, Chapter 4)

Differences in climate are mainly noticeable during typhoons. Totally different situations can occur, in comparison with situations in the Netherlands. During typhoons, the structure is in its most unfavourable situation. By these typhoons the water depth of daily floods increases significantly. A long fetch, in combination with strong typhoon winds, causes relative high wind waves, which causes relative high loads on the structure. The combination of high wind loads and high wind-wave loads creates an extreme situation in which the foundation structure still must give structural safety. Additionally, according to literature, dikes on the fishponds can both have a positive and a negative effect.

Both the foundation modules and connections must fulfil all criteria in multiple scenarios. The floating scenario is decisive for structures with a length that configures the wave length. The just-floating scenario, where the building touches the soil on one side due to a heeling moment by wind, waves, eccentric loading and a second order effect, is decisive for longer and wider structures. On this situations dimensions are based.

An analysis of the location leads to location based criteria, being: a robust structure, a durable structure which can sustain local hazards, and a manufacturable, transportable and affordable structure which can be built with local materials.

Structural design foundation module

How to create a proper and suitable amphibious modular foundation for Hagonoy?

In order to answer this questions similarities and differences between in the Netherlands and the Philippines as described are used for the design of the modular amphibious structure. The concept design is determined by rating several building types among building-concept criteria, floating-behaviour criteria and location based criteria. After a structural analysis, a suitable design for Hagonoy is made. A timber prefabricated cage, filled with barrels forms the basis of the design.

To deal with a lack of proper infrastructure prefabricated modules are designed in order to create a manufacturable amphibious structure, both during transportation and execution. Manufacturability is optimized by creating smaller and lighter building modules in comparison with Dutch building modules.

In order to withstand relative high forces during extreme load situations caused by typhoons, a robust, slightly over dimensioned, modular foundations and connections are designed. In addition, this modular flexible system provides the ability to add structural elements in case of extreme situations. As well after damage new structural elements can be added. To prevent the structure from decay, timber elements are wrapped with coir. In case of damages, barrels can be replaced after execution in a simple way. Plastic barrels are protected from direct sunlight by covers which can easily be mounted to the structure.

Several optimizations can be made to reduce materials, and increase the cost-effectiveness of the structure (chapter 14). This over dimensioned structure, however, is recommended for now, since the actual wave characteristics are not predicted precisely. In addition, the actual performance of the coir shipworm protection has not yet been proven.

A SCIA model is used in order to calculate the occurring forces. It is concluded from this SCIA model that wave forces on a floating objects with a length which is significantly longer than the wave length, can be schematized as upwards pointing block loads at the location of crests, and downward pointing block loads at the location of throughs. For smaller structures, a non-linear elastic support is translated in the z-direction in order to create a realistic model.

Structural design connections

How to create a proper and suitable connection for modular foundation modules for Hagonoy?

The concept of the design is made by rating existing types by the building-concept criteria, floating behaviour-criteria and location-based criteria. After structural analyses, a suitable design for Hagonoy is made. An upper and a lower connection are designed in order to take bending moments, shear forces and tension forces.

An important difference between building in the Netherlands and in the Philippines is that, however scaled construction workers are able to build good quality, often diverges from building plans are detected. In order to reduce chance of decrease in quality of structures, relative straight forward connections are designed in a way that only one way of connecting is possible. Self-alignment of modules is integrated in this connections in order to create a precise placement, which decreases deviations and so increases structural behaviour. This increases the manufacturability.

Affordability

How to create an affordable structure for the lower part of the middle-income class? What optimisations can be made?

An important factor for designing an affordable structure for the Philippines is that, in contrast to the Netherlands labour cost, is often a small part of the total costs. Mainly due to high transportation costs, material is the determining factor for the total price. By using recycled materials which are available in the Philippines, the building cost decreases. Local materials as bamboo and coir are used, to reduce costs and to support the local economy.

For structural reasons, the amphibious structure must be wider and longer than the wave length. By building a wide and long structure, more buildings can be placed on top, which increases the feasibility. It is concluded from case studies that a single building on the amphibious foundation is not feasible. By building a configuration of eight buildings on top of the foundation a feasible project can be gained. However several optimizations must be made in order to create a realisable project. (chapter 14)

Integration

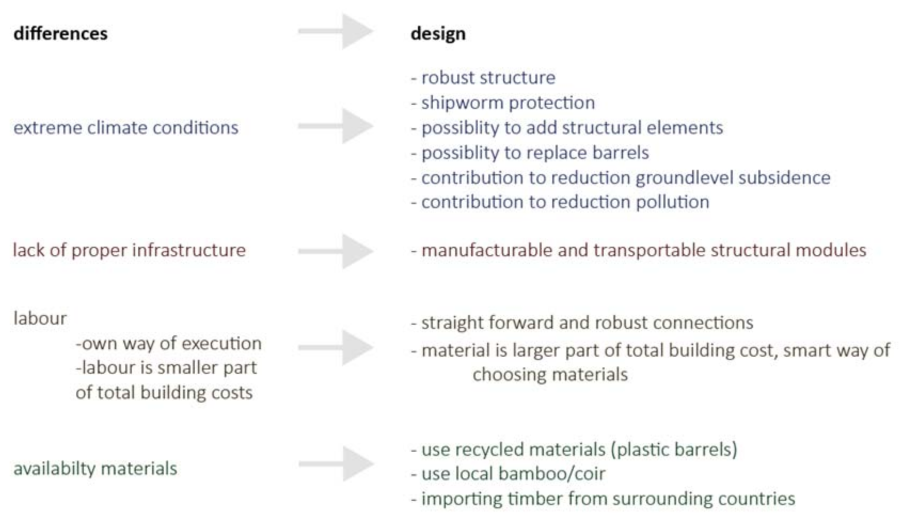
How to integrate the design with its surrounding?

To contribute to a decrease of ground subsidence, improvement of water management are integrated in the design of the modular amphibious structure. By collecting and filtering water in the rainy season, the pressure on the demand for groundwater extraction can be decreased. By filtering waste water in barrels by means of helophyte filters, a contribution on a decrease of the nowadays polluted water is implemented.

Mooring piles ensure the horizontal stability of the structure. Native ways of using bamboo piles are implemented. By replanting bamboo on the building location, bamboo can easily be replaced when it has lost its structural behaviour due to shipworm. Hereby a circular building method is obtained.

Overall conclusion

With this design, improvements in living conditions for inhabitants of Hagonoy can be gained. By listing and implementing the differences between building in the Netherlands and in the Philippines, and rating the design on configuring design criteria, a suitable structural design for an amphibious structure for Hagonoy is created.



Chapter 14 Recommendations

In this chapter several recommendations are listed. These recommendations can be used for comparable projects. As well recommendations for steps that have to be taken before a pilot version can be built.

Optimizations

Foundation modules

Several optimizations can be made in order to improve the cost-effectiveness of this design. Cost savings can be made in order to create a more realisable structure. In this design, dimensions of the structure are based on a single truss. However, after connecting foundation modules, a double width is gained. Further research can be made in order to find out, how this double counting influences the dimensions of the structure.

In this design the upper beam layer, which is placed in order to connect modular foundation with each other, is connected with steel plates to the under laying beam. It can be a solution to, instead of using a double layer, to make this beam-layer out of a single beam. By planing the beam the needed space to connect the upper plates achieved. This provides more labour, more timber is used, but a reduction in steel plates is achieved. Further research might be needed to show the more cost efficient solution, and which option performs better in structural point of view.

Design connections

The connecting procedure of modules can be optimized. In this thesis two ways are described. The first one describes the placement at which one module is weighted with water, sand or people, and will slide under the placed module. The other option is to raise one over the other by means of ropes. The best way to find out what the best solution is, is to try it with a pilot version.

The steel connections between foundation modules are expected to be relative expensive. It can be reviewed whether this specific connection can be executed in for example a recycled plastic building material.

Shipworm prevention

Coir fibre is determined to give a proper protection against shipworm attack. However, performance of this measurements is never tested. In order to build the first pilot version, simple tests can be executed to discover the behaviour of the coir wrapped structural elements. A piece of timber, wrapped in coir, can be submerged for a certain time and the decay of the timber element can be measured. This can be done with coir, cotton and rice hulks in order to determine which functions best.

Furthermore, WPC with bio derived plastics might be a suitable material in the near future, since it scores well in the field of sustainability and structural behaviour. However developments in producing this material in the Philippines are needed, in order to fulfil the locally-produced-criterion.

Waves

In this thesis, assumptions have been made for calculating characteristic values of waves. It is not very certain whether a wave during a typhoon will behave as described, since literature describes both an increase and a decrease of wave height due to obstacles. Before a pilot version can be built, more knowledge of the behaviour of waves in this area is needed. This can simply be done by placing a buoy on the construction site. As well 3d wave prediction model such as Delft 3d can be used.

In this thesis, waves that enter the foundation diagonally are not taken into account. These wave loads can have an influence on the structural behaviour.

Modelling

In this thesis a parametric model is made by means of Rhinoceros and a Grasshopper plugin. It is announced by developers that with Karamba, a parametric structural engineering tool, in the near future nonlinear elastic soils can be modelled in Grasshopper. With this tool, all expected scenarios and building configurations can be parametrically modelled. All scenarios and configurations can be tested on deflections and internal forces in an easier way. It is recommended to use this plugin for a similar project. In this thesis all possible load cases for all configurations were tested in SCIA in order to find the maximum deflections and maximum bending moments and shear forces, which is a quite time-consuming process.

The schematization of the situation in where the floating structure touches the soil on one side, creates an overestimation of bending moments and shear forces (chapter 11). In further research a more detailed calculation can be made, in order to calculate precise forces and moments.

Mooring piles

Bundled bamboo stems are recommended as mooring piles. An interesting study might be whether mangrove or a bundle of bamboo piles can grow naturally in brackish water. Then living timber elements can be used, so that pile are not susceptible to shipworm attack.

Future steps

The first steps into realisation of a pilot project are taken. After optimization of both the design for the amphibious structure and the design for the building upon it, crowd funds or investments can be gained. After realizing the first pilot buildings, this project can be up scaled by implementing a social housing association. First interesting contacts have been made during the field-research, which definitely can help with realizing this project.

Appendices

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1. Appendix: Location Analysis

1.1 Philippines

Developing a design for Hagonoy requires a basic understanding of the Philippines. The following topics are discussed: the geographic situation, the architectural history, the climate, politics, demography, economics, infrastructure, and the social and cultural backgrounds.

Geographic

The Philippines are located in the western Pacific Ocean in Southeast Asia. It consists of 7.107 islands, which are divided into three regions: Luzon, Visayas, and Mindanao. The capital of the Philippines is Manila, part of Metro Manila. (GOVPH, 2015)The Philippines are located on the Pacific Ring of Fire and relatively close to the equator. This makes the country prone to earthquakes and typhoons, but it has also an abundancy of natural resources and great biodiversity as result. The Philippines is the 64th-largest country in the world and has the 5th longest coast line in the world. (GOVPH, 2015) The extensive coastline and the rainforests are home to many animals, making the Philippines rank in the top ten on biodiversity. However, many species are endangered by deforestation, as a result of illegal logging. This is a major problem in the Philippines, both conservation wise and economically. (Peralta, 2005)

In 1521 the Spanish arrived in the Philippines. Twenty-two years later the archipelago was named Islas Filipinas in honour of Philip II of Spain. The Philippines were part of the Spanish Empire for more than 300 years. Manila became the western hub of the trans-Pacific galleon trade, which connected Asia with America. (Nations, 2014) At the end of the 19th century there was a short Philippine Revolution, which resulted in the First Philippine Republic. As a result of defeat of Spain during the Spanish-American War in Cuba, the islands were given to the United States. The United States would not recognize the Philippine Republic, so the Philippine-American War broke out, which was the end of the First Republic. During the American occupation the Philippines prospered and there were plans for independence. These plans were disrupted by the Japanese invasion during World War II. In 1945, the Philippines were liberated by allied troops. On October 24, 1945, the Philippines became founding member of the United Nations and in the following year it became independent. Since then, The Philippines are a democracy. (UNMemberStates, 2015)

Architectural history

The architecture of the Philippines is a mix of different styles and therefore reflects the history of the country, mixing indigenous, Indian, Chinese, Japanese, American and Spanish styles. Before the Spanish occupation the architecture consisted mostly of the Nipa hut or 'bahay kubo', made of natural materials. During the Spanish occupation the Philippines architecture was greatly influenced by Spanish design. This is also when the traditional 'bahay bato' emerged, a house with a stone first floor and a wooden second floor and roof. After the Unites States took control over the Philippines the architecture became influenced by American aesthetics. During this time the plans for modern city Manila were made. At the end of the 20th century brutalist architecture was the dominant choice for government buildings. Currently, respect for the traditional Filipino elements in the architecture is returning.

Climate

The climate in the Philippines is classified as a tropical maritime climate, which is usually hot and humid. Three seasons can be distinguished, the hot dry season from March to May, the rainy season from June to November, and the cool dry season from December to February. Temperatures on average range from 21°C to 32°C, but this can differ depending on the season (PAGASA, 2015)Heavy rains and thunderstorms are experienced from July to October. Yearly around nineteen typhoons enter the Philippine area of responsibility and eight or nine make landfall. Annual rainfall is 5.000 millimetres in the Philippines.

Politics

The Philippines is a republic with a presidential form of government wherein power is equally divided among its three branches: executive, legislative, and judicial. (GOVPH, 2015)The President functions as both head of state and head of government, and is the commanderin-chief of the armed forces. The president sits for a single six-year term.

Furthermore, the Philippines are a founding member of the United Nations and are active participant in the Human Rights Council. Relationships with the United States are especially valued.

Demographic

Currently the population of the Philippines is estimated to be more than 102 million. (Worldometers, 2015)2015) The Philippines was the 12th country in the world that reached a population of 100 million. According estimations half of the population live on the island of Luzon. The extreme population growth in the 90's is now decreased to 1,95%, but population growth remains an issue. The median age of the population is 23,2 years, with a life expectancy of about 72 years. About 12 million Filipinos live abroad. (Worldometers, 2015)Metro Manila is the most densely populated city in the Philippines and is the 11th most populated city worldwide. Its population was estimated to be more than 11 million. When suburbs in the adjacent provinces are included, the population is about 21 million. (PSA, 2015)) Tagalog is the largest ethnic group in the Philippines, consisting of 28% of the population. Other big ethnic groups are Cebuano, Ilocano and Visaya. Two big non-indigenous minorities are the Chinese and the Spaniards. The official languages of the country are Filipino and English. Filipino is a standardized version of Tagalog, which is spoken on the island of Luzon.

1.2 Hagonoy, Bulacan

Geographic

Hagonoy is a municipality in the southwestern corner of the province of Bulacan. The global distance between Metro Manila and Hagonoy is 54 kilometres. Hagonoy shares borders with the municipality of Calumpit, Paombong, Masantol, Pampanga and the Manila Bay. The town of Hagonoy belongs to the district of Bulacan together with the municipalities of Bulakan, Calumpit, Paombong, Pulilan and the City of Malolos. Hagonoy lies at the outfall of Pampanga River Basin, which is the fourth largest basin in the country. This has as result that Hagonoy is vulnerable to floods. Together with the relatively low elevation and the long coastline, Hagonoy is frequently subjected to high tide floods. The town is surrounded by major bodies of water on all sides. There is the Pampanga River to the northwest, Manila Bay to the south and Labangan channel, a man made waterway to the east. Seventy-one creeks are networked around the municipality. Hagonoy is divided into 26 barangays and is the 6th largest municipality in Bulacan.

Demographic

Hagonoys total population is 125,689 (National Statistics Office, 2010). It is ranked 8th largest and comprises 4.3% of Bulacan's population. The annual population growth rate is 1.28% from 2000-2010. Relatively lower than national (1.9%), regional (2.14%) and provincial (2.73%) level. However, Hagonoy has an expansive population, with a majority belonging to the younger age groups.

Population Composition, CBMS 2011

- Children 0-5 years old - 12,341 or 11.51%
- Children 6-12 years old - 15,011 or 14.01%
- Children 13-16 years old - 8,775 or 8.19%
- Members 10 years old and above - 86,426 or 80.66%
- Member 60 years old and above 8,811 hor 8.22%

Economic

Fisheries and aquaculture is the main economic driver in the fishpond-rich Hagonoy. With about three-fourths of its total land area devoted to fish-farming, the town is widely known in the province of Bulacan as the major source, supplier and trading centre of fish and other aquaculture products. It is ranked as one of the major fish trading areas within Manila Bay. Most of the fishponds are located at the southern part of the town where networks of rivers and tributaries are abundant. Due to saline intrusion, more farmlands are shifting to fishponds over time. The municipal government also has its own fishpond locally known as "Propyus". It is located in Pugad and Tibaguin, subdivided to 7 lots with a combined area of 412 hectares. Currently, only 1 lot remained operational. Large portions of western, southern and central barangay lands are considered unsuitable for farming and are already built-up into residential or commercial areas. Farming and livestock production is now largely confined to the northern barangays. Despite having an expansive land area, Hagonoy has limited areas devoted to farming.

Employment, Income and Livelihood Indicators, CBMS 2011

• Unemployment Rate (15 years old and above) – 4,397 (12.76%)
• Households with income below poverty threshold – 10,852 (44.1%)
• Households with income below food threshold – 6,454 (26.23%)
• Households who experienced food shortage – 257 (1.04%)

Infrastructure and utilities

Hagonoy's total road network is 79,82 kilometres, where more than 50% (42,36 km) is classified as barangay road, 8,2 km of municipal road and 29,2 km of provincial road. Around 90% of all roads are concreted, roughly 3.65% asphalted while 16.65% are unsurfaced (soil). Within the municipality are 28 bridges that are mostly made of concrete. The motorized tricycle is the most dominant mode of transportation. Passenger jeepneys transport commuters to Malolos City and Calumpit. There are passenger bus transportation services going to and from Hagonoy to Metro Manila. On the other hand, commuters from island barangays of Pugad and Tibaguin are served by passenger boats. All barangays, including coastal barangay of Pugad and Tibaguin, have access to water and electricity.

Housing Indicators, CBMS 2011
• Households living in makeshift housing – 1,646 (6.69%)
• Households who are informal settlers – 904 (3.67%)
• Households without access to safe water supply – 249 (1.01%)
• Households without access to sanitary toilet facilities – 815 (3.31%)

Social

Primary education in Hagonoy is provided by 29 public elementary schools, 10 private elementary schools, 4 public high schools, 4 private high schools. The municipality hosts Bulacan State University (BSU) – Hagonoy Campus and Hagonoy Institute of Technology (HIT) catering college students. Basic Education Indicators (CBMS 2011)

• Children 6-12 years old not attending elementary school – 3,289 (21.93%)
• Children 13-16 years old not attending high school – 3,371 (38.46%)
• Children 6-16 years old not attending school – 6,660 (28.03%)

There are 3 hospitals operating in the municipality, these hospitals are being complimented by private medical clinics, barangay health centres and rehabilitation centres. Health and Nutrition

Indicators, CBMS 2011
• Children under 5 years old who died – 62 (6.69%) • Women who died due to pregnancy related causes – 8 (1.07%)

• Malnourished children 0-5 years old – 206 (1.67%) • Household with members who got sick – 5,751 (23.38%)

• Household with members who seek treatment – 5,008 (87.08%)

Hagonoy is generally a quiet community despite being an urbanized municipality. Peace and order is being maintained by the existing 25 police personnel, a number far below the minimum standard police-topopulation ratio of 1:1,000. In 2011, there were 318 crimes reported with 94.65% crime solution efficiency. The Bureau of Fire Protection - Hagonoy Fire Station, which prevent and suppress fire incidence in the municipality, is composed of 12 fire personnel and currently maintains 4 fire trucks. 17 fire incidents occurred in 2011, lower than the 26 fire incidence in 2010.

2. Appendix: Field research

In order to design a proper structure which fits its location and fits the Finch philosophy, after the analysis a three month during field research has been done. In this field research five main problems, where Hagonoy deals with, are discovered by observations and surveys. The field research resulted in several solutions for these main problems. As a result of all design solution the main objective is divided into two sub-objectives.

2.1 Structure, field research

observations/ meetings → identifying main problems → interviews and surveys → preliminary design

2.2 Observations

Observing has been an on-going process. Many houses have been observed and documented to get a general idea of the local situation and of the quality of the housing in Hagonoy. Barangays Tibaguin and Sto. Rosario were visited in order to expand knowledge of its situation and living conditions. These barangays ranked among the poorest or most low lying parts of the municipality. Besides observations, several meetings with (former) majors and barangay counsellors have been arranged to gain knowledge of the situation of the area. By attending meetings about improving the environment by prevailing floods, this knowledge is expanded.

2.3 Main problems

By meetings and observations during the field research in Hagonoy, several problems are discovered. The found problems are categorized in five main problems, being: the low housing quality, daily tidal and fluvial floods, ground subsidence, overpopulation and climate change. All problems have influences on each other.

Low housing quality: A large percentage of the houses in Hagonoy are of low quality. There are many make-shift houses which are built with found materials and are constructed by the owners themselves. This generally results in unsafe housing, which is mostly dark, dirty and wet. The locations of the houses contribute to this problem. They are either built on a small lot surrounded by other buildings or they are illegally built on the riverside. The quality of the houses further diminishes because of lack of maintenance. The main construction materials are timber beams and columns, hollow concrete blocks and corrugated metal roof sheeting. For cladding and additional structures mostly cheap or even found plywood and bamboo are used. The houses of poorer quality are generally a combination of all these materials. Since houses are constructed by the owners, with limited knowledge about construction, the structural safety of the buildings is low. Plastic is mostly used for waterproofing the structure.

Daily floods: Every day the high tide causes parts of Hagonoy to be flooded. The severity depends on the height of the tide. The lower parts of the municipality of Hagonoy experience floods even during the lowest tides. For some citizens this means their houses are every day completely flooded.

When a typhoons passes over the island of Luzon, significant amounts of rainfall is to be expected. Rainfall is the biggest problem for the citizens of Hagonoy. The village is at the outflow of the biggest delta in the Philippines. In the days after the typhoon the water gradually rises to extreme levels. For safety reasons Hagonoy is shut off from electricity. When families have a second floor they live there for as long the flood endures. In the past Hagonoy would stay flooded for three weeks.

Ground subsidence: Due to the overuse of groundwater, the aquifers get depleted and the ground is subsiding rapidly, up to 4,5 cm/year. Research concluded that ground subsidence is the main contributor to the flood problems. The increased use of groundwater is caused by the growing population. Due to the ground subsidence the buildings and roads are also sinking. This worsens the effect of the daily high tide. Some households try to keep the water out by making high doorsteps or increasing their floor height. Some houses sank already too deep to be saved; this either resulted in an unused first floor, abandonment of their house or acceptance of water in their homes.

Overpopulation: The fast growing population causes many problems to worsen. More groundwater is used and more space is used for living. As a result of the lack of space, people start to build on the river, resulting in a narrower river, preventing the water to flow properly out to sea. Consequently the damage caused by the floods increases. Furthermore does overpopulation cause schools to be overfull. Classrooms are used by twice the capacity of students.

The rapid population growth lead to an increased density in all the barangays (town section). About 30 years ago families had sufficient outdoor space to grow crops. Large families divided their property over descendants, on which they all build their own house. This resulted in small lots which are fully used by housing, eliminating all green.

Climate change: Climate change is a worldwide problem; however, in the Philippines the results of climate change are more extreme. The IPCC (Intergovernmental Panel on Climate Change) 4th assessment report has found the following changes in climate in the Philippines. The mean annual temperature has risen, together with the annual mean rainfall and the number of rainy days. The occurrence of landslides and flood has increased over the timespan 1990 to 2004. There is an increase in frequency of typhoon entering the Philippine Area of Responsibility of 4.2. Furthermore there is a decrease of rice yield due to the increased temperature. (IPCC, 2007)

In Hagonoy the rising sea level is a contributor to the daily floods, the maximum temperature gets higher every year and the storms that are experienced are more severe. Hagonoy is however also a contributor to climate change, because of irresponsible use of materials, fossil fuels and extreme pollution. The irresponsible waste treatment causes the water to be extremely polluted. There is no sewage treatment, and sewage and garbage goes straight into the river.









2.2 Differences between building in the Netherlands and in the Philippines

Several differences have been detected between building in the Netherlands and building in the Philippines, being (1) climate conditions, (2) lack of proper infrastructure, (3) labour- customs and costs and (4) available proper building materials.

1. Climate conditions

Extreme climate conditions occur in the Philippines which are not taken into account for building in the Netherlands.

2. Lack of proper infrastructure

Due to the relative underdeveloped transportation system, the transport duration and cost are relatively high. This is partly due to the country's mountainous areas and scattered islands, and partly as a result of the government's persistent underinvestment in the nation's infrastructure. The lack of proper infrastructure makes it hard to bring heavy machinery to the construction site.

3. Labour customs and costs

An important difference between building in the Netherlands and in the Philippines is that, however scaled construction workers are able to build good quality, often diverges from building plans are detected.

A factor which plays an important role in designing an affordable structure for the Philippines is, that in contrast to the Netherlands, labour cost is often a small part of the total costs.

4. Available proper building materials

There is officially a nationwide ban on logging wood, because it is believed by current government that logging makes areas more prone to landslides and flooding. The ban on logging leads to the situation where no contracts will be granted for cutting natural forest anywhere in the Philippines. (McGeown, 2011) The ban on logging does not mean no forests are logged. The level of sustainability and fair trade timber is questionable, and therefore it is advised not to buy timber from the Philippines, when it is not officially certified. Furthermore, a due to relative underdeveloped transportation in the Philippines, transport duration and cost are relatively high. Resulting in relatively high prices, in comparison with other Southeast Asian countries, such as Malaysia and Vietnam.

Additionally quality of steel and concrete is often lower in comparison with Dutch standards.

2.3 Interviews and surveys

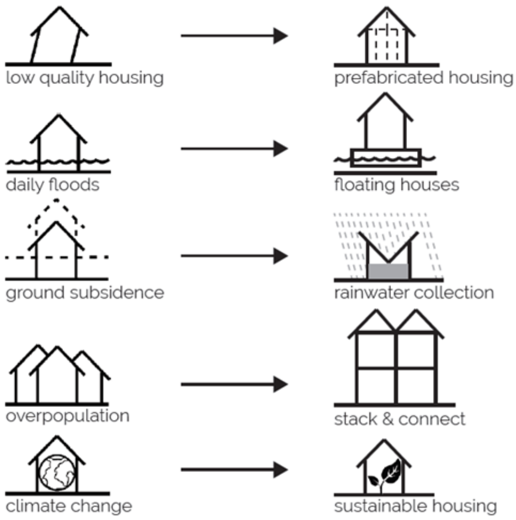
In order to have a proper view of living conditions and wishes and needs of people in Hagonoy, interviews and surveys have been taken with inhabitants of Sto. Rosario and Tibaguin. An overview of questions and answers are given in appendix 3.The important conclusion concerning the quality of the housing are: the way the house was built, mostly being self-built; all houses experienced floods; and the main bearing structure is either concrete or timber. Timber generally allows more flexibility to repair, rebuild and maintain the structure. When concrete houses fail, the building needs to be demolished and completely rebuild.

During the observations the inhabitants were asked for their wishes and needs by showing five series of pictures. These series are elaborated briefly in appendix 3

Concluding form these interviews and surveys: timber and bamboo in house design are accepted and preferred when the climate is considered. The idea of floating houses excites all interviewed homeowners.

2.3 Preliminary design

As a result of the fieldwork a preliminary design has been made. This design forms an integrated solution for the five main problems listed above. This preliminary design forms the baseline scenario for further investigations in this thesis. In this paragraph solutions for discovered problems are elaborated.



Prefabricated housing

As stated in conclusions from the field research, a design for a prefabricated structure, can be a solution for low quality of the current structures.

Construction time

Due to efficient scheduling and parallel production acitivies a shorter construction time can be gained. Wheater induced delays can be prevented, by prefabrication. Structures can be built sooner, which ensures a faster return of investment. (MBI, 2015)

Quality

Strict controlled conditions, dry building materials and a controlled work-environment improves the quality of buildings. In addition, a controlled environment increases labour productivity, and reduces risks of accidents and liabilities. (ATCO, 2015)

Prefabricated modular frames were designed to construct a 25m2 module with. During the two months in Hagonoy the basic design for the frames and connections was developed. Several possibilities of frame design have been explored. Stability, spacing for pipes and the interior have been addressed. A variety of materials can be used and the specifications, like transparency and ventilation, of the frames can be adjusted. The frames can be easily removed when the modules are connected. Just like the Dutch Finch module, numerous configurations are possible. This gives the possibility to also create schools or health centres.

Floating houses

To deal with major flood problems, a concept design for the amphibious structures has been developed. A modular amphibious structure, which is guided by poles, can move in vertical direction. The amphibious modules configure in size with the frames. Like the connections of the frames, the connections of the floating modules can be demounted, so the floating modules can be replaced, and extensions can be made. The foundation-modules are supposed to carry the building both in water, as upon wet weak soil. Several possible materials have been found.

Rainwater collection

By changing the source of water harvesting, the pressure on the groundwater extraction decreases. The wet season or rainy season is considered to start in June and to end in November. During this season rainwater can be harvest in order to use water for showering, washing and to flush toilets, or even to use as drinking water.

Relocate, stack and connect

Fisheries and aquaculture is the main economic driver in the fishpond-rich Hagonoy. With about three-fourths of its total land area devoted to fish-farming, the town is widely known in the province of Bulacan as the major source, supplier and trading centre of fish and other aquaculture products. However, several fishponds, owned by both individuals as the municipality, are vacant. Since an amphibious structure is designed, fishponds can be used as building location. By using these fishponds to relocate people, people are still able to stay close to family and work. By stacking and connecting building modules, a denser city plan is created.

In San Roque multiple fishpond, owned by the municipality and private owners, are vacant nowadays and not in business. Recommended by sir Agel Cruz, these fishpond are taken as first building site for this project.

Energy use, sustainable and renewable materials.

In the preliminary design a natural ventilated building is designed, in order to make less use of electricity. By placing solar powers, electricity can be generated. Like Finch Netherlands, a structure built in timber is designed. Timber is a renewable material, and is able store CO_2, instead of emitting CO_2.

Implementations

Furthermore, investigations in implementation the buildings have been made. The local parameters were discussed in a meeting with the mayor of Malolos, Christian D. Natividad, the former Mayor of Hagonoy, Angel L. Cruz, Jr., a manager of the DBP, Maria Dolores C. Guevarra, and a board member of the First Congressional District, Michael C. Fermin.

Generally the houses that are provided by social housing have a size of 25 to 30 m². Preferred is lot size of 50m² and a house of 25m². A house may cost 10.000 pesos/m² (210 $/m²). So a house of 25m² may cost 250.000 pesos ($5300). When public services are also taken into account an average of 300.000 pesos (€6000 or $6700) is taken. Public services are facilities like a bakery, sports, etc. Adding these things to a social housing project creates livelihood and allows people to continue their normal lives.

2.5 Conclusion field research

In the field research, observations and surveys had led to main problems which occur in the area. In addition, several differences has been detected between building in the Netherlands and building in the Philippines, being (1) climate conditions, (2) lack of proper infrastructure, (3) labour- customs and costs and (4) available proper building materials.

Solutions in the form of a preliminary design have been found. In order to make steps towards realisation, several subjects of this design needs to be researched further into detail. In order to create a proper design which is able to sustain typhoons and floods, an amphibious structure is necessary.

3. Appendix: Brief summary survey and interviews

In order to have a proper view of living conditions and wishes and needs of people in Hagonoy, interviews and surveys have been taken with inhabitants of Sto. Rosario and Tibaguin.

Sto. Rosario Sto. Rosario is situated south from the centre of Hagonoy, closer towards Manila bay. The barangay shares borders with Sagrada Familia to the east, Santa Cruz to the west and Mercado to the North. Sto. Rosario lies along a bend in the river. The barangay is known as one of the lowest laying parts of the municipality and has a great numbers of squatters. Five houses, one elementary school and one high school were visited.

Tibaguin Tibaguin is a barangay located in the south part of the municipality of Hagonoy. Tibaguin can only be reached by boat. In the barangay there are no motorized vehicles. The barangay is famous for the fisheries, since it is near Manila bay. Tibaguin and the neighbouring barangay Pugad have experienced severe damage of storm surges and typhoons in the past. During extreme weather most of the citizens leave Tibaguin to seek higher ground, since Tibaguin can be flooded for weeks. After typhoons a great number of houses become inhabitable and need to be rebuilt. In this barangay seven houses and one elementary school were visited.

An overview of questions and answers are given. The important conclusion concerning the quality of the housing are: the way the house was built, mostly being self-built; all houses experienced floods; and the main bearing structure is either concrete or timber. Timber generally allows more flexibility to repair, rebuild and maintain the structure. When concrete houses fail, the building needs to be demolished and completely rebuild.

During the observations the inhabitants were asked for their wishes and needs by showing five series of pictures. A brief summary of the survey and interviews is given:

Income per month:	6001 PhP to 15000 PhP/month (120 - 300 eu/month)
Year building/house was built:	Houses are often recently renovated. This is done with the help of the community, family and friends (bayanihan).
How the house was built:	Bayanihan (help of the community, family and friends)
Tenure status of the lot:	Family owned, mostly by the family of the man.
Acquisition of the housing unit:	Houses are mostly inherited. Some build their own house or when they earn a lot they hire professionals to build it.
Lot size:	average lot size is $35m^2$
House size:	average house size is $30m^2$
Is the building lifted?	All houses have experienced floods. Different ways of 'lifting' the house have been applied: increasing the floor height, looking for higher ground or building a house on stilts.

Number of floors	Houses of the less fortunate people have one storey.
Function of outdoor area:	The outdoor area is usually an extension of the living room. The outside area can be either part of the house or common space.
The load-bearing structure:	The two types that can be mostly seen are concrete houses with a wooden roof structure and full bamboo houses, cladded with plywood.
How to enter the building?	The lot is usually the building. Only richer people can afford to have a garden.
Connected to a public sewer?	The toilet have an open connection with the river. The river is therefore the sewer.
Additional observations:	The houses lack structure and maintenance, therefore they look very chaotic.
Number of rooms per floor:	The rooms in a house are mostly the living room with the kitchen, the bedroom (sometimes with door) and the toilet/shower.
The cladding of the building:	The construction material is also the finishing. Therefore concrete houses have a concrete cladding and bamboo houses have a plywood or bamboo cladding.
Electricity?	All houses have electricity. Whether this is an legal or illegal connection to the grid is unknown.
Household conveniences/devices:	All the houses have at least running water, lighting, a gas cooking pit, electric fans and a TV.
Source of water supply for laundry/bathing	The water comes from the well that gets the water from the aquifers.
Usual manner of garbage disposal:	The garbage disposal system is chaotic. Garbage is not separated and some garbage ends up in the river.

SERIE 1: TRADITIONAL DESIGN

Which one would you want to live? Concrete is preferred

Why yes/no? concrete is seen as the better material, because it is water resistant.

SERIE 2: THE NETHERLANDS

Would this house fit Hagonoy? Yes

Why yes/no? because of floods in Hagonoy, floating houses would be a good solution

SERIE 3: FLOATING HOUSES

Which one would you want to live? Bamboo and timber floating house

Why yes/no? because of the fresh air and open structure

SERIE 4: FINCH BUILDINGS

Would you want to live in a Finch Module? No

Why yes/no? People like to live alone and enjoy their privacy.

SERIE 5: MODERN DESIGN

Which one would you want to live? Bamboo and timber look is preferred

Why yes/no? Because of native look and the open structure.

4. Appendix: implementation

Summary of findings

Social housing can be financed is several ways, by private development, cooperatives, or local government units (mortgage). The most common way social housing is realised is community mortgage, where the property is first government owned and over time changed into private ownership. An example in Malolos is a land of 5 hectares which is owned by a private investor and is currently been used for social housing. The municipality created houses for 200 families through community mortgage for 25 years. After a period of 25 years the inhabitants own their house. The monthly cost of these social houses is 300 to 500 pesos ($6,30 - $10,50) over 25 years, or 90.000 pesos ($1900) after 25 years. The government is obliged to arrange housing for squatters (illegal living families), a community mortgage is therefore a system to reduce the expensive of creating housing. There are also social housing projects where the government allows people to live and people make their own house (bayanihan). Another social housing project creates housing for government employees. They earn a bit more and can afford better housing.

Business model

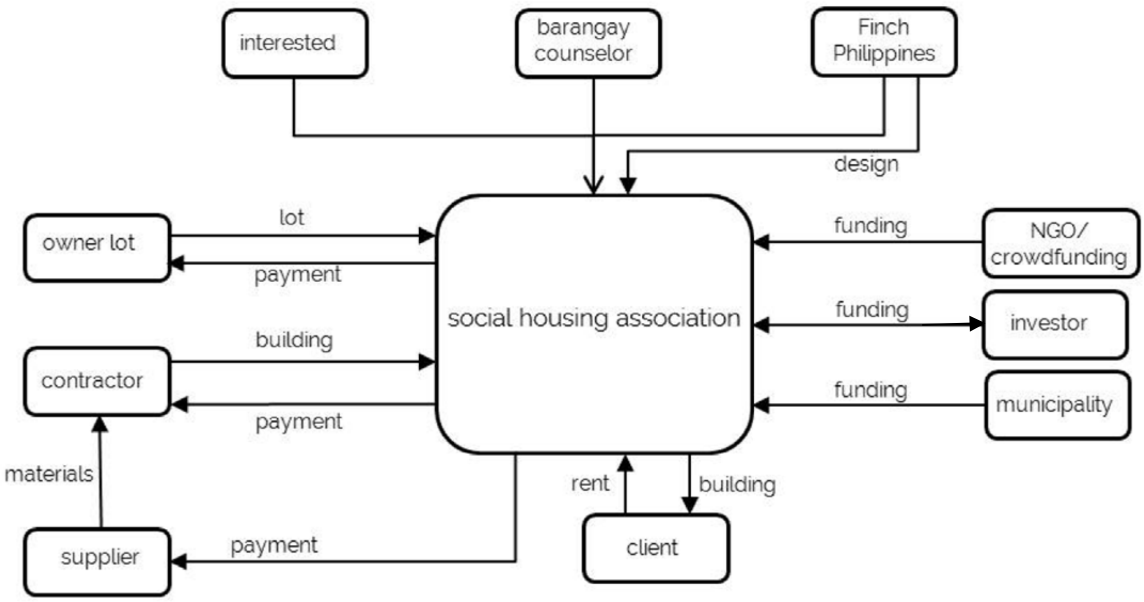


Figure 5: business model

Designing a Finch module for the Philippines is the goal of this thesis, however a feasible implementation is crucial to actually help the people of Hagonoy. A comparison between the situation in the Philippines now and the Netherlands in 1900 is made, in which social housing corporations are taken as an example. A concept for implementing a similar system is being developed.

Netherlands

Social housing associations were set up with private initiatives in the nineteenth century. The more wealthy citizens, entrepreneurs and church bodies were concerned about the living condition of the lower working class. The introduction of the Housing Act in 1901, made the social housing associations flourish, because this made it possible for the government to subsidise the building of housing. (Aedes, 2013)

Currently, social housing associations ensure that more than 2,4 million households in the Netherlands have access to good quality affordable housing, and they make sure the houses remain in good condition by maintenance. (Aedes, 2013) They also contribute to the quality of life in neighbourhoods, districts and regions. The social housing associations are responsible for 60 percent of the construction of new dwellings in the Netherlands and invest in areas such as care, student housing and sustainability.

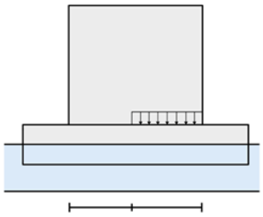
Philippines

The main concept of setting up a housing corporation is focussing of maintenance. Maintenance is generally lacking in the Philippines, because it is considered as not important. Maintenance is however the key to having a durable and sustainable housing project. The building remains property of the social housing association, therefore good maintenance will benefit the value of the building over time. This is a circular approach.

The social housing association will exist of interested, a representative of the local government and representatives of Finch Philippines. The housing project can be funded through crowdfunding or an NGO, by a private investor, or by the municipality or government. A lot can be rented or bought and the supplier and contractor can be paid for their services. The client, which is the homeowner, has to pay monthly rent.

This system is a first sketch of the possible setup of a social housing association. The difference with the current social housing project is the ownership of the buildings. This new association maintains ownership, it is believed that the building remain of higher quality over time. However, further research in necessary to verify the feasibility of this business plan.

5. Appendix: Eccentric loading



$M_p = g \times P \times y = g \times \sum P_i \times y_i$

With

M_p is the heeling moment as a result of people, kNm

P is the total mass of people that can enter the building, using a mean mass of 75 kg per person, in kg/1000

y is the lateral distance of the center of gravity P from the centerline of the floating structure, in m

g is the acceleration of the gravity, in m/s^2: $g = 9,81\ m/s^2$

P_i is the mass of on the surface A_i gathered people according to, $P_i = p_i \times A_i$, in kg/1000

With

A_i is the surface on where people are located, in m^2

p_i is the amount of people per m^2, dimensionless

y_i is the lateral distance from the center of gravity of the surface A_i to the center line of the floating structure, in m

The distribution of people must be the most unfavorable, from stability point of view.

(NTA8111)

6. Appendix soil properties

In this appendix information according soil properties is given.

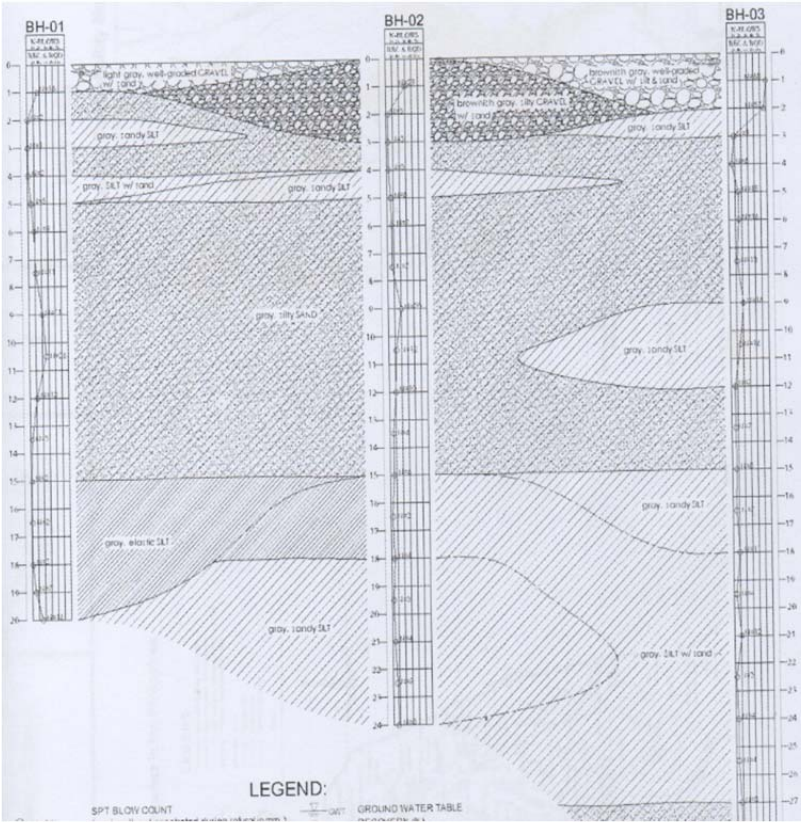


Figure 6: soil properties

Vertical load bearing capacity

Soil type	K_0 (N/mm^3)
Well graded gravel and gravel/sand mixtures, with	0,08-0,13
Poorly graded gravel	0,08-0,13
Gravel/sand/clay mixture	0,05-0,13
Well graded sand with gravely sand	0,05-0,10
Poorly graded sand	0,04-0,10
Sand/clay mixture	0,03-0,08
Very fine sand, loamy sand	0,03-0,05
Solid clay	0,01-0,03
Soft clay/peat	0,00-0,01

(Leijendeckers, Herwijnen, Fortijn, Roeck, & Schwippert, 2006)

Horizontal load bearing capacity (Tol, 2010)

depth from (m)	to (m)	material	consistency	Nvalue	qc/nvalue	qc (kpa)	β	α	R0	R	Ep	1/kh	kh	schematization kh
0	1	silty sand	loose	3	0,3	900	0,5	0,25	0,3	0,15	5800	7,86079E-05	12721,36499	**11154,49**
1	2	silty sand	loose	3	0,3	900	0,6	0,3	0,3	0,15	4500	0,000104301	9587,624636	**11154,49**
2	3	silty sand	loose	3	0,3	900	0,8	0,4	0,3	0,15	720	0,000689537	1450,248785	**1450,249**
3	4	silty sand	loose	3	0,3	900	0,8	0,4	0,3	0,15	720	0,000689537	1450,248785	**1450,249**
4	5	silty sand	loose	3	0,3	900	0,8	0,4	0,3	0,15	720	0,000689537	1450,248785	**1450,249**
5	6	silty sand	loose	6	0,3	1800	0,8	0,4	0,3	0,15	1440	0,000344768	2900,49757	**3263,06**
6	7	silty sand	loose	7	0,3	2100	0,8	0,4	0,3	0,15	1680	0,000295516	3383,913831	**3263,06**
7	8	silty sand	loose	7	0,3	2100	0,8	0,4	0,3	0,15	1680	0,000295516	3383,913831	**3263,06**
8	9	silty sand	loose	7	0,3	2100	0,8	0,4	0,3	0,15	1680	0,000295516	3383,913831	**3263,06**
9	10	silty sand	medium	20	0,3	6000	0,8	0,4	0,3	0,15	4800	0,000103431	9668,325232	**6888,682**
10	11	silty sand	medium	15	0,3	4500	0,8	0,4	0,3	0,15	3600	0,000137907	7251,243924	**6888,682**
11	12	silty sand	medium	12	0,3	3600	0,8	0,4	0,3	0,15	2880	0,000172384	5800,995139	**6888,682**
12	13	silty sand	medium	10	0,3	3000	0,8	0,4	0,3	0,15	2400	0,000206861	4834,162616	**6888,682**
13	14	silty sand	loose	8	0,3	2400	0,8	0,4	0,3	0,15	1920	0,000258576	3867,330093	**3383,914**
14	15	silty sand	loose	6	0,3	1800	0,8	0,4	0,3	0,15	1440	0,000344768	2900,49757	**3383,914**
15	16	silt with sand	very loose	6	0,3	1800	0,9	0,5	0,3	0,15	1620	0,00032341	3092,053213	**1958,3**
16	17	silt with sand	very loose	3	0,3	900	0,9	0,5	0,3	0,15	810	0,000646819	1546,026607	**1958,3**
17	18	silt with sand	very loose	4	0,3	1200	0,9	0,5	0,3	0,15	1080	0,000485115	2061,368809	**1958,3**
18	19	silt with sand	very loose	4	0,3	1200	0,9	0,5	0,3	0,15	1080	0,000485115	2061,368809	**1958,3**
19	20	sandy silt	very loose	3	0,2	600	0,9	0,5	0,3	0,15	540	0,000970229	1030,684404	**1958,3**
20	21	sandy silt	loose	4	0,2	800	0,9	0,5	0,3	0,15	720	0,000727672	1374,245873	**2061,369**
21	22	sandy silt	loose	5	0,2	1000	0,9	0,5	0,3	0,15	900	0,000582137	1717,807341	**2061,369**
22	23	sandy silt	loose	7	0,2	1400	0,9	0,5	0,3	0,15	1260	0,000415812	2404,930277	**2061,369**
23	24	sandy silt	loose	8	0,2	1600	0,9	0,5	0,3	0,15	1440	0,000363836	2748,491745	**2061,369**

$$\frac{1}{k_h} = \frac{1}{3E_p}\left[1{,}3R_0\left(2{,}65\frac{R}{R_0}\right)^{\alpha} + \alpha R\right]$$

With:
$R_0 = 0{,}3$m
$R = D/2$
$E_p = \beta * q_c$

For R=300 mm
Sand: q_c= 0,2-0,3
Peat: q_c = 0,3-0,45
with α and β:

Grondsoort	α	β
Veen	1	3,0
Klei	2/3	2,0
Silt	1/2	1,0
Zand	1/3	0,7
Grind	1/4	0,5

7. Appendix wind

In this appendix, information of calculations of wind loads is given.

Peak velocity to peak wind pressure

c_dir	Directional factor	1,00	-
c_season	Seasonal factor	1,00	-
v_b0	Fundamental value of basic wind velocity	37,20	m/s
ρ_air	Air density	1,25	kg/m^3
q_b	Basic velocity pressure	864,90	N/m^2
terrain category iii			
z,0ii	Terrain category II	0,05	m
z_min	Minium height	3,00	m
z	Height of object	8,00	m
z_	roughness length	0,05	m
c_0	Orography factor	1,00	-
k_r	Terrain factor	0,019	-
c_r	Roughness factor	0,96	-
v_m	Mean wind velocity	35,87	m/s
k_l	Turbulence factor	1,00	-
l_v	Turbulence intensity	0,20	-
q_p	Peak pressure	1913,45	N/m^2
w	Wind pressure	1,91	kN/m^2

8. Appendix wind waves

In this appendix, information of calculations of wind waves is given.

Bretschneider

$$\bar{H} = 0,283 \tanh(0,53\bar{d}^{0.75}) \tanh\left(\frac{0,0125\bar{F}^{0,42}}{\tanh(0,53\bar{d}^{0,75})}\right)$$

$$\bar{T} = 7,54 \tanh(0,833\bar{d}^{0,375}) \tanh\left(\frac{0,077\bar{F}^{0,25}}{\tanh(0,833\bar{d}^{0,375})}\right)$$

With:

$$\bar{H} = \frac{gH_s}{U^2}, \qquad \bar{T} = \frac{gT_p}{U}, \qquad \bar{F} = \frac{gF}{U^2}, \qquad \bar{d} = \frac{gd}{U^2}$$

F = strike length (fetch)
U = wind velocity at a height of 10 meters
d = waterdepth

$$L = \frac{gT}{2\pi} \cdot \tanh\left(\frac{2\pi d}{L}\right) \cdot T$$

(Koekoek, 2010)

Output wind generated waves

d (m)	U (m/s)	F (m)	d' (m)	F' (m)	H' (m)	H (m)	T' (s)	T (s)	L (m)	design H
0,5	**38**	**500**	0,003	3,397	0,002	0,308	0,584	2,262	**4,679**	**0,693803**
1,0	**38**	**500**	0,007	3,397	0,003	0,486	0,649	2,513	**7,035**	**1,094323**
1,5	**38**	**500**	0,010	3,397	0,004	0,596	0,679	2,630	**8,622**	**1,341898**
2,0	**38**	**500**	0,014	3,397	0,005	0,666	0,697	2,700	**9,757**	**1,497541**
2,5	**38**	**500**	0,017	3,397	0,005	0,711	0,709	2,747	**10,621**	**1,59998**

9. Appendix: Elastic foundation

Water can be schematised as an elastic foundation with a subgrade modules K=10 kN/m^3

Formula for stresses on an elastic support:

$\sigma = k * u$

σ = stress in N/m^2
k = subgrade modulus
u = deflection

$k_{water} = \rho * g$ = 10.000 N/m^3 = 10 kN/m^3

10. Appendix: Load cases due to wind waves

In this appendix an overview of wave situations is given.

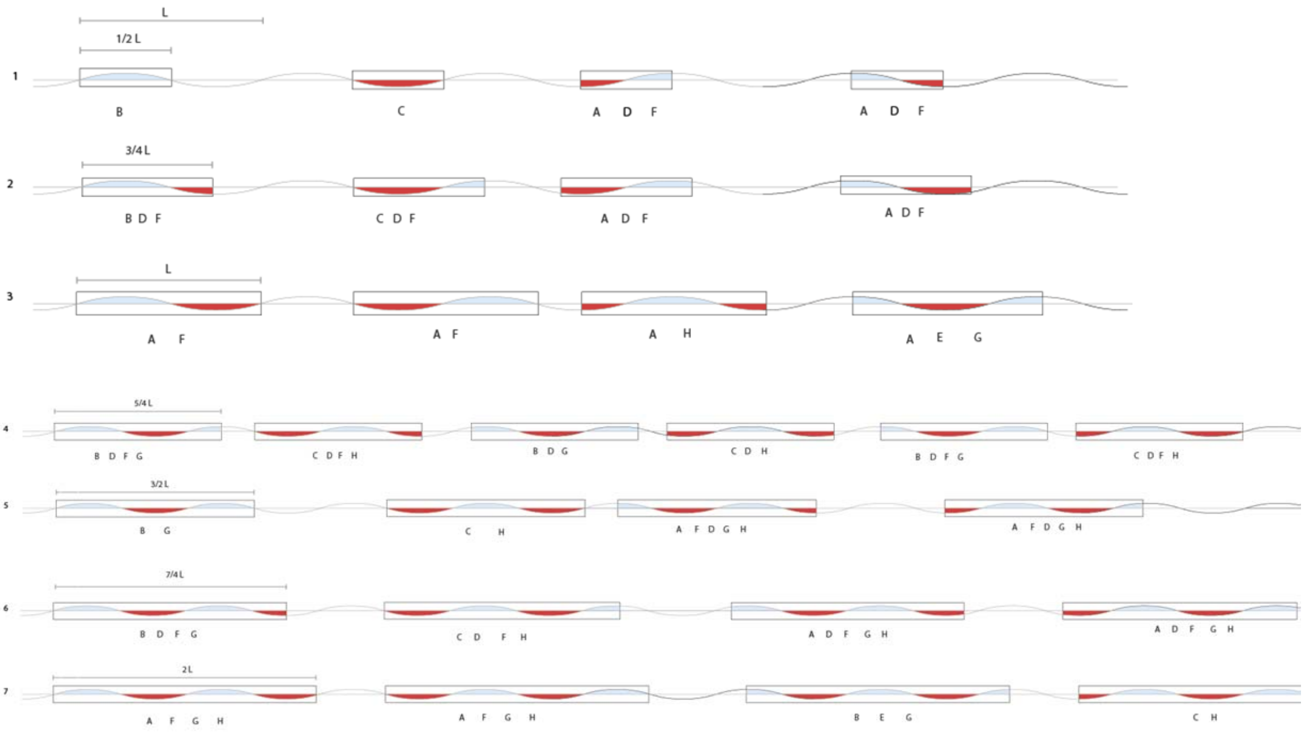


Figure 7: wave situations

11. Appendix: Parametric calculation

The parametric calculation model consists of several topics. Most important features are described.

1. Input. Here all dimensions and properties of building configurations and dimensions and properties of the amphibious module can be filled in. Dead loads and floating capacity, lead to the draught.

general		
dimensions		
width building (x)	4,8	m
length building (y)	4,8	m
height building	3	m
height roof	2	m
number buildings stacked	2	
number buildings connected x	2	
number buildings connected y	2	
symmetrisch=0	0	
width between (x)	0	m
length between (y)	0	m
total width, building (x)	9,6	m
total length, building (y)	9,6	m
width next building x	2,4	m
length next building y	2,4	m
total width floating structure x	14,4	m
total length floating module y	14,4	m
module size x	2,4	m
module size y	1,2	m
number floating modules x	6	
number floating modules y	12	
height floating module	1	m
total height, building	8	m
total amount barrels	576	
floating structure		
number barrels per module	8	per1,2*2,4
piles per module x	2	
piles per module y	2	
amount of piles total x	3	per zijde
amount of piles total y	3	per zijde
total amount of piles	12	
height barrel	0,931	m
radius barrel	0,2925	m
volume barrel	210	l
mean area	0,22556391	m2
beams		
x-direction		
width	0,069	m
height	0,215	m
length	2,4	m
amount	6	
y-direction		
width	0,069	m
height	0,215	m
length	1,2	m
amount	6	
z-direction		
width	0,069	m
height	0,069	m
length	1	m
amount	9	

upper plate		
thickness	0,024	m
density	660	kg/m3
dead load	0,1584	kN/m2
lower plate		
thickness	0,024	m
desity	400	kg/m3
dead load	0,096	kN/m2
A	0,02967	m2
E	10000000	kN/m2
I	0,00468514	m4
W		
weights		
Floating structure		
weight barrel	7,5	kg
denisty timber	340	kg/m3
dead load barrels	20,8333333	kg/m2
dead load timber	42,8878125	kg/m2
dead load plates	0,2544	kN/m2
dead load floating structure	0,89161146	kN/m2
weight floating module	183,5169	kg
Building		
dead load roof	0,31	kN/m2
Gstructure (per floor)	1,35	kN/m2
total dead load	3,01	kN/m2
weight floatings structure	81,1	kN
weight roof	28,5696	kN
weight building	248,832	kN
Gtotaal	358,5016	kN
Q	3	kN/m2
psi	0,4	
Qtotaal per m2	4,2	kN/m2
Qtotaal	387,072	kN
Fsum;d	745,5736	kN
Opp tonnen	129,924812	m2
Draught	0,57385005	m

2. All heeling moments are calculated in both x and y direction. As well the metacentric height is calculated.

x-direction

meta center		
x-richting		
KG	3,500435145	m
KM	30,39932106	m
MG	26,89888592	m
KB	0,286925025	m
BG	3,213510119	m
moment		
wind		
Fwind	189,0953551	kN
distance	4,213074975	m
Mwind	796,6729085	kNm
scheefstand	2,27662842	°
zakking hoek	0,286240223	m
Mexcentric		
p (personen per m2)	1	
q	1,03005	kN/m2
F	74,1636	kN
distance	3	m
M	222,4908	kNm
scheefstand	0,635651073	°
zakking hoek	0,079881547	m
TOTAAL		
Mtotaal	1019,163708	kNm
sin(phi)	0,050818183	
scheefstand	2,912922111	°
	0,050840082	rad
zakking hoek	0,366364291	m
M2e orde		
horizontale verpl G(bena	0,163516022	m
Gewicht	745,5736	kN
M2e orde	121,9132291	kN
scheefstand	0,348298278	°
zakking hoek	0,043768992	m
MTOTAAL	1141,076938	kNm
sin(phi)	0,056897098	
tilt	0,056927841	rad
	3,26172503	°

ydirection

meta center		
x-richting		
KG	3,500435145	m
KM	30,39932106	m
MG	26,89888592	m
KB	0,286925025	m
BG	3,213510119	m
moment		
wind		
Fwind	189,0953551	kN
distance	4,213074975	m
Mwind	796,6729085	kNm
scheefstand	2,27662842	°
zakking hoek	0,286240223	m
Mexcentric		
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q	1,03005	kN/m2
F	74,1636	kN
distance	3	m
M	222,4908	kNm
scheefstand	0,635651073	°
zakking hoek	0,079881547	m
TOTAAL		
Mtotaal	1019,163708	kNm
sin(phi)	0,050818183	
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	0,050840082	rad
zakking hoek	0,366364291	m
M2e orde		
horizontale verpl G(benadering	0,163516022	m
Gewicht	745,5736	kN
M2e orde	121,9132291	kN
scheefstand	0,348298278	°
zakking hoek	0,043768992	m
MTOTAAL	1141,076938	kNm
sin(phi)	0,056897098	
tilt	0,056927841	rad
	3,26172503	°

3. Eigen periods among heave, roll and pitch oscillation is calculated and compared with the wave period.

oscillation x-direction

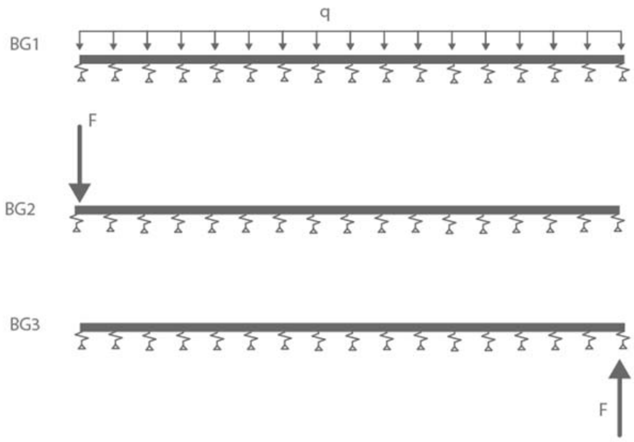
heave		
T(0)	4,059941	s
Twave	3,140101	s
roll		
Izz	73,728	m4
Ixx	0,8	m4
Ipolar	74,528	m4
Aw	92,16	m2
j	0,899267	m
T(0)	0,382343	s
pitch		
Izz	73,728	m4
Ixx	0,8	m4
Ipolar	74,528	m4
Aw	92,16	m2
j	0,899267	m
T(0)	0,382343	s

oscillation y-direction

heave		
T(0)	4,059941	s
Twave	3,140101	s
roll		
Izz	73,728	m4
Ixx	0,8	m4
Ipolar	74,528	m4
Aw	92,16	m2
j	0,899267	m
T(0)	0,382343	s
pitch		
Izz	73,728	m4
Ixx	0,8	m4
Ipolar	74,528	m4
Aw	92,16	m2
j	0,899267	m
T(0)	0,382343	s

12. Appendix: Non linear check

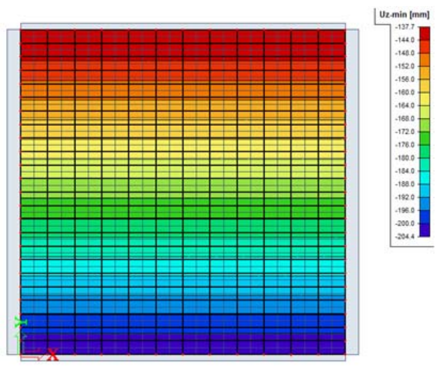
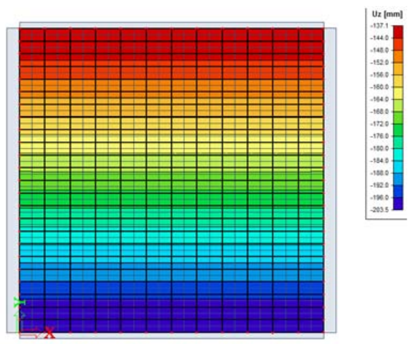
Non linear behaviour

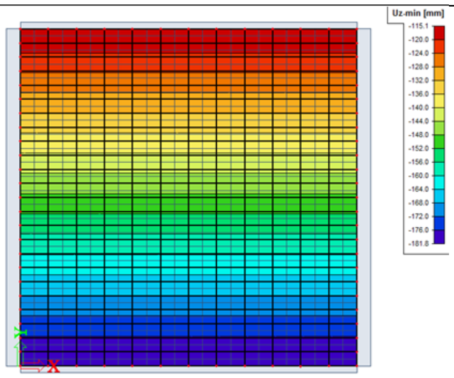
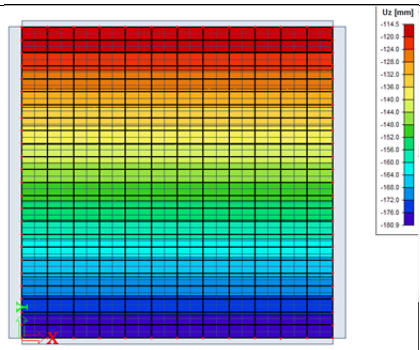
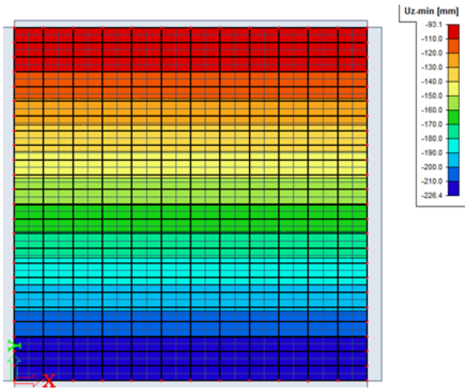
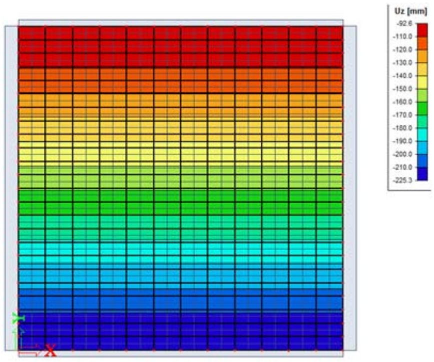
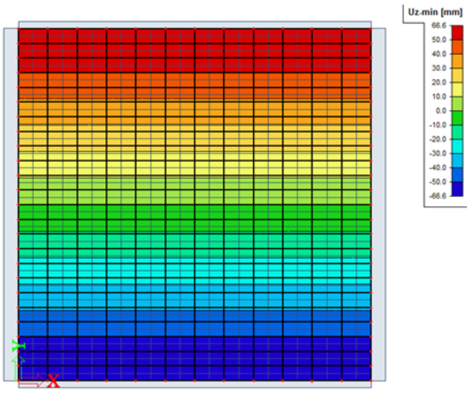
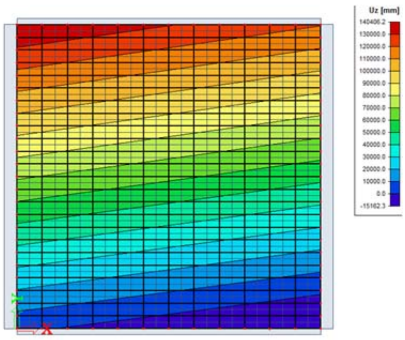
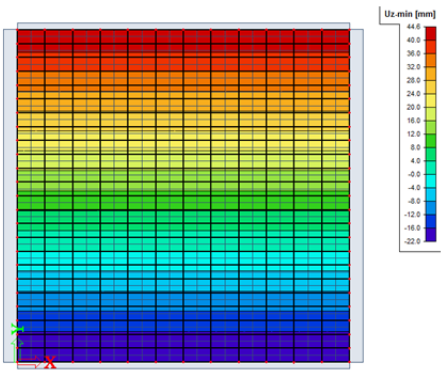


Linear combination 1: BG1,BG2
Linear combination 2: BG1,BG3
Linear combination 3: BG1,BG2, BG3
Linear combination 4: BG2, BG3
Linear combination 5: BG3

Non - Linear combination 1: BG1,BG2
Non - Linear combination 2: BG1,BG3
Non - Linear combination 3: BG1,BG2, BG3
Non - Linear combination 4: BG2, BG3
Non - Linear combination 5: BG3

Output:

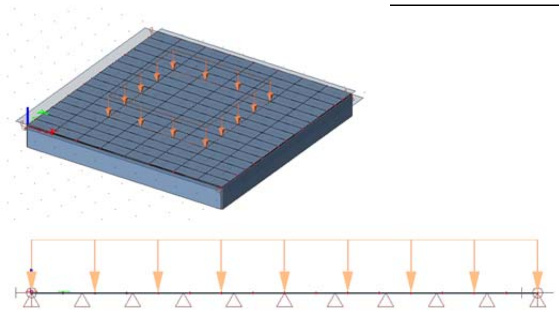
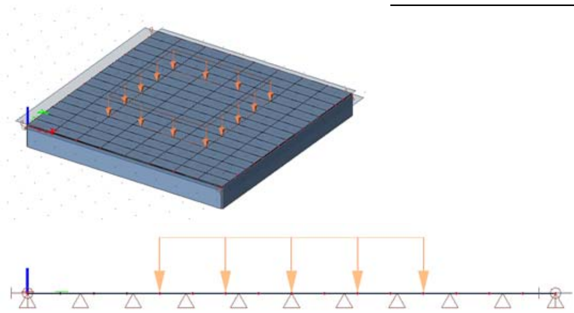
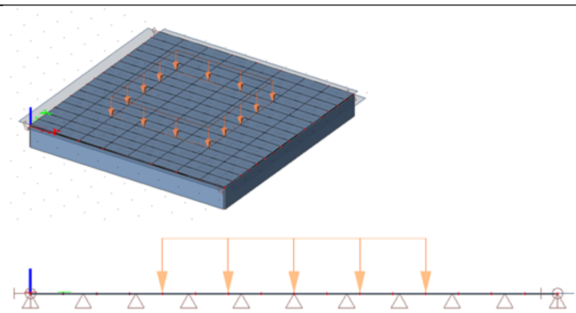
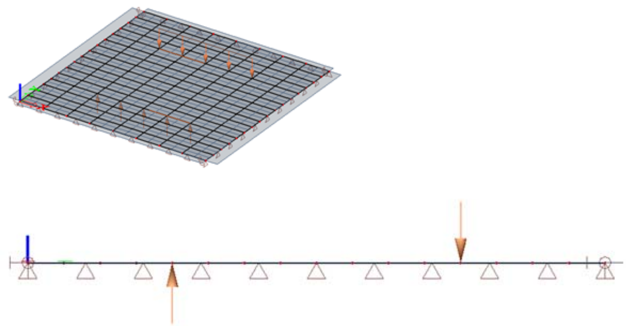
Lcombi 1: 	NLcombi 1: 
L combi:2	NL combi:2

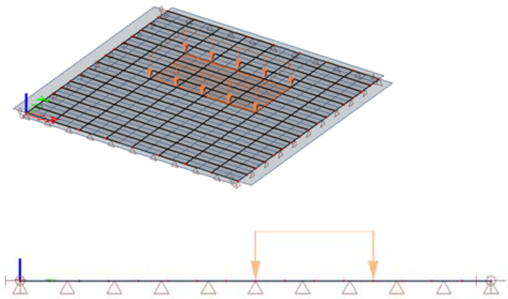
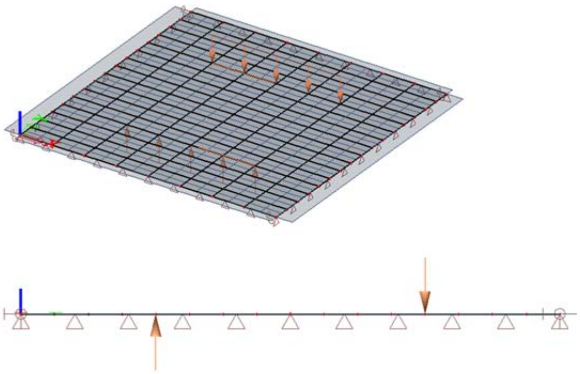
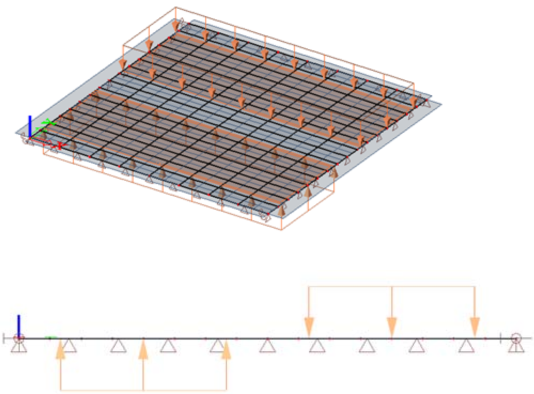
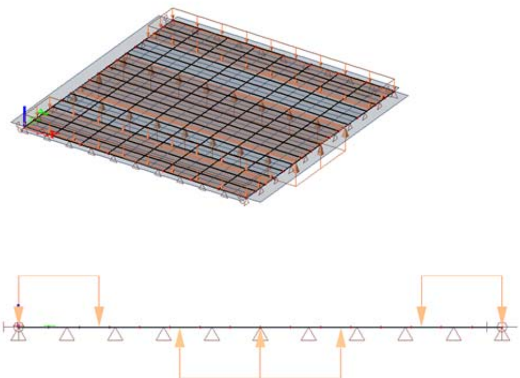
	
L combi 3: 	NL combi 3: 
L Combi 4 	NL Combi 4 
L Combi 5 	NL5: Unable to calculate

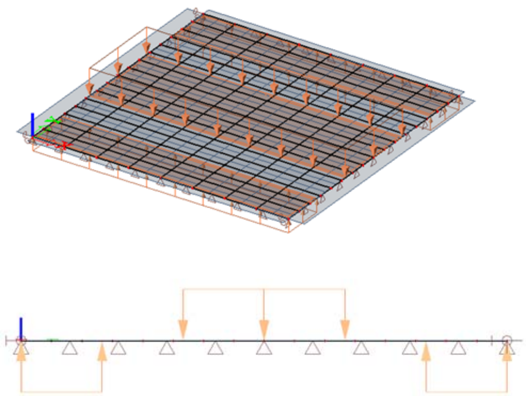
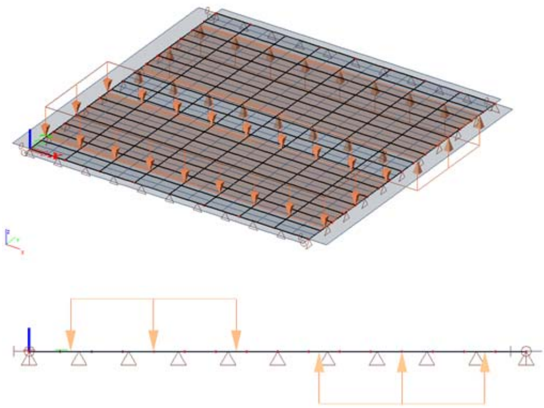
13. Appendix: Input SCIA

Scia input

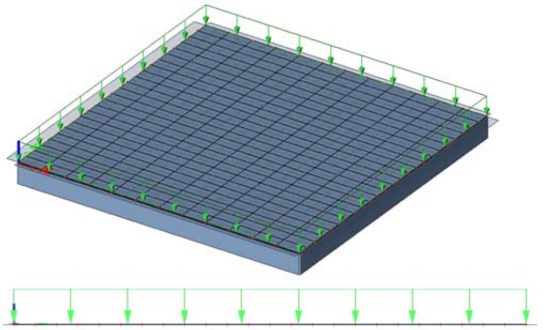
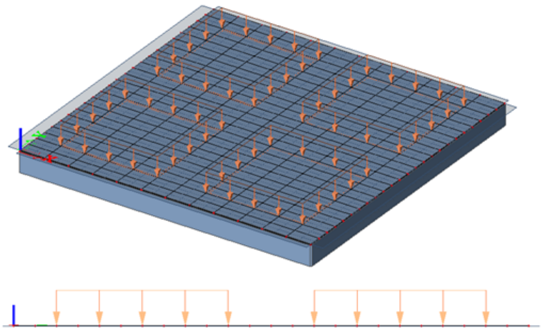
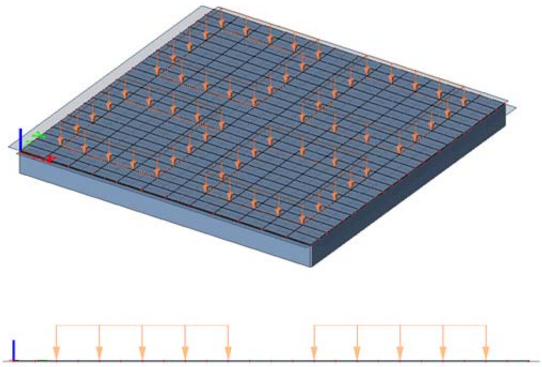
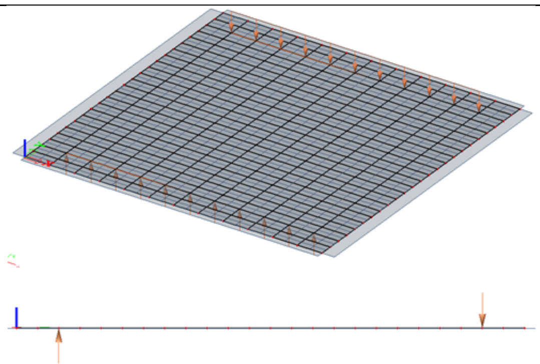
Single building on 9,6m x 9,6 m foundation

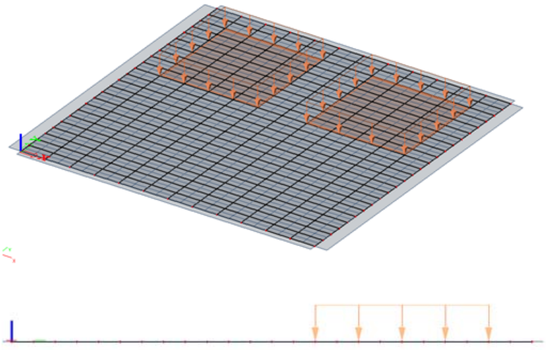
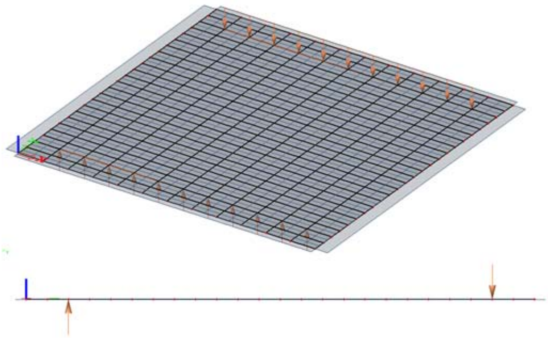
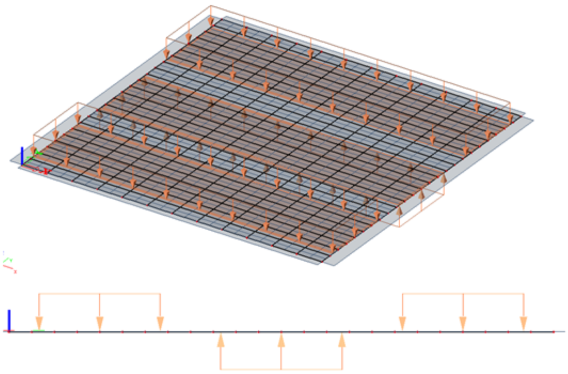
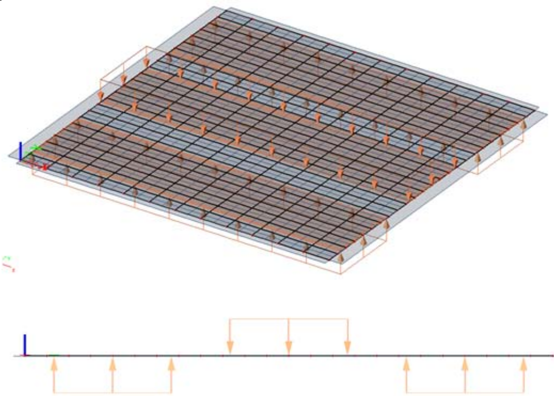
BG1 Dead load foundation		q = 0,88 kN/m^2
BG2 Dead load building		q = 3,01 kN/m^2
BG3 Live load		q = 4,20 kN/m^2
BG4 Wind		q1 = 6,70 kN/m q2 = -6,70 kN/m

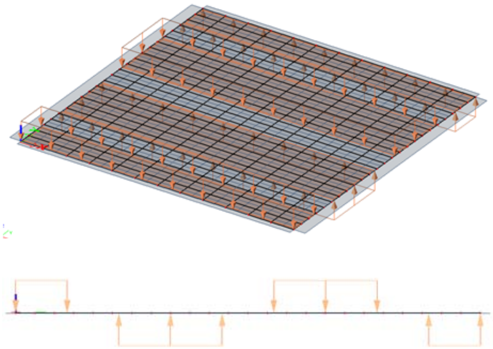
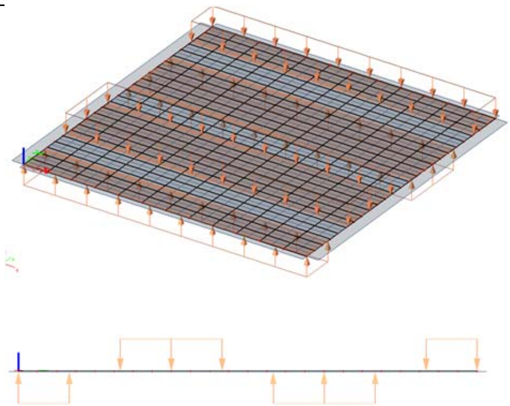
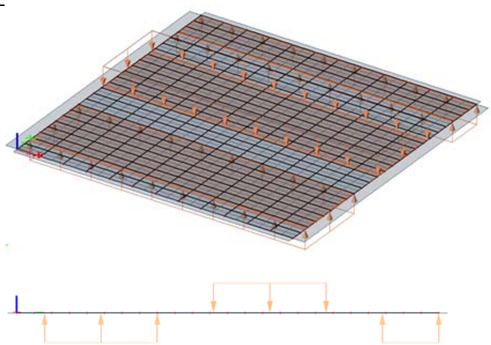
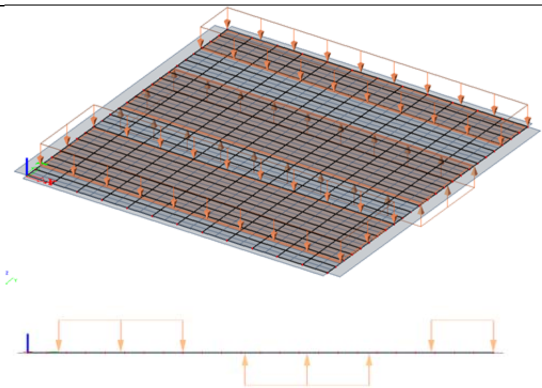
BG5 Eccentric		q = 1,03 kN/m^2
BG6 Second order effect		q= 0,86 kN/m
BG7 Wave 1.1		q = 4,78 kN/m^2
BG8 Wave 1.2		q = 4,78 kN/m^2

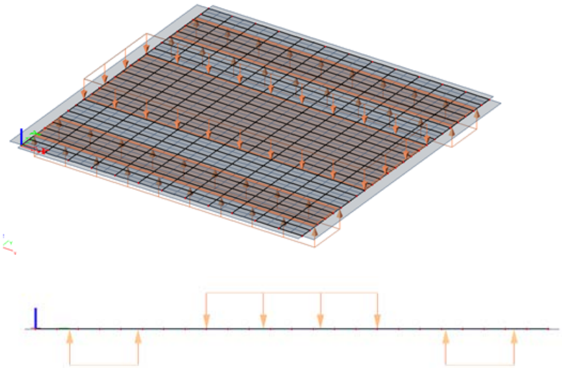
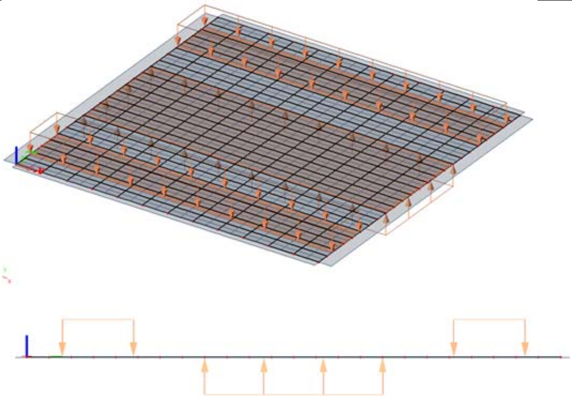
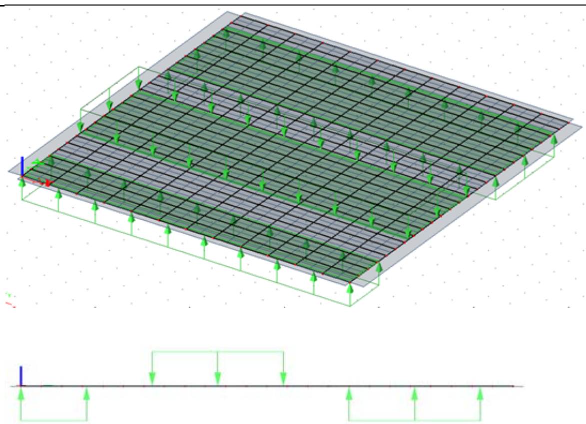
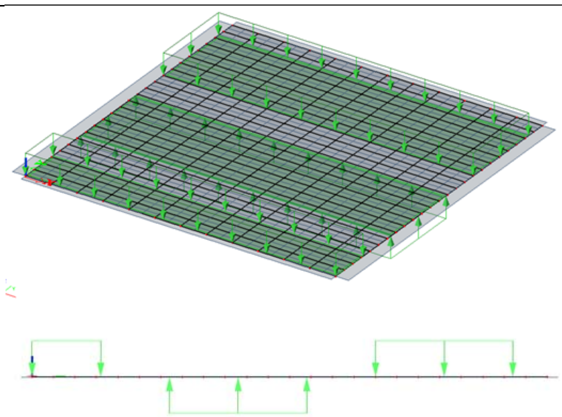
BG9 Wave 1.3		$q = 4{,}78\ kN/m^2$
BG10 Wave 1.4		$q = 4{,}78\ kN/m^2$

Configuration with eight buildings on 14,4 x 14,4 m foundation

BG1 Dead load foundation		q = 0,88 kN/m^2
BG2 Dead load building		q = 3,01 kN/m^2
BG3 Live load		q = 4,20 kN/m^2
BG4 Wind		q1 = 5,41kN/m q2 = -5,41 kN/m

BG5 Eccentric		$q = 1,03$ kN/m^2
BG6 Second order effect		$q = 0,73$ kN/m $q2 = -0,73$ kN/m
BG7 Wave 1.1		$q = 4,78$ kN/m^2
BG8 Wave 1.2		$q = 4,78$ kN/m^2

BG9 Wave 1.3		q = 4,78 kN/m^2
BG10 Wave 1.4		q = 4,78 kN/m^2
BG11 Wave 2.1		q = 4,78 kN/m^2
BG12 Wave 2.2		q = 4,78 kN/m^2

BG13 Wave 2.3		q = 4,78 kN/m^2
BG14 Wave 2.4		q = 4,78 kN/m^2
BG15 Wave 2.5		q = 4,78 kN/m^2
BG16 Wave 2.6		q = 4,78 kN/m^2

14. SCIA output

Single building with 9,6mx9,6m foundation:

Floating

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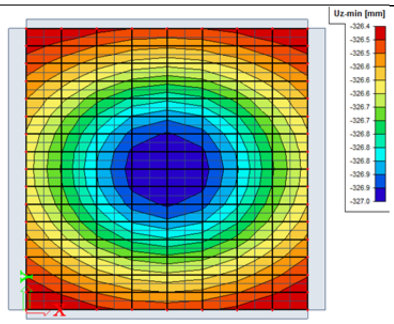
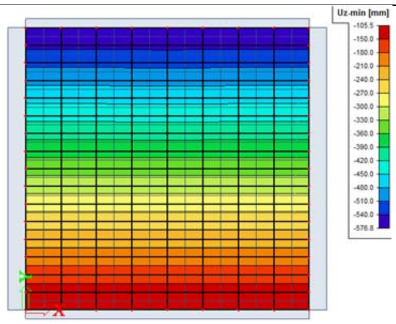
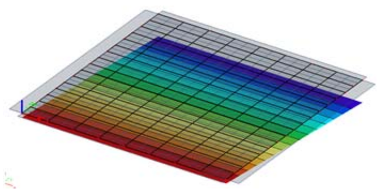
<tr><th>Combination</th><th>U (mm)</th></tr>
<tr><td>1</td><td>

-326,4 ; -327</td></tr>
<tr><td>2</td><td>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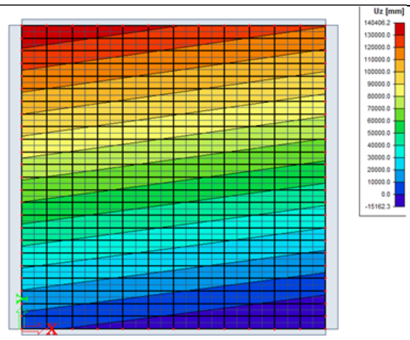
<tr><td>3</td><td>
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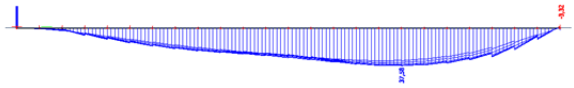
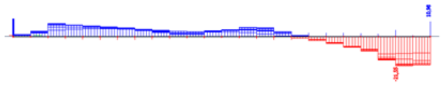
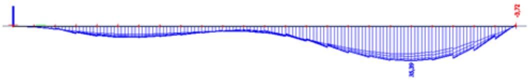
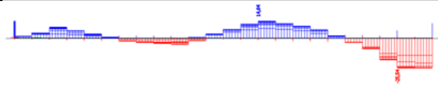
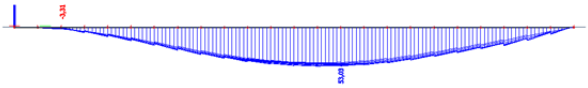
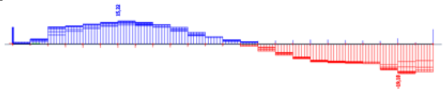
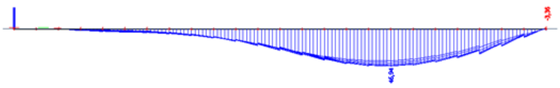
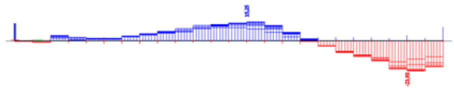
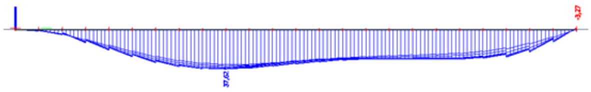
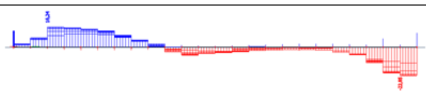
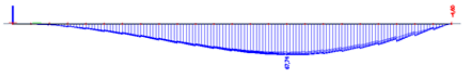
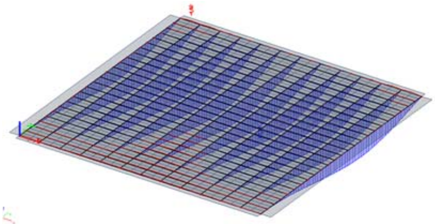
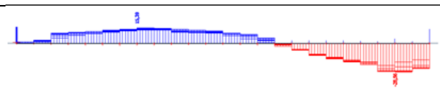
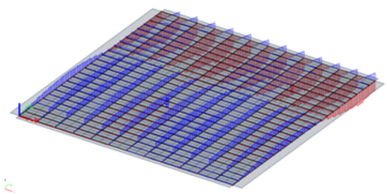
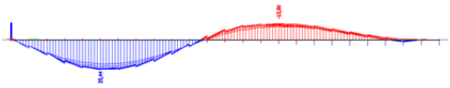
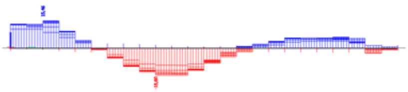
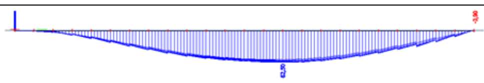
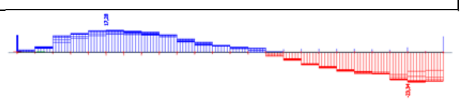
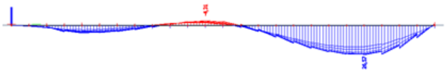
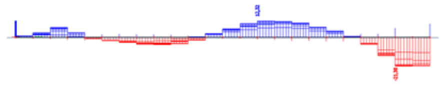
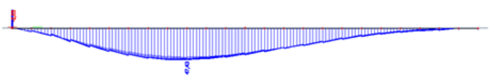
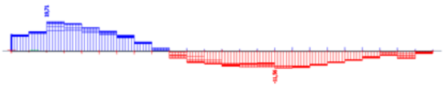
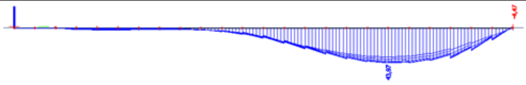
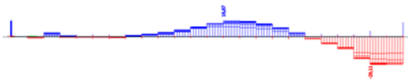
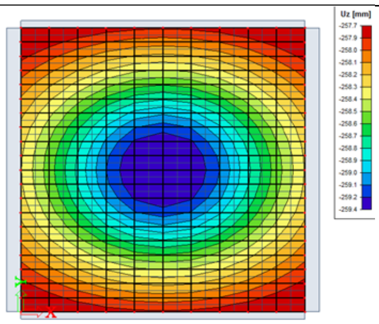
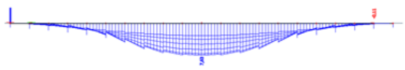
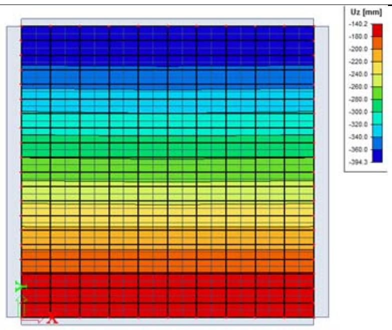
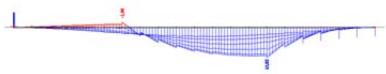
Just floating,

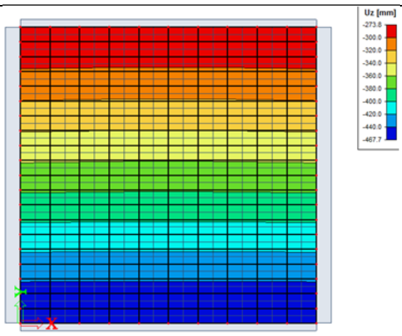
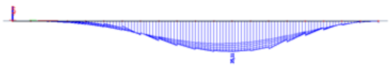
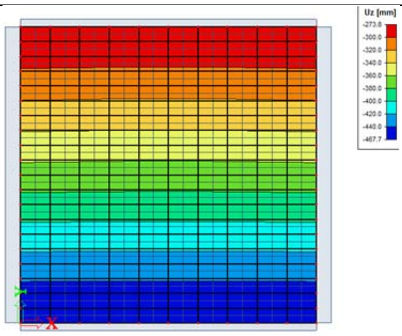
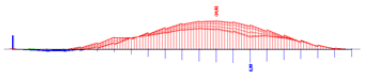
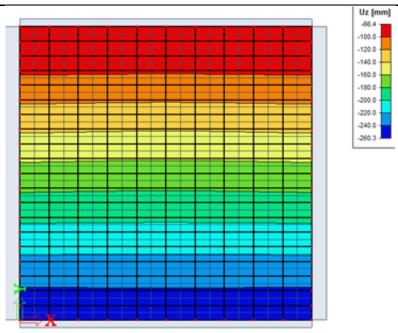
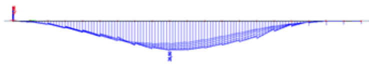
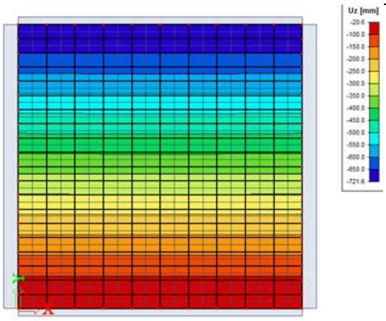
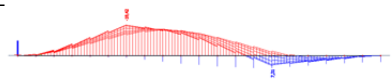
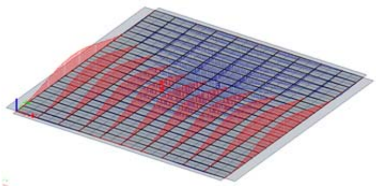
comb i	M_y (kNm)	V_z (kN)
tilt	 -3.32 kNm; 37,58	 -21,55 kN ; 10,88 kN
1.1	 -3,72 kNm; 35,29 kN,	 -25,54; 14,64
1.2	 -3,31 ; 53,03	 -19,10 ; 15,22
1.3	 -3,36 ; 46,94	 -23,93 ; 15,25
1.4	 -3,27 ; 37,62	 -22,85 ; 16,24
2.1	  -4,80 ; 67,74	  -28,56 ; 15,29
2.2	 -13,80 ; 25,44	 -15,60 ; 15,46
2.3	 -3,90 ; 62,50	 -23,34 ; 17,28

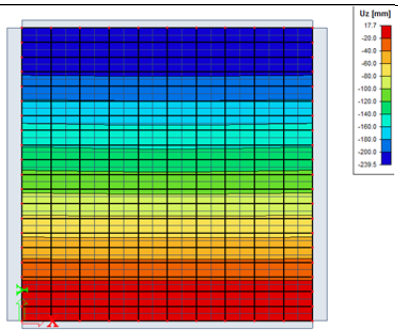
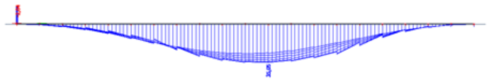
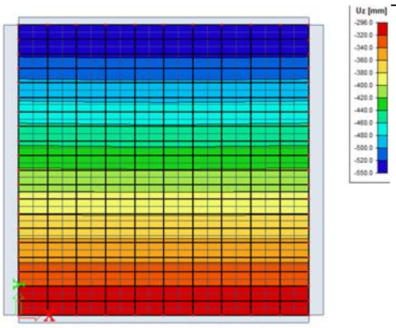
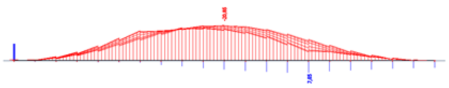
2.4	 -4,31 ; 26,57	 -21,30 ; 12,32
2.5	 -2,03 ; 47,43	 -11,56 ; 19,71
2.6	 -4,47 ; 43,97	 -29,11 ; 16,67

Single building on 12m x 12m

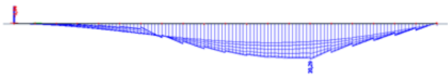
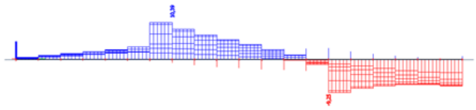
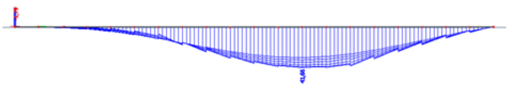
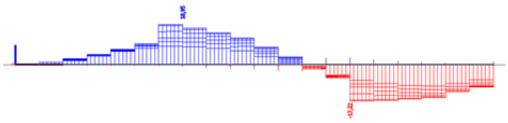
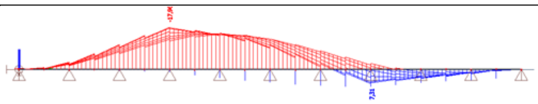
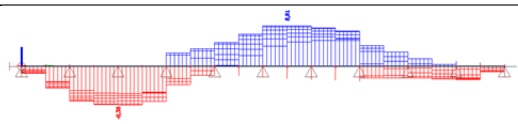
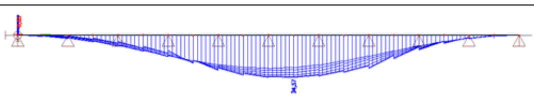
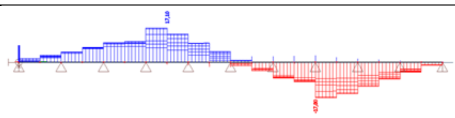
Floating

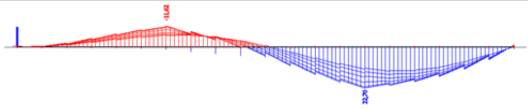
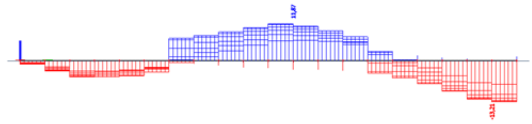
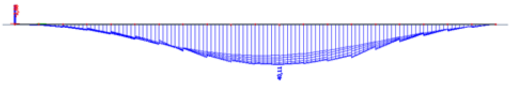
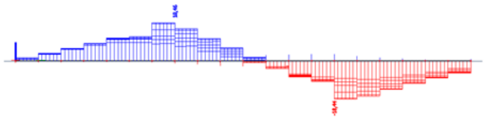
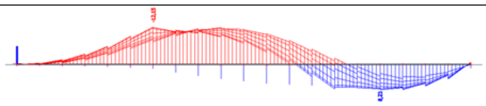
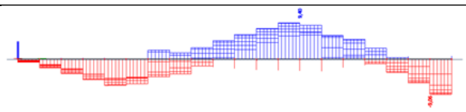
	U (mm)	M_y (kNm)
1	 -257,7 ; -259,4	
2	 -140,2 ; -394,4	

3	 273,8 ; -467,7	
4	 -273,8 ; -467,7	
5	 -66,4 ; -266,3	
6	 -20,6 ; -721,6	 

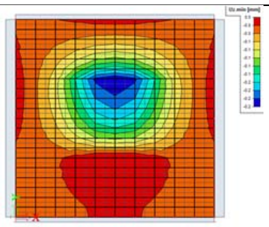
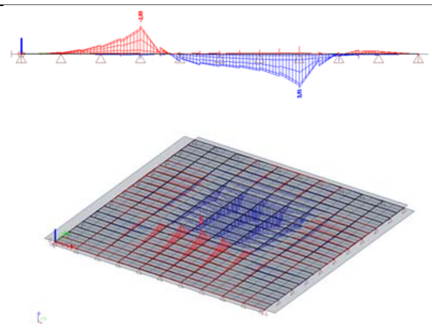
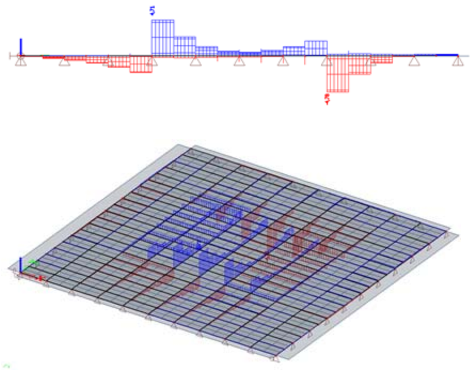
7		
8		

Just floating

	M_y (kNm)	V (kN)
2	 -1,04 ; 20,29	 -9,25 ; 10,39
3	 -1,79 ; 41,66	 -17,22 ; 18,95
4	 -17,96 ; 7,31	 -8,38 ; 8,81
5	 -0,65 ; 34,57	 17,10 ; -17,80

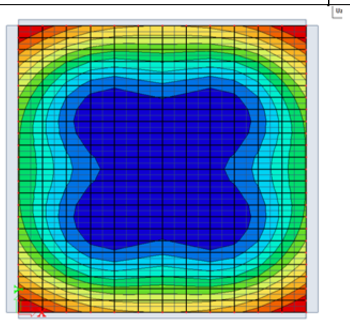
6	 -11,62 ; 22,70	 -13,2 ; 11,87
7	 -2,0 ; 40,11	 -18,44 ; 18,46
8	 -12,15 ; 8,23	 -9,06 ; 9,4

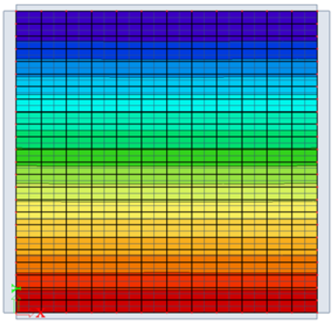
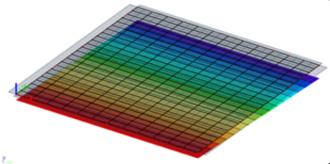
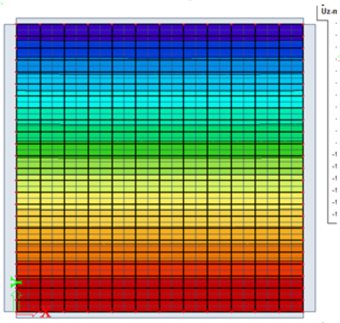
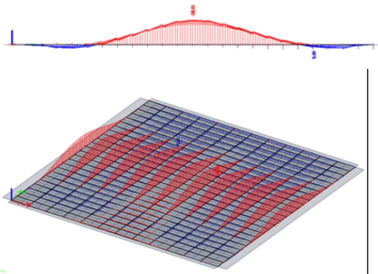
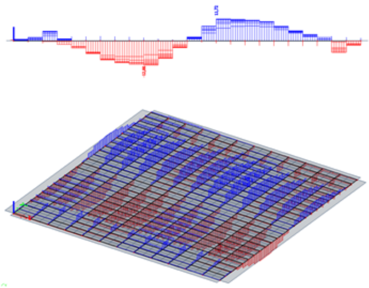
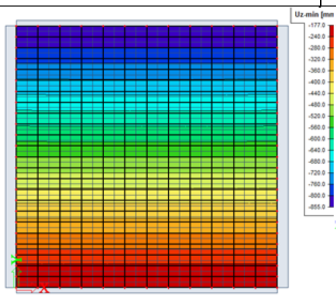
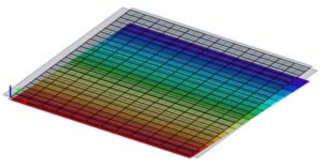
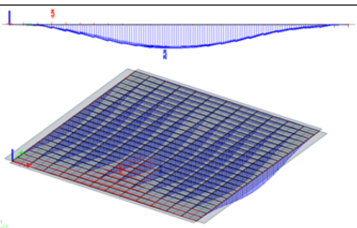
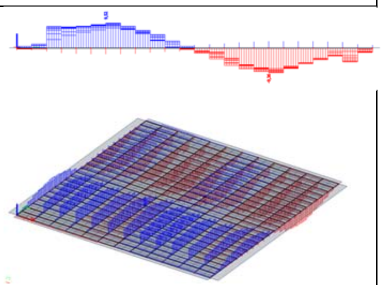
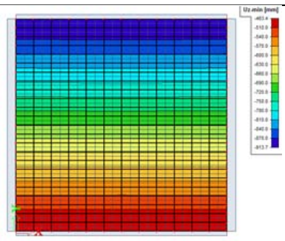
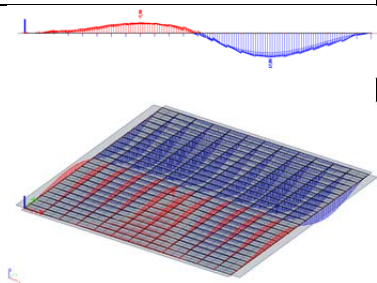
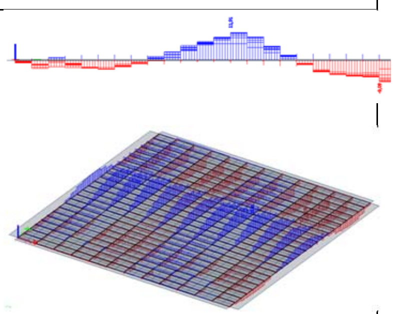
Dry

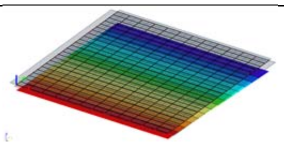
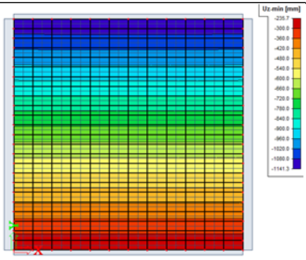
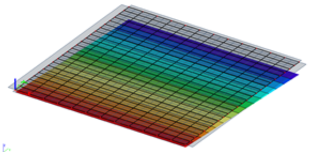
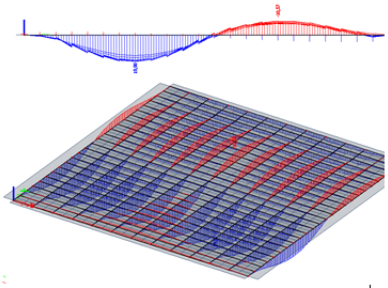
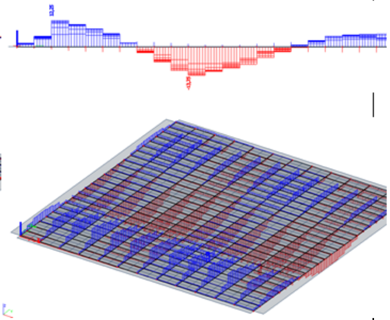
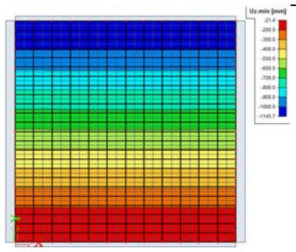
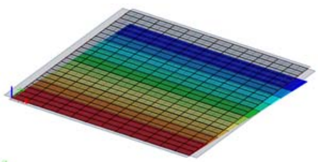
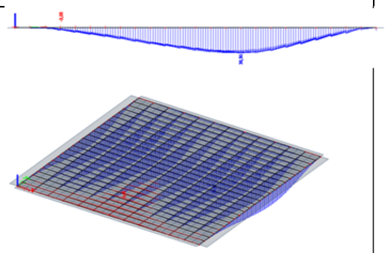
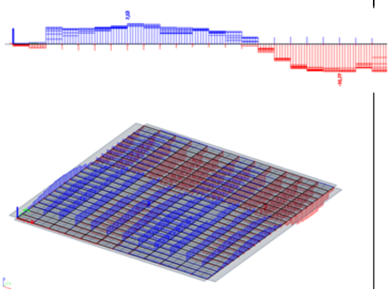
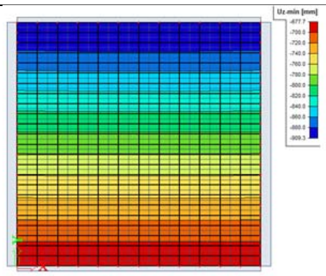
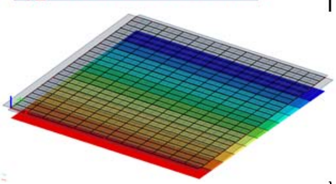
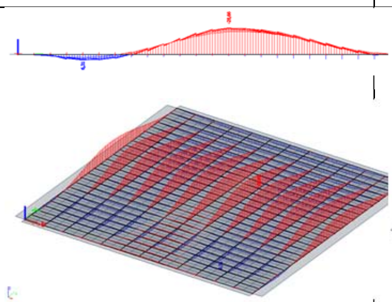
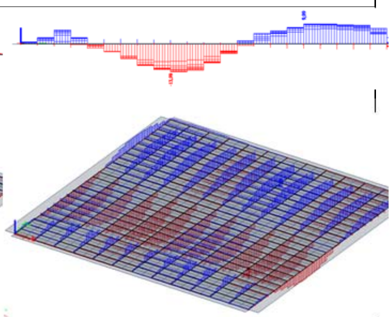
	U (mm)	M_y (kNm)	V (kN)
1.			

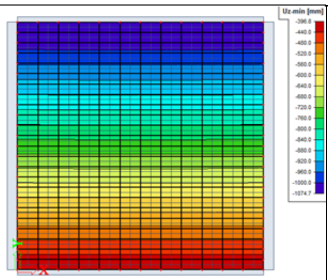
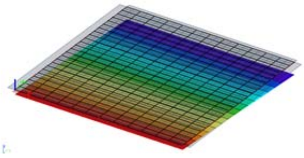
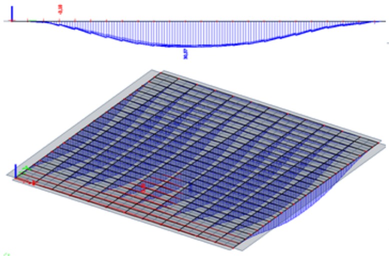
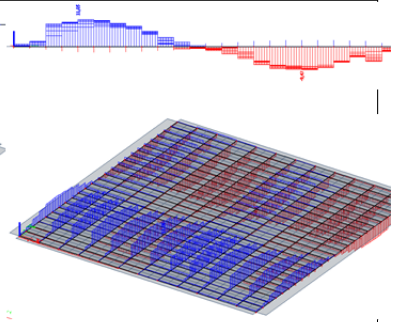
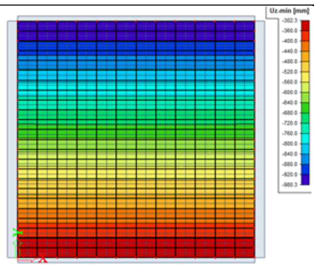
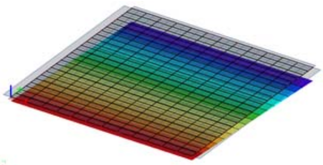
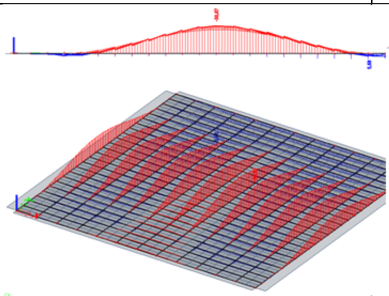
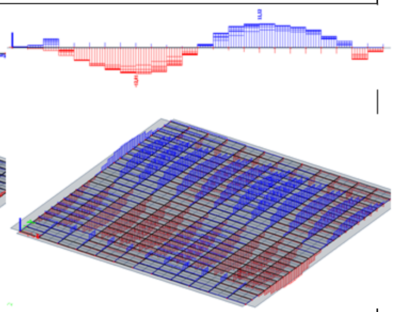
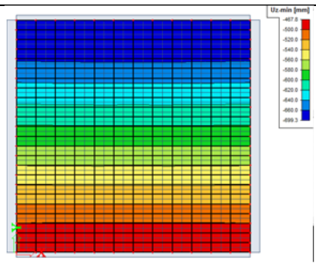
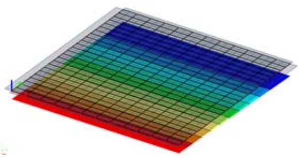
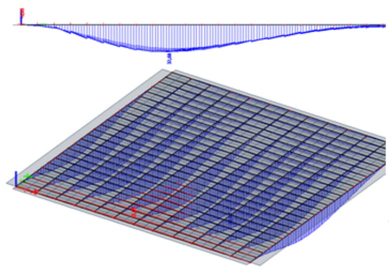
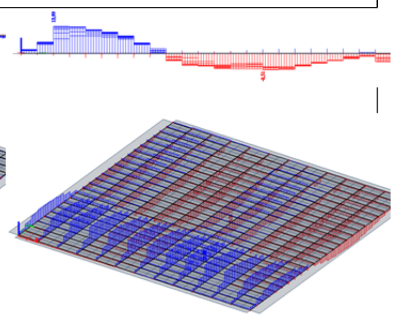
Configuration with eight buildings on 14,4 x 14,4 m foundation

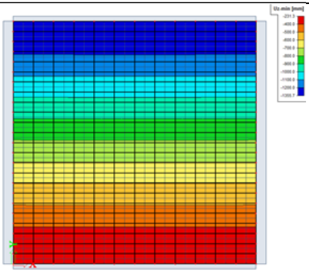
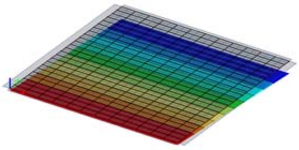
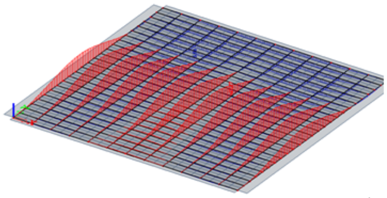
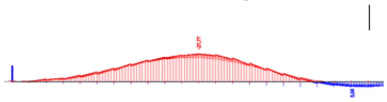
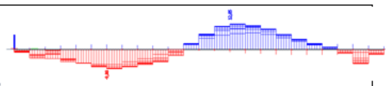
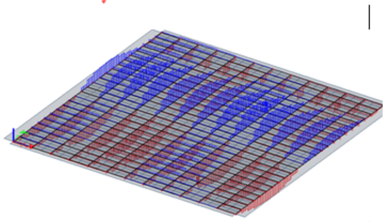
Floating

	U (mm)	M_y (kNm)	V (kN)
1	 -651,7 ; -652,8		

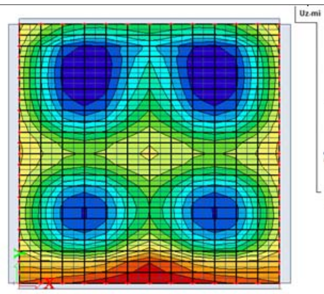
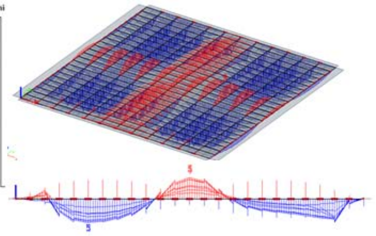
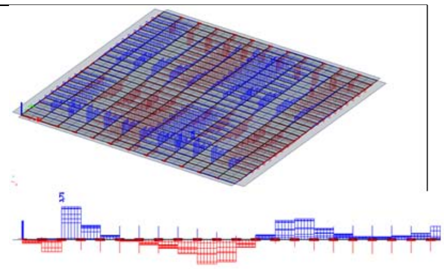
2	 -349,5 ; -1027,5		
1. 1	 	 -28,01 ; 5,65	 -12,86 ; 11,72
1. 2	 	 -3,04 ; 28,36	 -9,36 ; 9,52
1. 3		 -7,58 ; 17,05	 -9,09 ; 11,91

	 -463,4 ; -913,7		
1. 4	  -235,7 ; -1141,3	 -10,57 ; 19,90	 -13,25 ; 12,25
2. 1	  -21,4 ; -1145,7	 -3,05 ; 30,5	 -10,27 ; 7,53
2. 2	  -677,77 ; -909,3	 -28,66 ; 6,13	 -13,99 ; 9,99

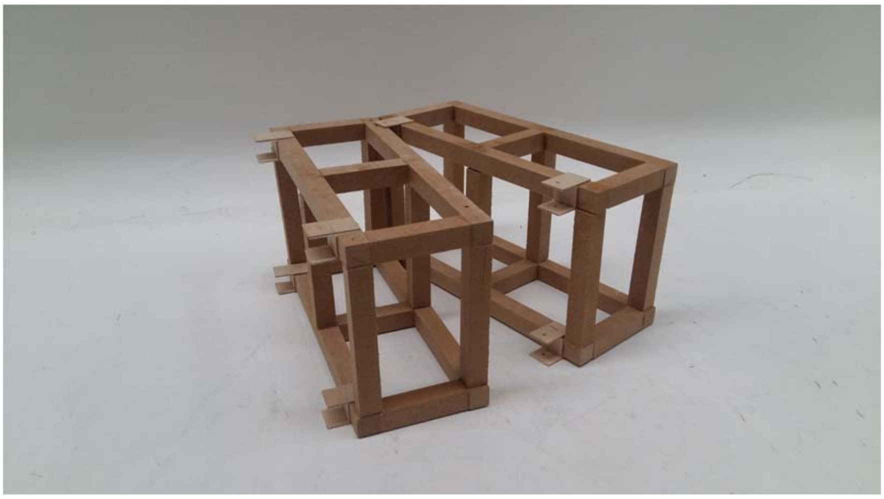
2.3	  -396,8 ; -1074,4	 -3,10 ; 30,57	 -9,47 ; 11,05
2.4	  -302,3 ; -980,3	 -30,07 ; 5,68	 -12,01 11,12
2.5	  -467,8 ; -699,3	 -3,05 ; 32,68	 -8,51 ; 13,99

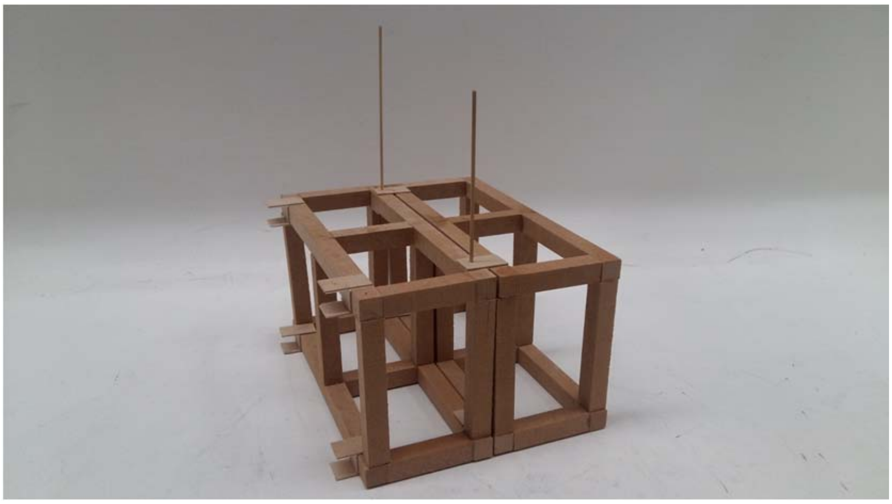
2.6	 	  -27,77 ; 5,68	  -9,88 ; 12,85

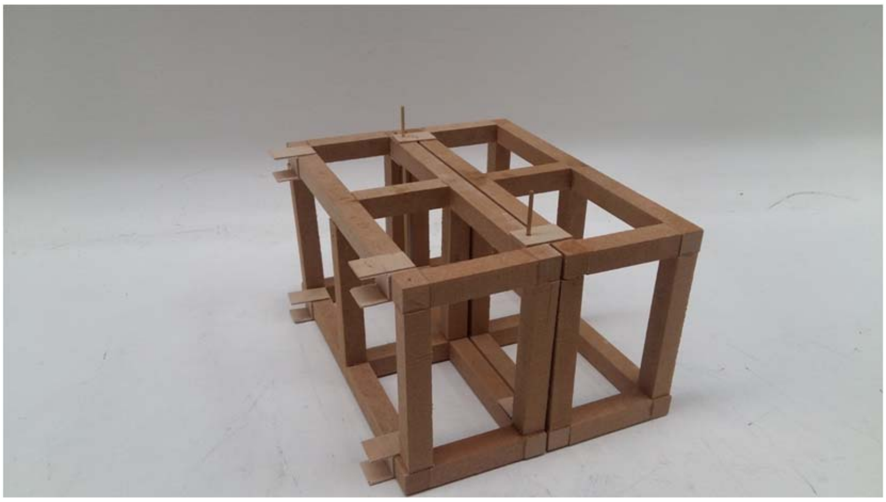
Dry

15. Appendix: Design alternatives







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