ERASMUS MUNDUS MSC PROGRAMME

COASTAL AND MARINE ENGINEERING AND MANAGEMENT

COMEM

[EXTENDING THE COASTLINE: MANMADE ISLANDS AND PENINSULAS]

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24/06/2010
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DEDICATION

This dissertation is dedicated to Prof. Eivind BRATTELAND of Norwegian University of Science and Technology, Prof. Marcel STIVE of Delft University of Technology and Prof. Laurie BOSWELL of City University London, three men of extraordinary vision.

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ABSTRACT

MEHMET TOPAL: Extending the Coastline – Manmade Islands and Peninsulas
(Under the Direction of Prof. Laurie Boswell)

This dissertation shows two methods of Extending the Coastline, namely Manmade Islands and Manmade Peninsulas. It explains the importance of coastline in urban development and for human beings. Previous practices of coastal extension in different parts of the world and related literature are studied. The dissertation investigates the social, economic and environmental effects of manmade island and peninsula construction on marginal and leading edge coasts. Then the dissertation sets forward guidelines that increase feasibility and decrease failure mechanisms of such coastal structures. The results are revealed, and the conclusion that Coastal Extension via Manmade Islands and Peninsulas lead to a significant improvement on the coastal zone are discussed.

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1 INTRODUCTION

The coastline of the world adds up to approximately 356,000 km (*CIA 2010*). In general, a coastal zone has a number of functions. Among those major functions are housing, fishing, agriculture, water supply, navigation, nature, defense, recreation. The coastal zone system can be schematized in different ways. The system elements can be grouped into two subsystems: the natural and artificial. The latter is created by human interference, characterized by infrastructure and socio-economic functions (d`Angremond 2001).

This dissertation introduces the subject of Extension of Coastline and outlines two major coastal extension types: Manmade Island and Manmade Peninsulas. The dissertation aims to review the related literature and previous practices regarding the coastal extension. Then the dissertation inductively comes up with guidelines which increase the feasibility, sustainability and decrease failure mechanisms of such coastal structures.

The method adopted consists of literature review in the subject, case studies of economic, social and environmental and engineering aspects. Then the dissertation sets forward guidelines that increase feasibility and decrease failure mechanisms for implementation of such projects in the future.

Manmade Islands and Peninsulas have been an issue of interest to me due to my internships at Palm Jumeirah Island in Dubai and Kashagan Oil Field Development in Kazakhstan.

Figure 1: Jumeirah, Dubai

Studying the Erasmus Mundus MSc in Coastal and Marine Engineering and Management at Norwegian University of Science and Technology-Norway, Delft University of Technology-the Netherlands and City University London-the UK has also piqued my interest about importance of the length of a coastline and benefits in extension of it.

Figure 2: Kashagan Oil Field Development, Caspian Sea, Kazakhstan

Today, the world is facing a rapid increase in human population. Moreover the majority of the cities in the world are situated in coastal zones (d`Angremond 2001). In facing all these problems, one possible solution is Extension of Coastline by Manmade Islands and Peninsulas.

Figure 3: Development of Urban Conglomerations in the World (d`Angremond 2001)

In order to find out an answer to the research question "Is extension of coastline by manmade islands and peninsulas feasible in different parts of the world?" the following effort has been implemented.

(1) Literature has been reviewed regarding coastal extension, including coastal engineering, soil mechanics, different types of coastal zones, failure mechanisms of earth structures, hydraulic structures, previous examples of coastal extension, uncertainties in the coastal design and climate change.

(2) Engineering, economical, social and environmental aspects of coastal extension by manmade islands and peninsulas were investigated.

(3) After the pros and cons of the manmade islands and peninsulas are clearly understood, the focus will shift to the design and guidelines in building these structures. Methods that will minimize the disadvantages and maximize the advantage will be analyzed and proposed.

(4) Findings are further analyzed and concluded.

The next section consists of the literature review regarding the implementation of manmade islands and peninsulas.

2 LITERATURE REVIEW

Despite its importance in human life and cities, the literature that deals directly with coastal extension: manmade islands and peninsulas is limited. However, a broad understanding of coastal processes, classification of coasts, climate change, sea level rise, dredging, soil mechanics and other hydraulic structures is necessary in order to be able to come up with guidelines on how to build these substructures. In this section, results of the literature research are summarized moving from general considerations to more specific issues. Relevant previous work on the subject will be described and discussed.

2.1 Tectonic Classification of Coasts

Coasts are strongly influenced by plate tectonics. If a coast is situated close to a plate boundary it develops differently from a coast that is not. Coasts are classified into three major types (see Inman & Nordstrom 1971)

2.1.1 Leading Edge or Collision Coast

Leading edge coasts develop along the border of a landmass where the oceanic edge of one plate converges with the continental edge of another. They are distinguished by rugged, cliff shorelines. The tremendous friction created by the converging plate edges causes the lighter continental crusts to fold and buckle, creating the mountain ranges that can often be found near leading edge coasts. This tectonic sitting does not have a shallow, near shore area on which sediments can accumulate (d’ Angremond 2001).

2.1.2 Trailing Edge Coast

Trailing edge coasts develop not at the leading edge of a plate and typically have been tectonically stable for at least tens of millions of years. Along these coasts one can find huge deposits of sediment (d' Angremond 2001).

2.1.3 Marginal Sea Coast

Marginal Sea Coasts are near to the plate boundary where a collision is occurring, but are kept apart from its influence. Although it is fairly close to the tectonic zone, the marginal sea coast is far enough to be unaffected by convergence tectonics. Thus it behaves like a trailing edge coast. A broad and gently sloping continental shelf provides an ideal resting place for large quantities of land derived sediment (d' Angremond 2001).

2.2 Sea Level Change

2.2.1 Sea Level Change by Climate Change

In the past, mean sea level changed by the alternation of interglacial and glacial periods. During the glacial period, icecaps were developed, resulting in a drop in sea level and some parts of the continental shelf becoming dry and swampy. In the warm period, interglacial, the icecaps were melted, producing a restoration of sea level.

The ice sheets (formation and deformation) and the water load (based on the balance of surface gravity with water flow in the ocean) are the regional factors (Verhagen 2009). These changes are also caused by the tectonic movement of the individual coastal areas.

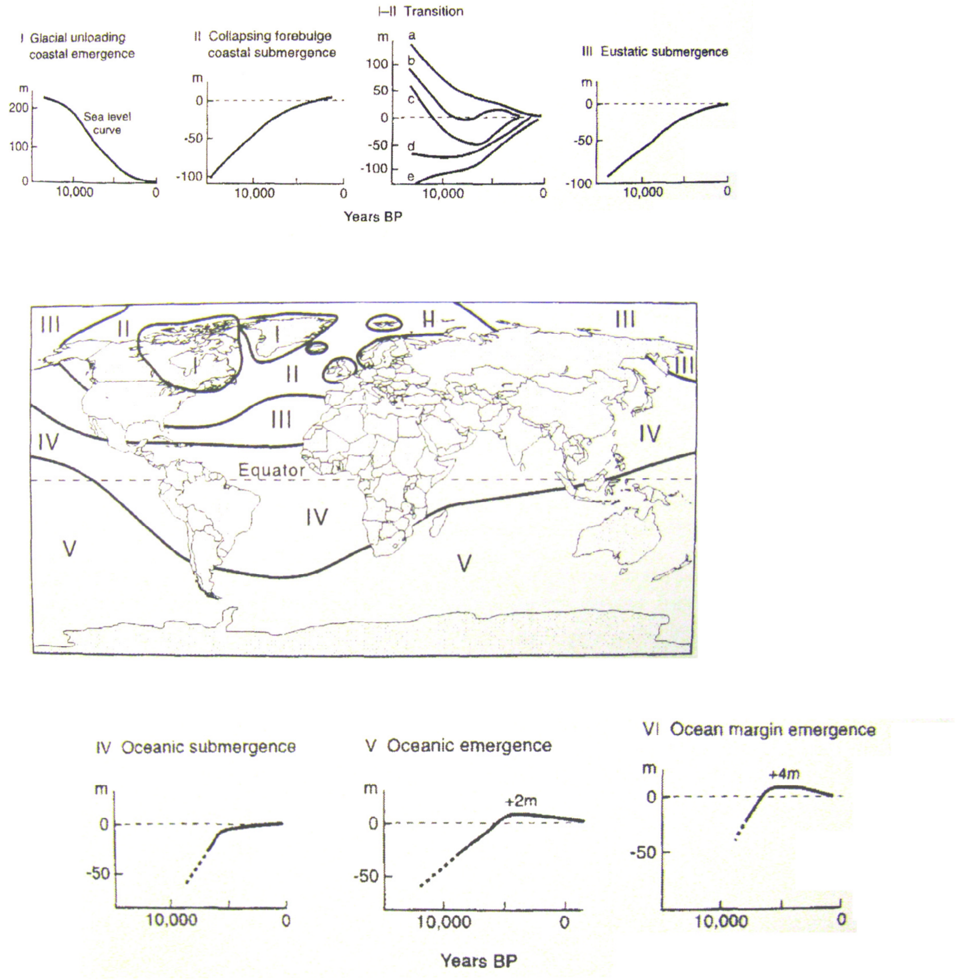


Figure 4: Global Distributions of Six Level Zones of Sea Level Change (Stive 2006)

The climate is expected to change due to the greenhouse effect. This will cause a number of consequences. The temperature change leads to a change of mean sea level, river discharge amount and distribution (because of changing of precipitation and evaporation amount in time and space). According to The Dutch Delta Committee, from present to 2100s, the rising of mean sea level is likely to be between 85 and 130 cm. Moreover, frequency of storm surge is influenced by increasing of temperature. These factors directly affect the design of the coastal extension.

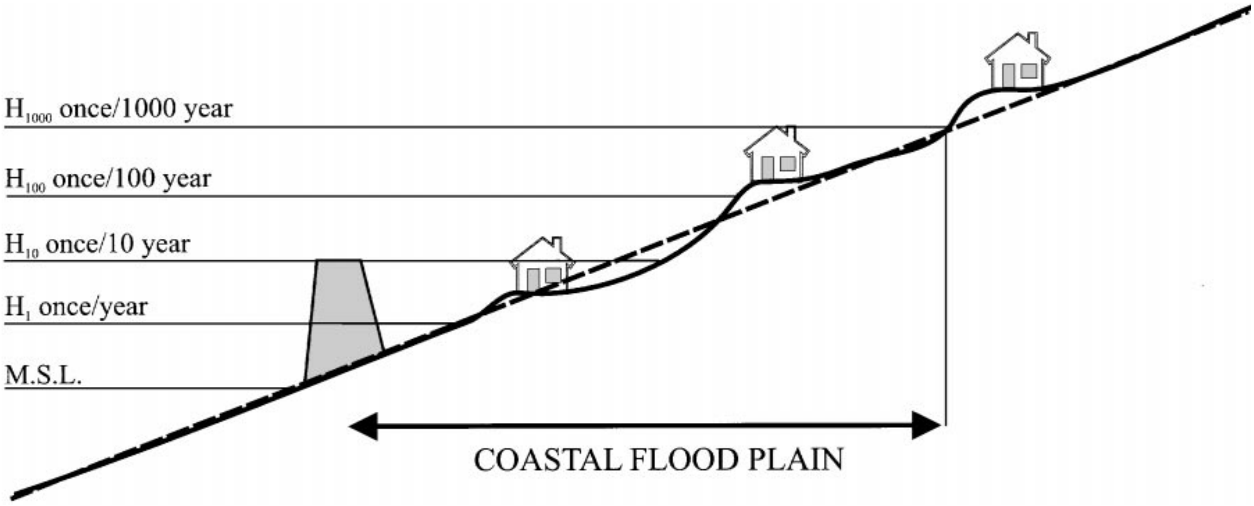


Figure 5: Coastal flood plain and corresponding high water level frequency (Marchand et. al. 1999)

2.2.2 Land Subsidence

Subsidence is the motion of the Earth's surface as it shifts downward relative to a datum such as the sea level. The subsidence of the earth's surface may be caused by different factors. Ground movements, mining activities, gas, oil and water withdrawal are some examples that can causes ground subsidence. There are several different types of land subsidence: *faulting induced, isostatic rebound, extraction of natural gas and oil, dissolution of limestone, mining induced, seasonal effects, groundwater related subsidence.*

In dry areas because of extensive ground water withdrawal, the rate of subsidence increases rapidly (more than 10 cm /year). A decrease in ground water level causes an increase in effective stresses at clay layers which results in the consolidation of lower layers (Kumarci K. et. al 1994). Subsidence rates can vary along the longitudinal profile of deltaic rivers.Drained soil layers tend to consolidate as a result of increased effective stress. In this way, land subsidence has the potential of becoming self-perpetuating; having rates up to 5 cm/yr in the extreme cases (Galloway 2000).

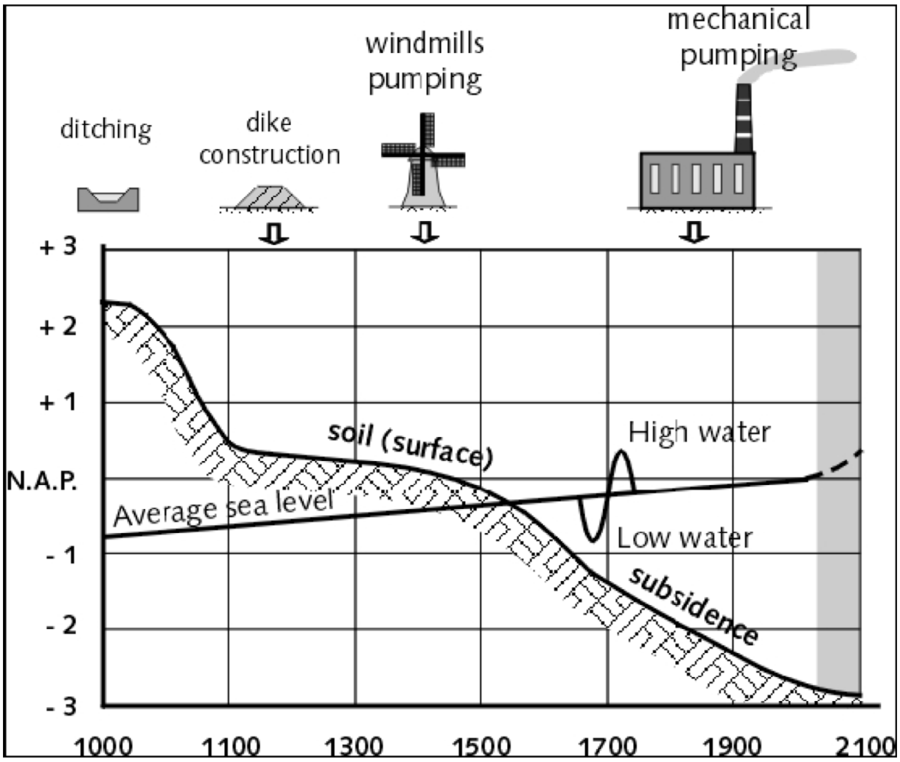


Figure 6: Sea Level in the Last 1000 Years

2.3 Failure Modes of Soil Structures

The following figure illustrates the different circumstances that may compromise the efficiency of soil structures.

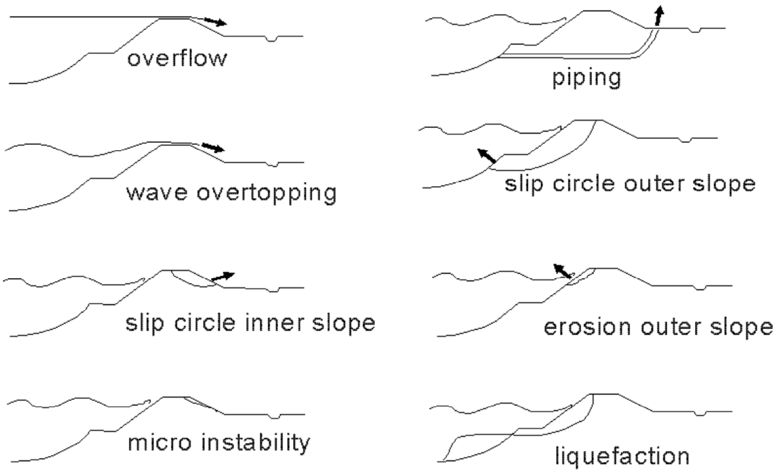


Figure 7: Different failure mechanisms of soil structures

If any of these mechanisms occur to an extreme degree, the soil structure may breach, resulting in ultimate failure. The most common modes of failure are due to piping and flow slides caused by liquefaction of slope soil.

2.3.1 Seepage and Piping

Seepage refers to the presence of a water flow through or beneath a permeable structure such as an earth structure. As long as the flow possesses a relatively low velocity and volume and is well monitored, it can be tolerated. Problems begin to arise when both the flow and quantity increase resulting in erosion of the foundation soil. Also, the increase in saturation of the soil will decrease the strength of the substructure's foundation. This will also decrease the island`s resistance to strong wave attacks and current.

Seepage can occur either beneath or through an earth structure (Byron 2009). In order to avoid such situations, a filter is applied at the toe of the earth structure (Mishra & Singh 2005). This filter is necessary to keep the top phreatic line as low as possible so that the dry zone of the earth structure can be as large as possible. A larger dry zone produces a more stable earth structure. The effectiveness of the filter is dependent on its positioning and length.

If the seepage underneath an earth structure causes severe erosion of the soil, it will result in piping. Soil particles will become entrained in the groundwater flow (Van Noortwijk 1999). This mixture flow will emerge on the downstream side of the earth structure due to capillary effects, seriously reducing the stability and support of the island. Piping occurs when the critical head becomes less than the stress presented on the peninsula/island (Van Noortwijk 1999). This stress is dependent on the difference in water level on either side of the peninsula/island.

2.3.2 Flow Slides

Flow slides are defined as a large quantity of sand is washed away from a sloped structure in a short period of time, usually a few minutes (Den Adel et al

1995). They are the direct effect of soil liquefaction. When liquefaction occurs, loose or fine sand will begin to flow as a liquid. The occurrence of liquefaction is dependent on the soil properties, such as the density and degree of packing, as well as the slope geometry. Within the slope, the sand mass is usually supported by the effective vertical stress (the stress between the grains). If a sudden influx of water occurs, the pore pressure will rapidly increase and begin carrying the load of the sand mass. In this situation, the effective vertical stresses become zero, as will the shear strength of the sand, which can no longer prevent the sand from acting like a liquid.

The following figure shows effects of shear on the shear resistance (relative shear stress) of both loosely and densely packed sand (Den Adel et al 1995).

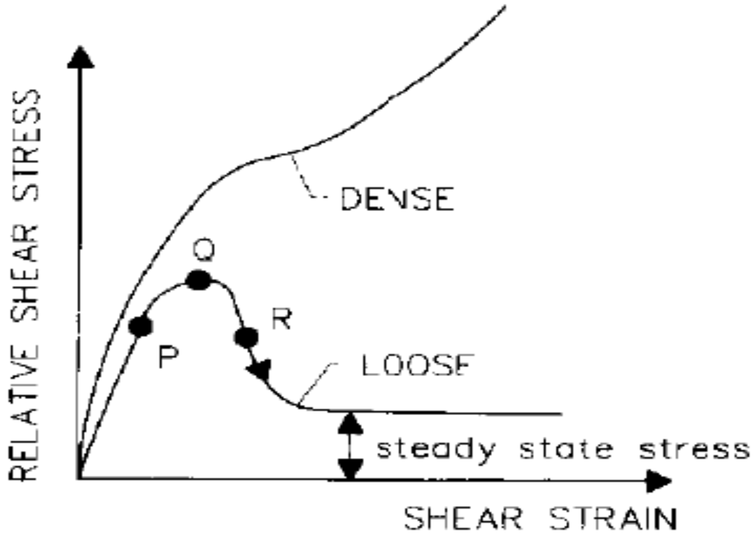


Figure 8: Stress-Strain Functions for Undrained Loading of Loose and Dense Sand (Den Adel et al 1995)

Point *P* on the graph represents a stable situation while point *R* shows when the threshold for allowable shear has been surpassed and liquefaction will occur.

Other effects include a change in the slope. If a slope has been steepened due to scour, it becomes more susceptible to flow slides. Waves and current can cause erosion and, in turn, scour. This will lead to a variation in the stress conditions which precedes the process mentioned above (Den Adel et al 1995).

2.4 Structural Elements of Earth Structures

For an earth structure in the coastal region, there are many important elements involved. Although the manmade islands and peninsulas have their own characteristic profile, we can still show some general elements for these structures (Vrijling 2009).

The main body of earth structure is the core. The function of the outer berm and inner berm is to ensure the stability of the soil structure and also to withstand the hydraulic loading (seepage wash out or piping problem) from the water side. The slope as a rule of thumb is 1:300 in coastal earth structures to allow stability. (Vrijling 2009) The height and slope of the manmade island/peninsula is crucial and will be investigated in design and guidelines section under methodology.

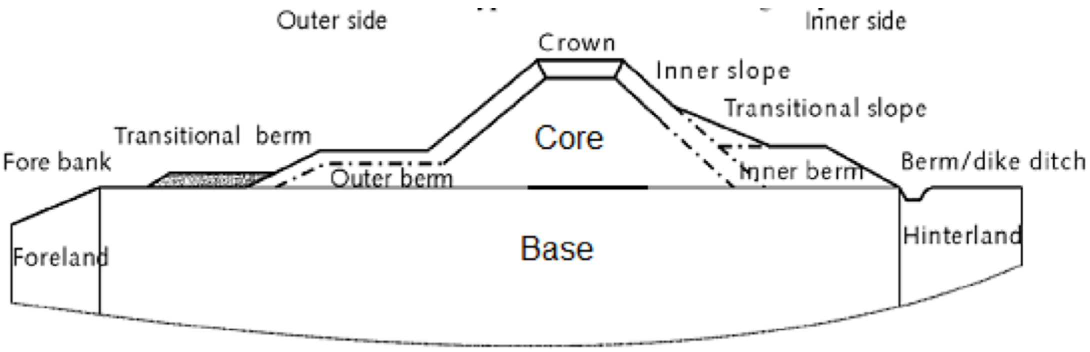


Figure 9: Transverse profile of a earth structure (Vrijling 2009

2.5 Height Calculation of Coastal Earth Structures

In determining the height, the following situations have to be taken into consideration:

1) Water level rise due to climate change and ground subsidence in the design period

2) Oscillations, seiches, local wind set-up

3) Wave run-up and wave overtopping height

4) Ground settlement

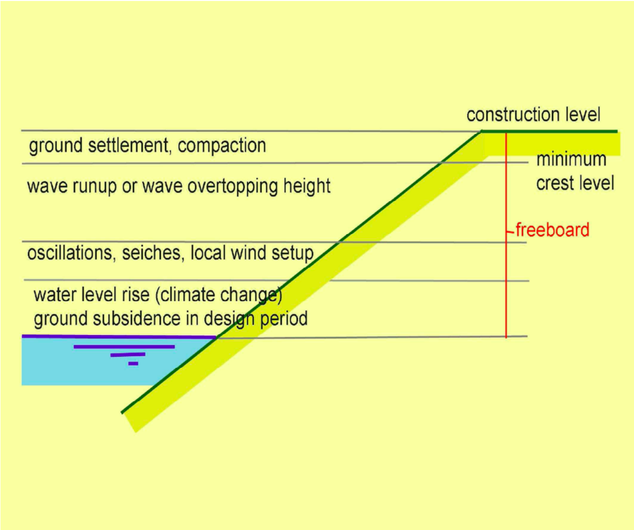


Figure 10: Illustration of Earth Structure Height Calculation Method (Vrijling 2009)

The wave run-up height is a variable of significant wave height, structure angle and the condition on the slope, such as a berm or the use of pitching.

For conventional coastal structures the formula is adopted to determine the wave run -up height:

$$Z = 8\gamma_B \gamma_s H_s \tan\alpha$$

H_s : significant wave height

γ_B : run-up reduction factor due to the construction of a berm

γ_s : run-up reduction factor due to the revetment

α : an outer slope angle

2.6 Alternatives in Coastal Extension

2.6.1 The Zero-Option

The first alternative to analyze is the *zero-option*. Due to factors such as sea level rise and sediment transport, coastline of the world is regressing. Additionally, the increased temperature of the Earth is likely to lead to increased precipitation. This precipitation will, in turn, lead to higher river discharges. The zero-method option suggests that nothing should be done to combat this; instead, it should be allowed to progress as it would and the citizens of the world should adapt. Currently, this option prevails in most parts of the world in terms of coastal zone management.

The zero-option implies that the solution to this problem is just to maintain or possibly apply small improvements to the present coastal system without implementing any new strategy. Another advantage to this idea is that there would be no need for farther research or design since the base of the plan is already in existence and being utilized. The behavioral characteristics of the present coastal system are fairly predictable as well.

On the other hand, the zero-option method is not practical with the population increase that we face today. Some coastal regions need an increase in coastline and proper coastal zone management (Hoozemans 1995).

2.6.2 *Beach Nourishment*

By introducing a beach nourishment project, great portions of land could be reclaimed. Beach Nourishment is achieved by dredging technologies (Van Der Schrieck 2009) Financially speaking, beach nourishment is one of the least expensive ways to protect a coastline. It also has the advantage that it could positively affect sediment transport, if the extra sand load is positioned correctly. However, there is still a large amount of uncertainty associated with sediment transport, and predicting its behavior is a difficult task.

2.6.3 Hard Structures

Hard engineering involves the application of structures such as dikes, breakwaters, groins seawalls and revetments. However, these structures alone do little in coastal extension. This implies that they could only be used in combination with some other forma of coastal extension methods, such as manmade islands and peninsulas.

The only advantage that groins could provide is the capture of sediment from long shore sediment transport. This will build up a beach which will have the same effect as artificial beach nourishment. However, this interferes with sediment transport and might result structural erosion in the following parts of the coastline (d' Angremond 2001).

2.6.4 *Beach Drainage*

Underground Drainage has been used for more than a hundred years in agriculture to reduce the amount of water in soil whose presents prohibits the growth of crops. By the installation of these pipes, farmers can control the groundwater level and adjust it to fit their needs. These pipes are usually perforated and can be made of clay, concrete, or plastic. The water collected in them is funneled into nearby rivers or streams (Salmonella S. 2006).

There are studies to channel this technology into flood protection, especially in coastal extension. By installing underground pipes, the excess water during high water can be collected and redirected back into the sea through pumping stations. The water may also be redirected elsewhere, such as desalination plants to be used for other purposes. The following figure depicts the set-up of a drainage system:

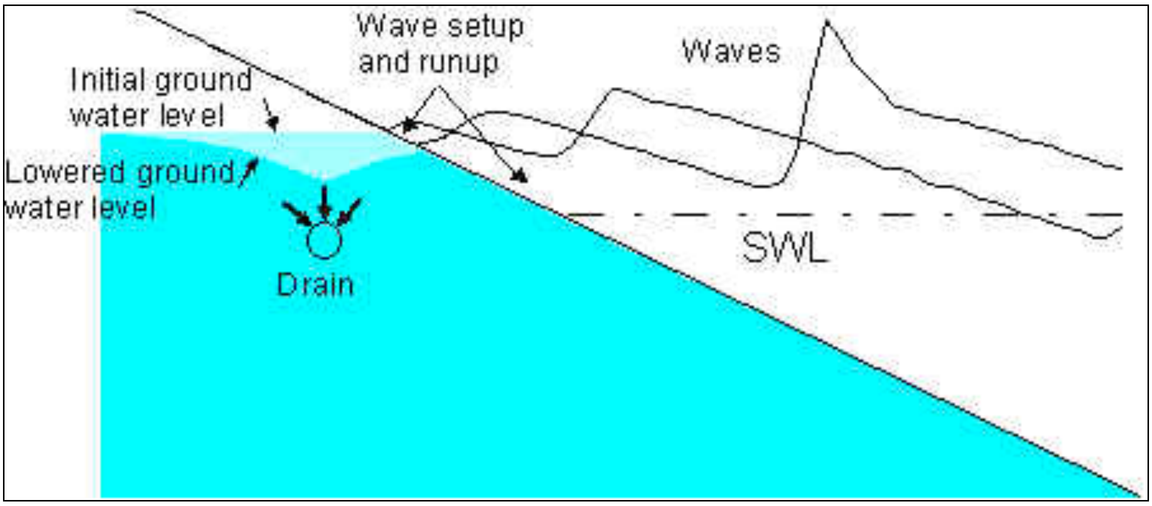


Figure 11: Beach Drainage System (Salmonella S. 2006)

This system will affect accreting beaches by increased accretion and eroding beaches by decreased erosion. An advantage of this proposed solution is that the system is invisible once installed, keeping beach areas attractive to tourist. Additionally installation costs are minimal. However, maintenance and running costs are substantial.

2.7 Uncertainties in Coastal Design

There are uncertainties in coastal design. These uncertainties can be sub grouped as follows.

2.7.1 Loading

Weijers & Tonneijck (2009) argue that there are three rules of thumb regarding uncertainties in loading of coastal structures.

1) The probability a certain water level would be exceeded could be calculated with a reasonable accuracy.

2) The probability of the wave actions could not be calculated with equal ease, reasonable estimates are however developed.

3) Correlation between this data was obvious, but could not be calculated; extreme water levels and extreme wind waves were assumed to be fully correlated.

2.7.2 Strenght

Likewise there are five rules of thumb regarding the strength of coastal structures (Weijers & Tonneijck 2009).

1) The strength of the water defenses can be measured quickly;

2) The geotechnical stability against sliding/piping/seepage related failure mechanisms are based on hands-on experience and can not be expressed in terms of probability with ease.

3) The effects of human error are not incorporated in the approach.
4) The effects of ice dams or ship collisions are not taken into consideration.

The assumption is that a coastal structure should withstand the load of a normative high water. In terms of probability: the contribution of the uncertainties of the strength should be so little they can be neglected.

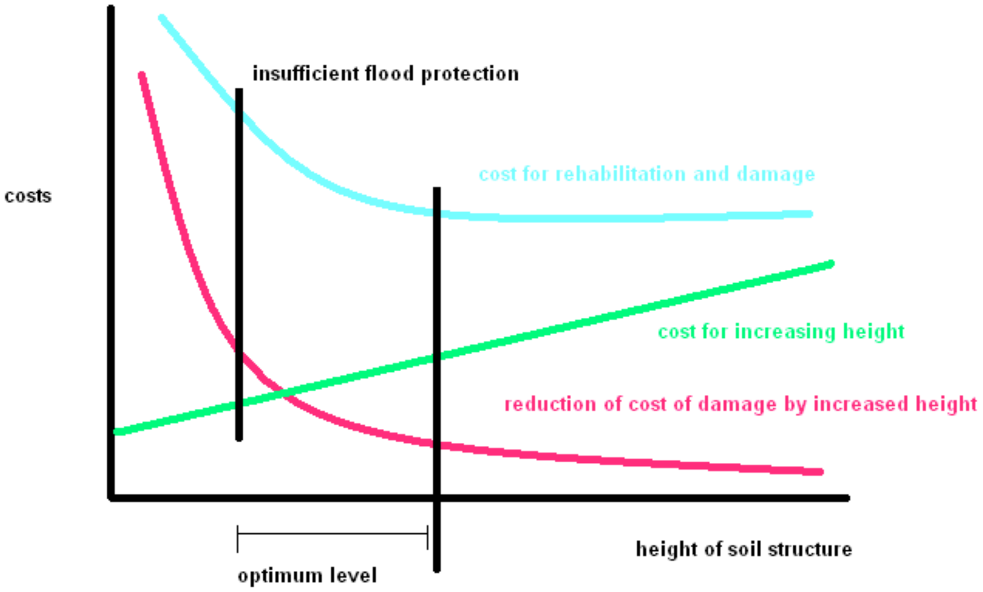


Figure 12: 1 Determination of Coastal Structure Height (Weijers & Tonneijck 2009)

As is shown in the figure above, in both the loading and strength cases, there is a certain degree of estimation and assumption. Due to these uncertainties, a large safe margin is required during design. From a safety perspective only, under so many uncertainties, the larger the safety margin, the safer the people will be. However, in the assumption, there exist some assumptions that are not so effective for setting a large safety margin.

2.8 Stakeholders Involved in Project Implementation

For a project to be a prevailing solution, it is important for its implementation to take into consideration the needs of different stakeholders involved. The stakeholders involved in the implementation of a project may consist of the following:

- Developers

- Users

- Regulators

- Others (Brumsen 2001)

2.9 Sediment Transport

When the waves approach the shore at an angle, the current can be divided into vectors; namely cross shore and alongshore current.

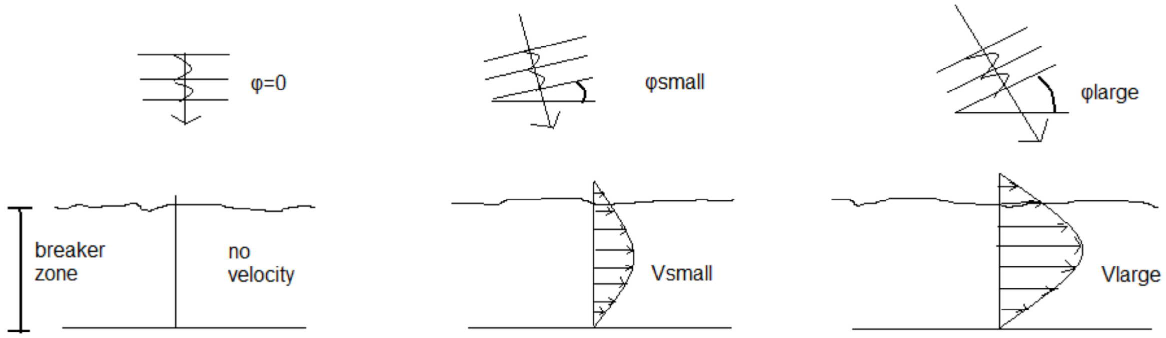


Figure 13: Longshore Current (d' Angremond 2001)

Cross shore current plays a significant role in ripping of sand and alongshore current plays a major role in transportation of sediment along the beach.

Sediment transport in itself does not cause any changes in the topography of the coastline. Only when there are gradients in the transport rate (ds/dx, ds/dy) will there be erosion or sedimentation. Gradients in the cross shore direction will lead to a steeper or more gentle slope, gradients in the longshore direction will lead to systematic erosion or sedimentation along the coastline.

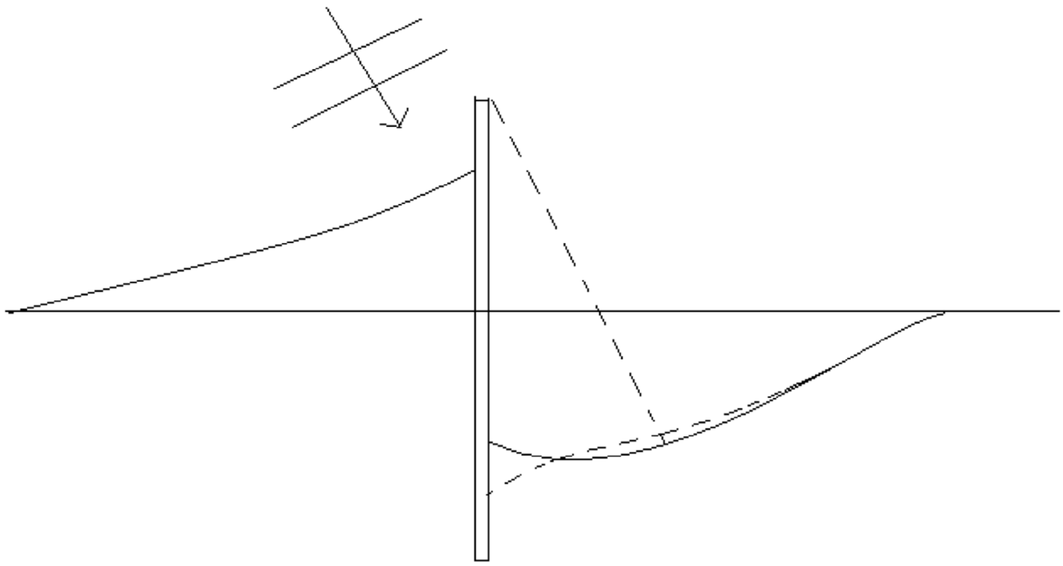


Figure 14: Structural Deposition and Erosion on Two Sides of A Coastal Structure (d’ Angremond 2001)

Typical orders of magnitude of this type of erosion and deposition vary between 10 and 50 m^3/m per year (d’Angremond K. 2001). Construction of manmade islands/peninsulas is clearly an action with adverse effects on coast.

2.10 Stone Pitching

The stone pitching can protect coastal structures from erosion so as to increase the service life and reduce the maintenance cost. Pitching allows an individual stone to be more stable than a rock of the same weight in a dumped rock assembly. Mechanisms regarding stone pitching are introduced in detail in the following subsections.

2.10.1 Flow over the top of the pitching

When flow exists over the top of the pitching, the drag force of the flow ($\frac{1}{2}\rho u^2$) should be less than the resistance force ($\rho_0 g D$). Accordingly, we have the following formula to calculate the thickness of the stone pitching:

$$\Delta D \geq 0.44 \cdot \frac{u^2}{g}$$

Δ: Relative density of the elements $\Delta = \frac{\rho_0}{\rho}$ [-]

D: thickness of top layer = height of the elements [m]

u: mean current velocity over the water depth at the toe [m/s]

g: acceleration of gravity [m/s^2]

1) Wave force

2.10.2 Wave withdrawing induced large internal pressure

At the moment of the withdrawing of waves, the internal pressure within a coastal structure is very large (pressure phase lag due to the low permeability of the material used to construct the manmade island/peninsula). Consequently, it is possible that the internal pressure is so large that the stone pitching layer will be damaged.

Based on Darcy's law and continuity,

$$\Lambda = \sqrt{\frac{D}{K'} \times Kb}$$

In which

D: Thickness of top layer = height of the elements [m] b: Thickness of the granular layer beneath the stone pitching [m]

K’: Transmissibility of the stone pitching

K: Transmissibility of the granular layer

In order to ensure the stability of the stone pitching, leakage length should be decreased, which means an increase in the transmissibility of the stone pitching and decrease in the transmissibility of the granular layer beneath the stone pitching (Vrijling 2009).

2.10.3 Wave Impact on Stone Pitching

When the wave slamming force is very large, it will impact on the top layer and bring about damage as shown in the following figure. The wave impact force can be so large that the strength of the stone pitching is of importance. Observation has been made that under very large wave force, the stone pitching behaves like a series of piano keys(Vrijling 2009).

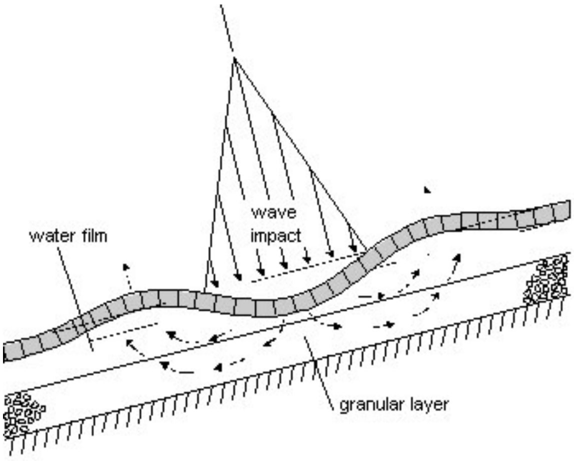


Figure 15: Illustration of wave impact on stone pitching (Vrijling 2009)

The next section consists of the methods adopted to answer the research question “Is extension of coastline by manmade islands and peninsulas feasible in different parts of the world?”

3 METHODS

Literature has been reviewed regarding coastal extension, including coastal engineering, classification of coasts, sea level change, previous cases, failure mechanisms of earth structures, hydraulic structures, alternative methods of coastal extension, uncertainties in coastal design, stakeholders involved and sediment transport.

The method section starts with the case study of manmade islands and peninsulas consisting of social, environmental, economic, functionality and engineering subsections. In these subsections each topic is further investigated. These topics imposed for the case study are essential for a thorough understanding of the applicability of coastal extension via manmade islands and peninsulas in different parts of the world.

The social case study consists of the investigation of the stakeholders involved, population to coastline ratio, primary and secondary social impacts of manmade islands and peninsulas. The environmental case study is composed of the investigation of biodiversity loss, water shortage and quality and interference with currents. Economic case study investigates the quantifiable costs and benefits of manmade islands and peninsulas. This study is further be expanded in the design and guidelines subsection. Functionality case study investigates factors such as flood defense, modes of transport, living, working and recreation functions. Lastly engineering case study investigates fault tree and failure mechanisms.

Then the methods section shifts from the case study to design and guidelines subsection. The design and guidelines include parameters such as angle of slope, height, and width. The angle is determined by serviceability and previous cases as defined in the literature review. The height will be determined by water level rise, oscillations, sieches, local wind set up, wave run-up, wave overtopping and ground settlement. The width of the manmade island and peninsula is related to the slope of the structure and the height of the structure. Additionally, the minimum with of the manmade islands and peninsulas will be determined by micro instability and piping length, allowance for infrastructure and superstructures.

These parameters mentioned are powerful tools for the overall assessment regarding the applicability of the project. Additionally, defining guidelines will be a starting point for researchers in the future. However researches should be aware that these parameters might not be sufficient enough to cover all the issues regarding the implementation of manmade islands and peninsulas throughout the world. However this dissertation has been compiled with the best available information within the limited time and data.

After methods adopted in the dissertation are introduced, the dissertation continues with the case study of coastal extension by manmade islands and peninsulas.

3.1 Case Study

Environmental, Social, Economic, Functionality and Engineering aspects of coastal extension by manmade islands and peninsulas were investigated. After the pros and cons of the manmade islands and peninsulas are clearly understood, the focus will shift to the design and guidelines in building these structures. Methods that will minimize the disadvantages and maximize the advantage will be analyzed and proposed. Findings are further analyzed and concluded.

3.1.1 Social Case Study

The social issues will describe the different stakeholders involved as well as the primary and secondary impacts of the realization of manmade islands/peninsulas

3.1.1.1 Stakeholders involved

Manmade islands and peninsulas are to be implemented on coastal zones, yet these projects have a much wider scope, affecting the whole society. As discussed by Brumsen (2001) and introduced in the literature review, for the manmade islands and peninsulas to be a prevailing solution, it is important for its implementation to take into consideration the needs of different stakeholders involved. The stakeholders involved in the implementation of the manmade islands and peninsulas technology may consist of the following:

Developers: It all starts with inhabitants that want to take advantage of the coastal zones by building residential structures or settling there. Construction of manmade islands/peninsulas in broadest sense is the expansion of the coastline

States are one of the most essential actors in the development of manmade islands/peninsulas. In each country, the Ministries of Transport, Public Works and Water Management shall set the policy and legislation framework including safety standards. Government in the scale of national, provincial and local shall be included. Water boards should be framed as the governing body.

Developers also include decision-makers and dredging, marine contracting and construction companies.

Users**:** Users include all of the population profiting by these structures. Citizens who live above the mean sea level are also included, since they actively pay taxes. Risk is reduced throughout the country where a structure of this sort is built and national wealth is increased. A great emphasis should be given to the ones to be relocated due to the claiming of land by the governments.

Regulators: Different organizations are involved in the decision-making, construction, and maintenance. The Ministry of Public Works and Water Management and the Water Boards should also play a key role in the construction, management and maintenance of coastal structures that change the outlook of a coastal area.

Others: Others include the environmentalists, fisherman, land owners, investors in related sectors, the media and etc.

3.1.1.2 Coastline and Population

The world has seen a rapid expansion in its population. 6,830,586,985 occupants (July 2010 estimate) are located on a land area of 148.94×10^6 km^2. (CIA 2010) This yields to an average of 45 people per km^2. The population growth rate of the world is 0.412%. It is 4 times the average growth rate of the European Union. (CIA 2010)

Due to this, the ratio of coastal population to coastline has risen as well. The implementation of manmade islands/peninsulas would increase the coastline and thus decrease this ratio.

In the future it's estimated that the world population over the years will be as follows (CIA 2010):

1950 – 2.5 billion

1975 – 4.1 billion

2000 – 6.2 billion

2025 – 8.3 billion

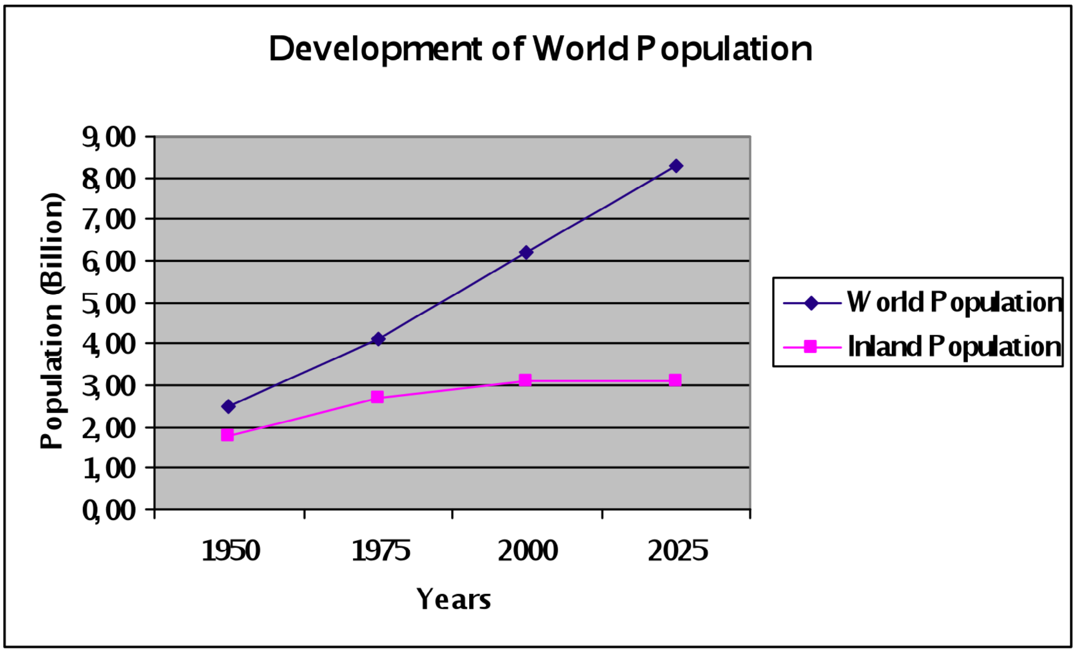


Figure 16: Population Projection of the World (d' Angremond 2001) (CIA 2010)

In 1950 the ratio of coastal population to world's coastline was 2247 people per km. The ratio of world's population to coastline was 7022 people per km.

According to 2025`s population projections, the ratio of coastal population to world’s coastline will be 14607 people per km. The ratio of world’s population to coastline is likely to rise to 23034 people per km.

The formulation of this ratio shows the increase in population compared to an almost constant coastline. Increasing the coastline in certain parts of the world would improve the quality and the functionality of the coastal zone.

3.1.1.3 Primary Impacts of Manmade Islands/Peninsulas

Living and Housing Aspect

Manmade islands/peninsulas have a very wide range of living and working functions. Due to their large reclaimed area, buildings can be constructed above. Generally speaking, buildings above or near the manmade islands/peninsulas tend to increase the effective stress on the subsoil. Living spaces add on additional weight on the substructure body. In return, because of differential settlement, the serviceability of the housing properties might be influenced.

Relocation Aspect

World’s coastal and river zones are highly populated. Due to this, in the execution of manmade islands/peninsulas, many inhabitants will have to be relocated. This will give an extra burden on the society. Mass housing complexes could be built to host the relocated population for a temporary period, but permanent locations may be more difficult to provide. This will also not be accepted positively by the community.

Demolishing historical or religious buildings might also increase opposition.

Landscape, Natural, and Cultural Heritage Aspect

With the building of manmade islands/peninsulas, some parts of coastal zones will be demolished or else buried. This impairs natural and cultural heritage.

3.1.1.4 Secondary Impacts of Manmade Islands/Peninsulas

Aspects associated with maintenance and repairs

Compared to natural islands/peninsulas, manmade islands/peninsulas require more periodical maintenance in order to ensure their effectiveness. This in turn should have a negative effect on cost of maintenance.

Traffic aspect

Space may also be allocated for passing roads on the manmade peninsulas. Tunnels may also be passed inside the manmade peninsula core or through the seabed to reach the islands.

Pride and influence aspect

Implementation of manmade islands/peninsulas might be a project that will arouse national pride in the citizens of that country. The citizens and national wealth of the country will be preserved. For example, Dutch companies which gained experience in the making of levees and delta works are able to implement this technology in other countries.

In order for manmade islands/peninsulas technology to be a sustainable solution, in the development and implementation phase, social issues should thoroughly be taken into consideration. As mentioned earlier, the manmade islands/peninsulas technology in the broadest sense is the continuum of coastal settlement. Due to these reasons, primary and secondary impacts of manmade islands/peninsulas on society can be predicted. It is also essential to state that the manmade islands/peninsulas technology has a very broad social stake holder profile. Secondary and primary impacts of manmade islands/peninsulas on society with regard to implementation are interconnected. One social impact might influence another social impact. On a bigger scale; social, environmental and economical impacts of manmade islands/peninsulas technology are also interconnected. This takes us to the next part; namely the environmental issues.

3.1.2 Environmental Case Study

For construction of manmade islands and peninsulas to be a reasonable solution, it is important for their implementation to not contribute anymore to the existing environmental problems.

It is of the up most importance for developers to be aware of the environmental consequences of their projects. Coastal and alluvial areas are especially vulnerable to any variations to their natural surroundings. Construction of any artificial structure, manmade islands/peninsulas, will evidently have an impact on the environment. One leading explanation of this is the hydrology effect of an area, specifically, the amount and type of water and how it moves. This subsection will outline the most significant ecological problems related to the manmade island/peninsula construction.

3.1.2.1 Biodiversity Loss

Nature is not sustainable without biodiversity. Ecosystems would cease to exist without it; this would have a direct effect on many aspects of life from the basic needs to entertainment and luxuries. Any type of structural addition to an ecosystem will affect it in some way. Manmade island/peninsula construction can lead to the disappearance of these resources, such as fish, mammals, algie, etc. The influence of manmade islands/peninsulas to this function can be seen when one considers the removal of woods or wooded areas (such as mangroves). This area help to retain water and stabilize soil, thus, it is a natural form of protection from both flooding and erosion (VROM 2009).

3.1.2.2 *Water Shortage and Quality*

The world is now facing a shortage of clean or fresh water. By the construction of coastal structures, such as manmade island/peninsulas, in sensitive ecosystems such as river banks or estuaries, an unbalance between the salt and fresh water might result. As Bell (2009) discusses, coastal structures built around river deltas or estuaries do not allow the natural coastal processes to proceed as usual. This will have an effect on the ecosystem of the river basins. Also, with less precipitation and no entrance of sea water, areas such as swamps and marshes that are usually drowned may start to dry, which can have devastating effects on this sensitive ecosystem. These areas have the advantage of being natural water-detaining zones, so it is in the communities' best interest to preserve them. So to preserve the natural processes, manmade islands/peninsulas can not be built along all coastlines of the world.

As introduced in the literature review, less precipitation and smaller discharges also imply that groundwater level should be expected to drop as well. This water would no longer be available as drinking water for an ever-growing population. Desalination plants would have to be implemented.

Aside from the effect that manmade island/peninsulas have on the environment, the environment has an equally crucial impact on the structures. With the drying of the soil due to lack of precipitation and flood-waters, the strength decreases due to a pore pressure decrease. As discussed in the literature review, this results in instability for the manmade islands/peninsulas and may end in horizontal sliding and failure.

Water quality is just as important an issue as water supply. Any slight deviation can produce negative consequences on the ecosystem. Saltwater intrusion is the primary negative consequence of coastal structure construction. The reduction or possible extinction of freshwater-preserving flora and fauna along the coastal line in the ecosystem might severely be affected due to manmade island/peninsula construction.

3.1.2.3 *Interference with Currents*

Coastal structures have been proven to alter the flow of currents. Changes in ocean circulation, especially in tidal inlets or estuaries, will lead to changes in sediment transport and deposit, which will have major effects on the ecosystem of the area. The loss of vegetation on the foreshore will also come with a loss in wave dissipation, resulting in stronger attacks.

All these problems are, in one way or another, interrelated. A shortage of water may result in the degradation of the water quality and loss of biodiversity. Construction works such as manmade islands/peninsulas must be implemented in such as way as to minimize the disturbance their presence may cause of the natural environment. This will directly impact man with respect to his economy, entertainment, and quality of life

Figure 17: Tombolo Formation Due to Interference with Currents (Bell 2009)

3.1.3 Economic Case Study

Another primary issue of investigation concerning manmade island/peninsula is economic feasibility. Most notably, the introduction of a manmade island/peninsula will constitute of a huge initial investment. Additionally, maintenance and monitoring will also play a significant role compared to natural landmasses of the similar type. It is expected that the reduction of failure mechanisms will also reduce the necessity of frequent repairs. An advantage from the economic perspective is that once the manmade island/peninsula has been constructed, there will be a return investment for the land available on top of the manmade island/peninsula. It will be a challenge for both economists and engineers to decide whether the advantages outweigh the disadvantages of the manmade island/peninsula as a coastal extension

Cost Regarding Manmade Islands and Penisulas

Improvements made to the coastal system can be divided into two categories: 1. Investment costs and 2. Maintenance costs (Verhagen 2009). Investment costs include both the planning and construction costs associated with the manmade island/peninsula construction.

The investment costs can be subdivided into two components. The first of these is the planning and design of the improvement; the second is the construction which includes the material needed (usually dredged), the labor costs, and the cost of relocation compensation. It is estimated that planning costs are approximately 15% of construction cost (Nijlan 2007). The second of the associated cost is maintenance.

Since the design and construction of a manmade island/peninsula is very closely related to the economic aspect, the majority of economic information is presented in the guidelines.

The following table illustrates the monetary advantages and disadvantages associated with the manmade islands/peninsulas:

Benefits	**Costs**
• Return of Investment due to increased amount of land and marketing of the region • Less failure mechanisms implies less major and costly repairs • Increase in civil works and increased employability	• Large initial investment • Significant Euro/year for maintenance and monitoring • Relocation costs

Table 1: Cost and Benefit Analysis of Manmade Island/Peninsulas

Manmade islands/peninsulas have the potential to provide a significant return on investment even before their construction is completed. The land reclaimed will be safer and more feasible, increasing the value of the real estate. Also, failure mechanisms such as piping overflow/overtopping erosion on the crest, and collapse due to horizontal sliding will not be present in the manmade islands/peninsulas, which can be translated to a decrease in costly coastal. Additionally, increased volume of civil works will increase employability. However yearly maintenance and monitoring will be costly due to sustain the reclaimed land.

Adding such a massive amount of material to the coastal line will require a large initial investment. Such sums of money are not readily available and can be troublesome to obtain. One of these examples is the withdrawal of the extension of the Palm Island, Dubai, the UAE.

In some parts of the world, large sums of capital might be needed to compensate the residents and businesses that will have to relocate. Also, current infrastructure, such as roads, pipelines, parks, etc…, might have to be demolished to make room and access to the manmade islands/peninsulas.

3.1.4 Functionality Case Study

3.1.4.1 Flood Defense

Flood defense is the major function for a manmade island/peninsula, and the manmade islands and peninsulas are better equipped for this compared with a conventional coastal system elements. This will further be investigated in the engineering case study where the failure modes are depicted.

3.1.4.2 Traffic

The manmade peninsulas are capable of carrying different modes of transportation compared to manmade islands. For instance, a manmade island can not be reached by road transport unless there are tunnels or bridges connecting the structure to the shore. Additionally, there is the core in the middle of the manmade peninsula where roads can be constructed. However, in manmade islands and peninsulas, air transport via heliports and sea transport are possible. Lastly, once again due to the proximity of the shore, there may also be differences in the infrastructures of these two different coastal extension systems.

3.1.4.3 Living and Working function

The conventional coastal structures have a very limited living and working function. Due to their smaller area, few buildings can be constructed on them. Generally speaking, buildings above or near the coastal structure might have a negative effect on them. However, for manmade islands and peninsulas, constructions above the them are purposely embedded in the design. Aside from settlement, there will be no other side effect due to buildings on the manmade island and peninsulas.

3.1.4.4 Landscape, Natural, and Cultural heritage (LNC values)

1) *Architectural value*

The presence of monuments (formal denomination for valuable houses, pumping stations, sluices, locks or other elements on national, provincial or local level);

2) *Archeological value*

The construction of a manmade island/peninsula will definitely have negative effects on all these aspects as well, since the urban landscape of the coast will totally be altered. Many old constructions will have to give way to the manmade island/peninsula. A decision will have to be made between preserving these valuable structures and constructing the manmade island/peninsula. There do exist compromises such as moving those monumental structures to somewhere else, like in an open air museum or constructing the manmade island/peninsula in such a way that those monumental constructions can stay inside the structure. Either way requires large investment and complicated engineering skills. Moreover, undiscovered archeological values are likely to be totally covered by the manmade island/peninsula.

Function Comparison Between Manmade Islands and Peninsulas		
	Islands	**Peninsulas**
Flood defense	+	+
Traffic	-	+
Road Transport	-	+
Sea Transport	+	+
Air Transport	+	+
Living or working functions	-	+
Recreation function	+	+
LNC Values	+	-
Maintenance	-	+
Infrastructures	-	+

Table 2: Functions comparison conclusion

This chapter mainly concentrates on the comparisons between manmade islands and peninsulas. From the above comparison, we can see that, the two structures satisfy different needs. The manmade peninsulas and islands will largely improve the functions of coastline and moreover bring other benefits, eg, more effectively use the land. However, these structures also pose a negative effect to the LNC value and environment. The next subsection will investigate the engineering aspects.

3.1.5 Engineering Case Study

The manmade islands and peninsulas will largely prevent the failure mechanisms of the coastline due to the following reasons:

3.1.5.1 Larger overtopping discharge capacity due to its large mass

Overtopping is a great threat for coastline. However, when overtopping occurs, coastal structures not necessarily collapse. Only when a certain amount of discharge is exceeded, the stability of the coastal structure is impaired due to the infiltration of water in the inner slope which will lead to a heavier inner slope (water content increase) and less shear resistance (pore pressure increase).

However, for a manmade island/peninsula, the gentle slope and large mass are its two most obvious structural properties. Due to its gentle slope, the stability could be ensured. Large mass means larger capacity to absorb the overtopping discharge. Furthermore, due to its broad crest, certain equipment could be installed so as to alleviate the damage brought about by overtopping

It can be concluded that overtopping will pose less of a threat to a manmade island/peninsula compared to a conventional coastal structure.

3.1.5.2 Less wave run-up

Since the manmade island/peninsula has a very gentle slope which means that the wave run-up height will be largely decreased. Using the delta formula: $Z = 8\gamma_B \gamma_s H_s \tan\alpha$, the gentle slope will effectively dissipate the wave energy and decrease the wave run-up height. After the wave run up height has been decreased, some other following threats like overtopping would also be largely alleviated.

Also, the gentle slope will ensure the stability of the manmade island/peninsula. From the soil mechanic, the steeper the slope, the larger the driving force and the resistance force will decrease. However, with the presence of a gentle slope, the driving force will decrease while the resistant force increases.

Since the stability could be better fulfilled, the danger of micro instability, slip circle of outer and inner slope could also be alleviated.

3.1.5.3 Piping

Piping occurs because of a water pressure gradient. The seepage line forms through the earth structure and, due to the presence of a cohesive up layer, a pipe will form followed by upstream erosion. The manmade island/peninsula with great presicion prevent the initiation of piping by reducing the water pressure gradient.

Thus, piping is not a problem for the manmade islands and peninsulas, which is one of its beneficial characteristics.

3.1.5.4 Erosion and Liquefaction

Because of the gentle slope of the manmade island/peninsula, the chance of liquefaction will decrease because liquefaction is a combination of pore pressure increase and stability insufficiency, both of which are a threat to both conventional coastal structures.

However, the outer slope must be protected in order to prevent erosion and possible liquefaction. One possible solution is to apply pitching and routine checks of the manmade island/peninsula slope.

In total, due to the gentle geometry, the wave attack on the slope and instability of the manmade island/peninsula has already been largely reduced, which will lead to a less suffering from erosion and liquefaction.

3.1.5.5 Stone Pitching

The stone pitching can protect the manmade island/peninsula from erosion so as to increase the service life and reduce the maintenance cost. Pitching allows an individual stone to be more stable than a rock of the same weight in a dumped rock assembly. As introduced in the literature review stone pitching is an effective solution to wearing and erosion. Additionally, applying stone pitching increases the service life of the structure.

Figure 18: Illustration of the stone pitching (Vrijling 2009)

As introduced in the literature review (Vrijling 2009), we have the following formula to calculate the thickness of stone pitching:

$$\Delta D \geq 0.44 \cdot \frac{u^2}{g}$$

Δ: Relative density of the elements $\Delta = \frac{\rho_0}{\rho}$ [-]

D: thickness of top layer = height of the elements [m]

u: mean current velocity over the water depth at the toe [m/s]

g: acceleration of gravity [m/s^2]

2) Leakage Length

Using Darcy's law and continuity, we come up with the concept of leakage length Λ in this situation.

$$\Lambda = \sqrt{\frac{D}{K'} \times Kb}$$

In which

D: Thickness of top layer = height of the elements [m]

b: Thickness of the granular layer beneath the stone pitching [m]

K': Transmissibility of the stone pitching

K: Transmissibility of the granular layer

As discussed in the literature review (Vrijling 2009), to ensure the stability of the stone pitching, we should decrease the leakage length, which means that we should increase the transmissibility of the stone pitching and decrease the transmissibility of the granular layer beneath the stone pitching.

When the wave slamming force is very large, it will impact on the top layer and bring about damage as shown in the following figure. The wave impact force can be so large that the strength of the stone pitching is of importance. Observation has been made that under very large wave force, the stone pitching behaves like a series of piano keys (Vrijling 2009). Stone pitching will decrease the effects of cross shore and long shore currents on the manmade islands and peninsulas.

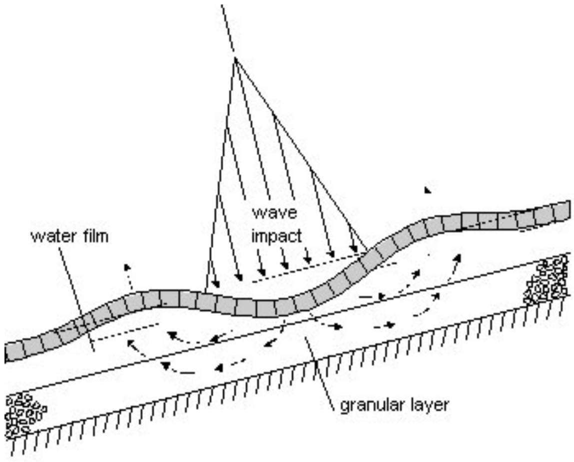


Figure 19: Illustration of wave impact on stone pitching (Vrijling 2009)

Some of the main points concerning application of stone pitching on manmade islands/peninsulas have been discussed. By following the above consideration, we have to construct the thickness of the stone pitching layer large enough meanwhile choose the proper material and shape of the stone pitching. Then, they must be constructed in such a way that they interlock with each other. By doing so, the pitching can withstand wave impact and pressure difference. Furthermore, the transmissibility of the stone pitching layer should also be properly considered to reduce the wave withdrawing induced pressure.

3.1.5.6 Higher safety level in manmade island/peninsula

As described above, the safety has been improved in several aspects for the manmade island/peninsula compared with coastal structures. Several failure modes can be more reasonably neglected in the situation of a manmade island/peninsula, e.g. the failure modes of piping, stability and collision.

The following two fault trees can be used to compare the different failure modes of conventional coastal structures and manmade islands/peninsulas.

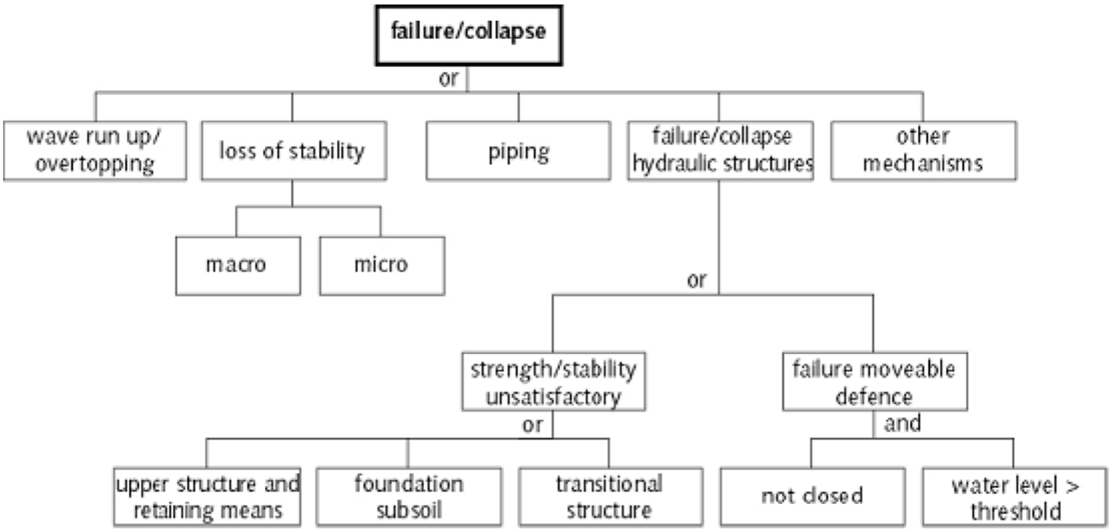


Figure 20: Fault tree of current flood defense system (conventional coastal structures + hydraulic structures) (Vrijling 2009)

For the manmade island/peninsula, the fault tree will much simpler because certain failure mechanisms can be reasonably neglected.

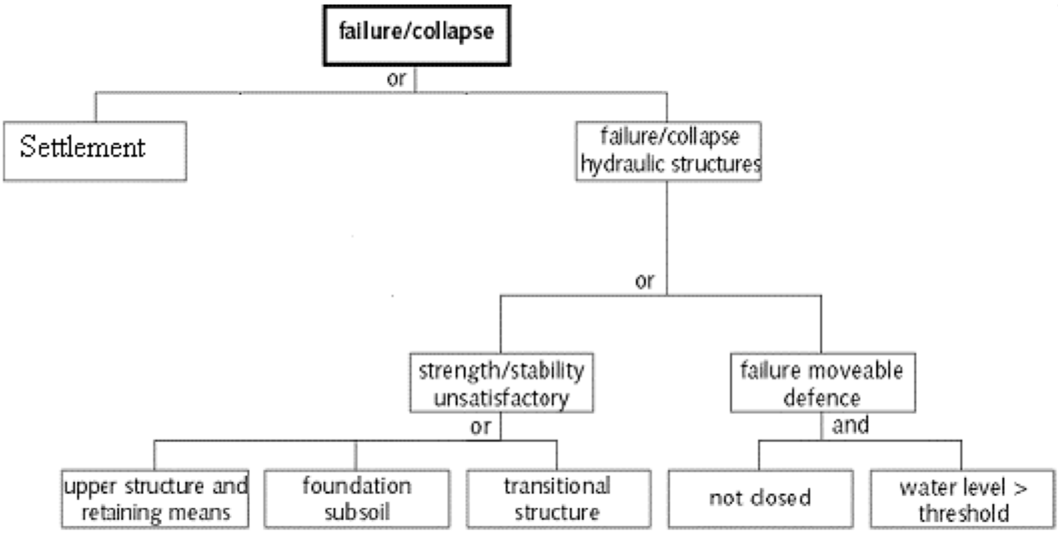


Figure 21: Manmade Islands/Peninsulas + Hydraulic Structures

There are three points to be stressed in two figures above.

1. Both fault trees include hydraulic structures.

2.. Although there are different failure modes in the conventional coastal structures + hydraulic structure fault tree, actually only overtopping and overflow are taken as failure mode in most coastal earth structure design.

3. The fault tree figures do not show the interaction between the conventional coastal structures and the hydraulic structures. Once the hydraulic structure fails, the connection part with the coastal structure is likely to severely erode, and finally lead to even larger breach of the coastal structure.

This subsection investigated the important aspects regarding implementation of manmade islands/peninsulas. The case study consisted of social, environmental, economic, functionality and engineering subsections. The execution of the proposed plan must be economically feasible as well, such that the disadvantages are overcome by the advantages. The design and implementation should also satisfy the different needs of stakeholders in the society. Likewise population to coastline is a powerful indicator which has been expending rapidly in the last 50 years. In implementation also, the failure systems and uncertainties due to failure can be reduced. Implementing manmade islands/peninsulas in some of the parts of the world is the right solution for satisfying most of these criteria.

3.2 The Design and Guidelines of Manmade Islands/Peninsulas

In this chapter, we will shift our attention from the social, environmental, economic, functionality and engineering case studies of manmade islands/peninsulas to the design and guidelines needed for these structures. The design and construction method will focus on how to maximize the advantages of the manmade islands and peninsulas and also minimize their disadvantages.

3.2.1 Introduction to the Design Method of Manmade Islands and Peninsulas

As discussed earlier in the literature review, the current design approach to hydraulic load is the overload approach by section. It has been mentioned that by using this approach, certain assumptions and estimations are adopted in the designing process of the coastal structures. As analyzed earlier, these assumptions and estimations actually are also suitable for a manmade island/peninsula.

Accordingly, in the design of a manmade island/peninsula, we will continue to use the overload per section method. We will use all the possible formulas for coastal structure design. Also, we will take into consideration sea level rise, subsidence, etc...

Since the manmade islands and peninsulas should be durable structures, the design standard should ensure the manmade island/peninsula function for a long time interval. Approximately, we estimate a 50-year (According to the Euro codes depending on the type of structure, 15 years and 50 years service life have been specified) service life, and an additional 40 years of the service time. So, our design standard is to make sure the manmade island/ peninsula would successfully defend the hydraulic load and serviceability needs until 2100.

In the literature review, there has been research about the future sea level, taking into consideration, cumulative the sea level rise up to 2100, subsidence up to 2100 etc… In the following design, we will design the manmade islands and peninsulas based on these pre-calculated environmental conditions and use the overload section method.

Now, using these methods to design the manmade islands/peninsulas, the following are the limitations;

1) The flood risk method is still under development and many unknowns are involved in the model.

2) Manmade Islands/Peninsulas will better suit for the assumptions made in the current design method.

3) Since the failure mechanisms will be largely decreased due to the construction of the manmade islands/peninsulas, we can expect the safety will be satisfactory.

4) As mentioned already, the current design is just expediency. Another advantage of manmade islands/peninsulas is that they are flexible to heightening.

3.2.2 Profile of a Manmade Island Peninsula

For a manmade island/peninsula, the stability, seepage erosion and piping will not be a problem since its width is long enough to withstand the hydraulic loading. Additionally, as stated in the literature review, the manmade islands and peninsulas are multifunctional coastal extension structures. The construction of a manmade island/peninsula can also serve other purposes, for example, transportation, housing, recreation. Accordingly, the elemental design in manmade island and peninsulas should be adapted due to the function needed.

In the following figure, profile view of a manmade island/peninsula is shown. From the figure, we can see that the outer slopes of the manmade islands and peninsulas are gentle.

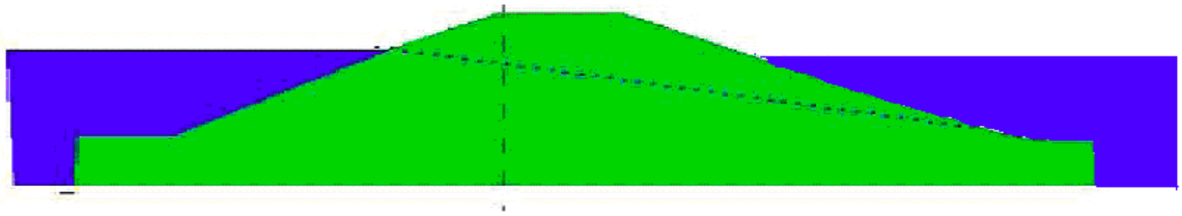


Figure 22: Manmade Islands and Peninsulas

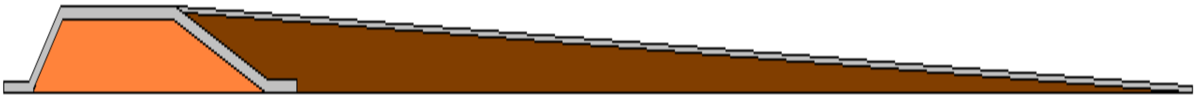
(Attention: This is a conceptual drawing, not with proper scaling. In a real situation, the slope should be much gentler)

For manmade islands and peninsulas, when applied in different areas, their profiles should also be different. However, the gentle slope should be ensured.

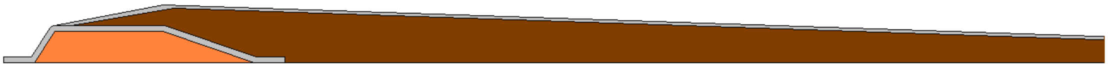
Sea Manmade Islands/Peninsulas

For manmade islands/peninsulas, we have the possibility to construct a gentler outer slope. Here, we will illustrate different examples.

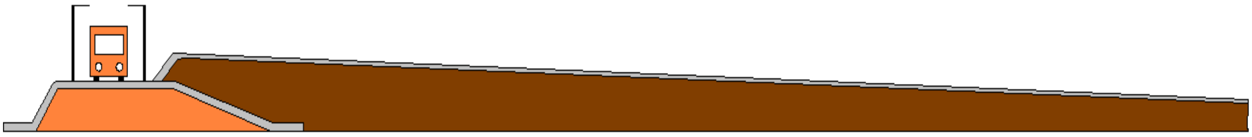
1. Conventional earth structures, from original slope (1:3) to manmade island slope (1:300)



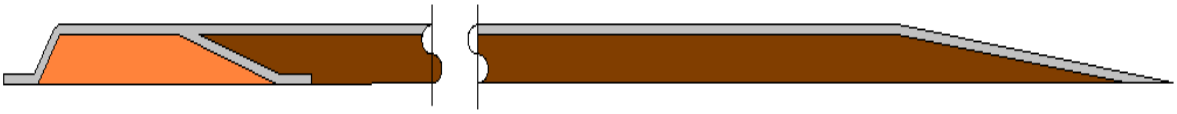
2. Some coastal structures need further strengthen (slope: 1:300)



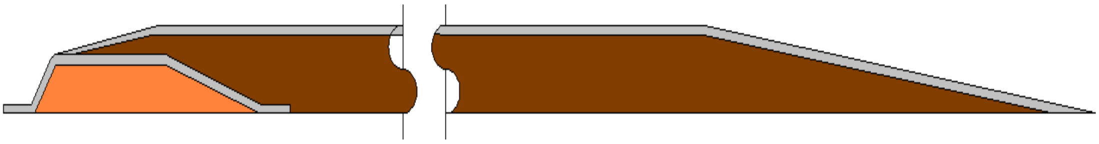
3. Manmade islands/peninsulas with public transport on the core (slope: 1:300)



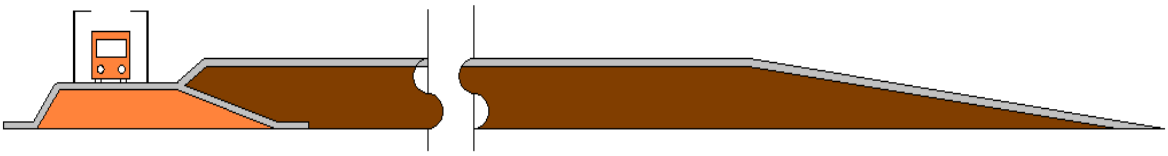
4. Instead of using a very gentle slope, we can also use flat and very wide crest



5. Flat wide crest with heightening

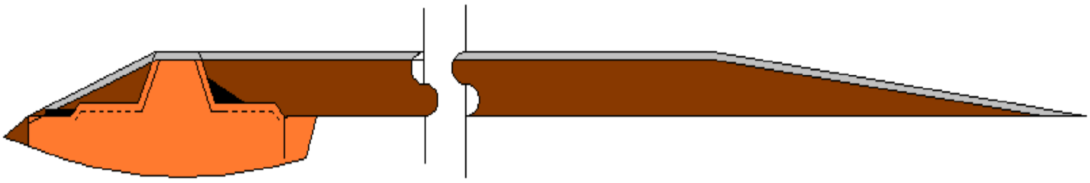


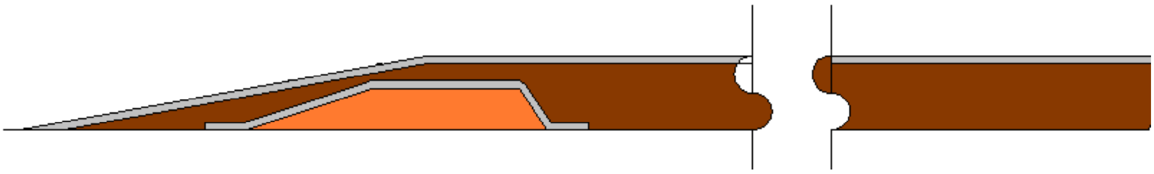
6. Flat wide crest with public transport on the core



Lake Manmade Islands/Peninsulas

A lake manmade island/peninsula has slope angles designed due to the largeness of the lake. Wave height and run up play a significant role in deciding the slope of the coastal structure. If the lake is small, wave height will be smaller as well. In return, the slope can be steep. Typical profile maybe shown as:





As shown above, many different types of profiles are available for constructing a manmade island/peninsula. Also, in different locations, due to different functions, the manmade island/peninsula profile may vary slightly.

However, as stated in the definition of manmade islands/peninsulas, the most important characteristics of these structures are:

1) Wide cross-section,

   Micro stability problems are largely alleviated;

   And infrastructures' constructions above are possible.

2) Gentle slope,

   Overtopping discharge will flow over the manmade island/peninsula with a very slow velocity such that erosion problem are reduced and discharge capacity is increased;

   And a gentle slope ensures normal everyday life for the people who live on the manmade island/peninsula.

Some other requirements should also be satisfied by adding certain elements during the construction of a manmade island/peninsula.

The design and profiles in the previous subsections are conceptual . Now, we need to further introduce guidelines regarding height and angle of slope of manmade islands and peninsulas

3.2.3 Manmade Island and Peninsula's Angle

As we have shown above, different manmade islands and peninsulas (lake and sea) are likely to have different profiles and thus different angles. Generally speaking, we have the following characteristics concerning the manmade island peninsula angles:

1) Inner slope and Outer slope

   i) The angle of the coastal structure concerns the macro stability of the manmade island/peninsula and also the wave impact from the water.

By reclaiming land, the height of the sea bed should be increased, resulting in the emergence of the manmade island/peninsula. Yet to guarantee a higher requirement for the macro stability, we need a smaller slope angle, and a greater base.

ii) Two important issues should be taken into consideration. Firstly, the inner slope should be small so that overtopping discharge capacity can be increased. Secondly, the inner slope should be small so as to ensure the manmade island/peninsula's residences' everyday life activities without too much difficulty. In a word, the inner slopes should be constructed as gentle as possible.

2) Lake and Sea Manmade Islands and Peninsulas

As discussed earlier, the same reason as stated for conventional coastal structures, sea manmade islands/peninsulas will be designed with a gentle outer slope. A lake manmade island/peninsula's outer slope angle can be steeper. All of their inner slope angle should be as small as possible, as stated earlier.

3.2.4 Manmade Islands and Peninsula's Height

First, we will review the height calculation method for other coastal structures, and then we will come up with the idea of calculating the height of a manmade island/peninsula.

Height of the conventional coastal structure

As mentioned in the literature review, in determining the height, the following factors have to be taken into consideration:

1) Water level rise due to climate change and ground subsidence in the design period

2) Oscillations, seiches, local wind set-up

3) Wave run-up and wave overtopping height

4) Ground settlement

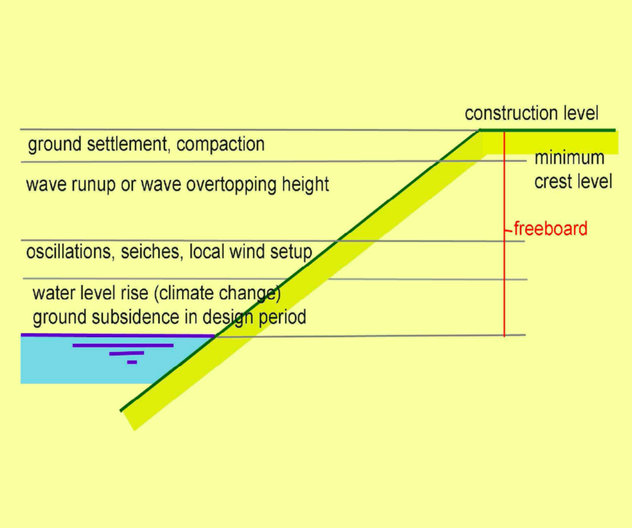


Figure 23: Illustration of Earth Structure Height Calculation Method (Vrijling 2009)

The wave run-up height is a variable of significant wave height, coastal structure angle and the condition on the slope, such as a berm or the use of pitching.

For a conventional coastal structures the formula is adopted to determine the wave run -up height:

$$Z = 8\gamma_B \gamma_s H_s \tan\alpha$$

H_s : significant wave height

γ_B : run-up reduction factor due to the construction of a berm

γ_s : run-up reduction factor due to the revetment

α : an outer slope angle

For a manmade island/peninsula, the profile is relatively simple, but due to its gentle slope (sea and lake manmade islands/peninsulas), the wave run-up height will not be significant. However, in light of construction reasons, we simply can just build the manmade islands/peninsulas the same height as the conventional coastal structures, so we are going to adopt the same calculation method as for conventional coastal structures.

. Although using the same calculation method, we still need to determine different parameters (sea level rise, subsidence etc) based on a probabilistic approach.

1) Sea level rise

As already been mentioned in the literature review, if we want to reach the safety level (1:10,000), we need to increase our current sea structure at least the same level of expected mean sea level rise which is 85 cm.

2) Ground subsidence

As stated in the literature review, we have different subsidence values in different areas of the world. The overall subsidence will on the other hand influence the design standard of the manmade island/peninsula.

3) Wave run up or wave over topping height

As mentioned earlier, the formula above will be used to calculate the wave run up height:

$$Z = 8\gamma_B \gamma_s H_s \tan\alpha$$

The values for γ_B and γ_s can be found in the appendix.

For lakes, this is a conservative formula since in the lake the wave is not as much a concern as in the sea. However, by applying this formula also in lakes, we get a larger safety margin.

4) Settlement and compaction

The construction height of the manmade island/peninsula refers to the height immediately after completion of the construction. Accordingly, the settlement that will occur after construction, should be taken into consideration.

There are two main kinds of settlements. When the consolidation plays a major role, it is called the hydrodynamic period of settlement. After completion, the second phase settlement, including the creep process, is called residual settlement which could be very large if the construction period is very short. Accordingly the building height is often larger than the construction height.

Usually, a 50-year period of settlement is taken into consideration during the design. The following earth structure increase concerning settlement is given (Vrijling 2009, pg *56*).

Soil type	**Height increase**
Clay	10%
Ripe clay	5%
Sand fill	5%

5) Local increase in the water level

The local increase in the water level includes wind set-up, seiches, and water oscillations. It is highly site specific and influenced by many parameters. We will leave this as a variable.

After going into detail about the determination of the manmade island/peninsula, we can conclude that most of the coastal structures need to be heightened due to the sea level rise and local increase in water level. For a general rule of thumb, the sea manmade island/peninsula needs to be heightened by approximately 1 meter compared to the coastal mean water level.

3.2.5 Manmade Island and Peninsula’s Width

A manmade island/peninsula should be a broad structure that can allow infrastructure and superstructure constructed above it. The disadvantages of piping and micro instability (induced by the seepage water reaching the manmade island/peninsula inner slope) could be eliminated.

Accordingly, we have 3 requirements about the width of the manmade island/peninsula.

1) It should be wide enough to avoid the occurrence of piping and micro instability without the help of other special structures, e.g. seepage screen.
2) It should be wide enough to allow infrastructure and superstructure.
3) Since a very gentle slope (typical 1:300 Vrijling (2009)) is required for the stability of outer slopes, the width of the manmade island/peninsulas should allow such a gentle slope. Thus the minimum width depends on the slope and required height.

Based on the 3 guidelines mentioned, we can calculate the minimumd width of manmade islands and peninsulas. However, one should bear in mind that the width being calculated is not a ‘fixed requirement’ for the definition of manmade islands and peninsulas.

3.2.5.1 Micro Instability and Piping

Micro instability

Micro instability will lead to several failure modes depending on the construction material.

A clay structure is not likely to be damaged from seepage water since its permeability resistance is strong. Sand wash problem may happen to sand structures if the seepage water line reaches the inner slope of the manmade island/peninsula. For a sand core with clay covering, the seepage water will increase the internal pressure of the earth structure and eventually push off the revetment of the inner slope.

As discussed earlier in the literature review, all the micro instability problems are caused by the seepage water line reaching the inner slope.

The width of the manmade island/peninsula is largely influenced by the phreatic line which is influenced by the hydraulic pressure gradient and the soil type.

The length of the manmade island/peninsula is discussed in the piping problem which can be viewed as a special problem of micro stability.

Piping

The piping problem has been covered in the literature review. Now, we are going to further determine the seepage length for piping problem which is crucial for our decision about the width of the foundation manmade island/peninsula.

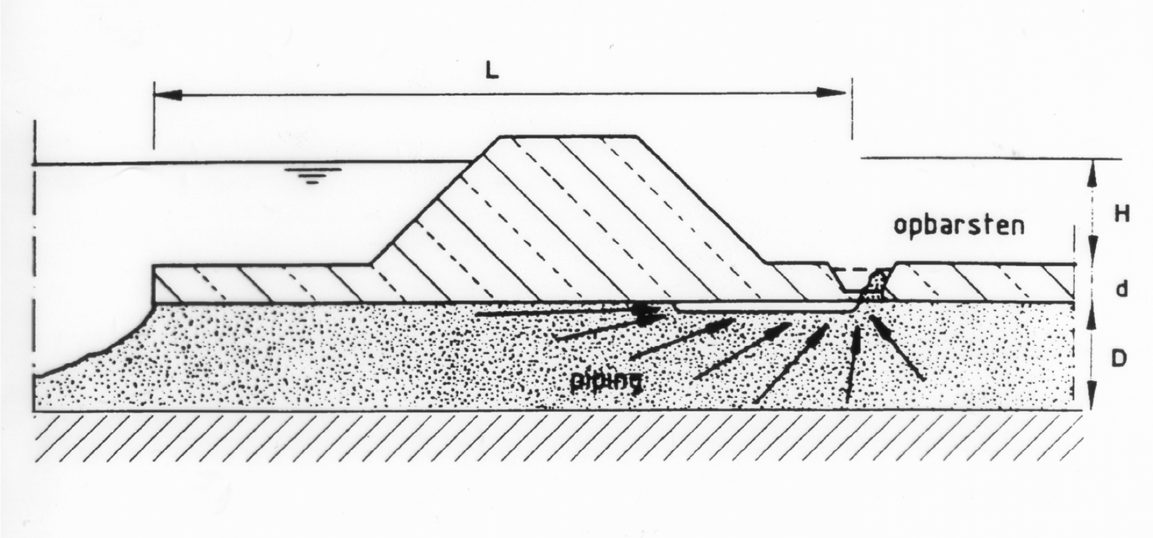


Figure 24: Illustration of the principle of piping (Vrijling 2009)

Many scientists have done research on piping problems. Some classical rules were at our disposal to handle this problem. Among those rules are the empirical rules of Bligh and Lane, and the sophisticated rule by Sellmeijer.

The Bligh and Lane method are very simple, but due to their simplicity, they neglect certain important factors. The Sellmeijer method is more sophisticated. However, Bligh and Lane’s methods are more conservative with larger safety margins. Accordingly, Bligh method is embedded in the code and Lane rule is used for special hydraulic structures.

Here, we will focus on the width of the foundation, and use different rules to calculate the required manmade island/peninsula foundation width.

Bligh method (1912):

$$L = C_{creep} \times H$$

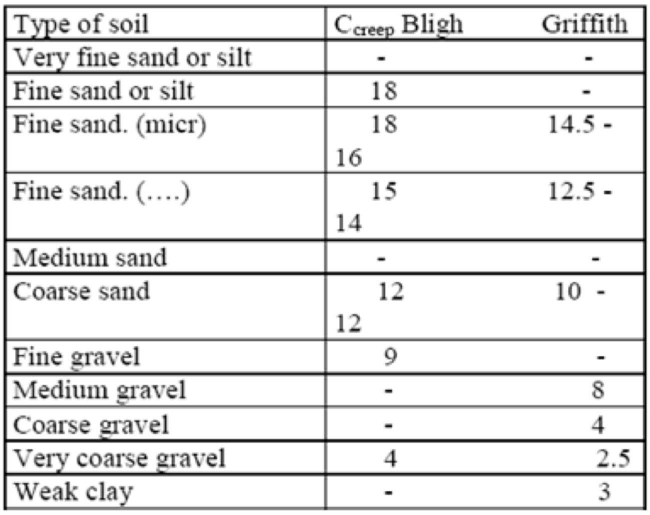
In which,

L : Leakage length [m]

H : Critical difference in water head [m]

C_{creep} : Parameter used to calculate the leakage length. It varies with different soil types as can be seen in *Table 7.2.*

One can refer to *Figure 7.7* to see the meaning of different parameters.



Type of soil	C_{creep} Bligh	Griffith
Very fine sand or silt	-	-
Fine sand or silt	18	-
Fine sand. (micr)	18	14.5 - 16
Fine sand. (….)	15	12.5 - 14
Medium sand	-	-
Coarse sand	12	10 - 12
Fine gravel	9	-
Medium gravel	-	8
Coarse gravel	-	4
Very coarse gravel	4	2.5
Weak clay	-	3

Fgure 25: C_{creep} of Bligh and Griffith for different soil types

From the above table, we choose several typical values from Bligh rules as shown in the following table and then we draw the required length of the foundation versus the water head difference under different soil types as shown in *Figure 7.8*.

Type of soil	**Creep Bligh**
Fine sand or silt	18
Coarse sand	12
Fine gravel	9
Very coarse gravel	4

Table 3: Bligh parameter for the calculation of leakage length

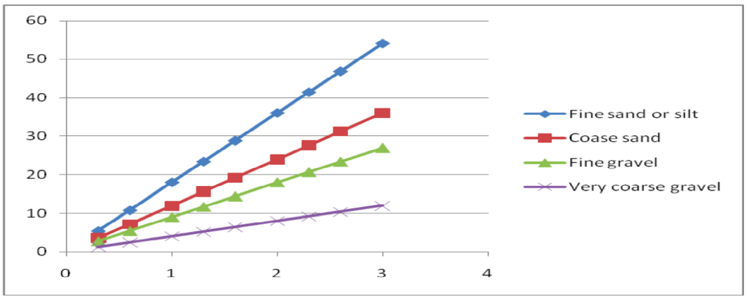


Figure 26: The leakage length (vertical coordinate) versus the water head difference (horizontal coordinate) under different soil types based on the Bligh rule

Compare the above figure with that from Sellmeijer rule and laboratory result.

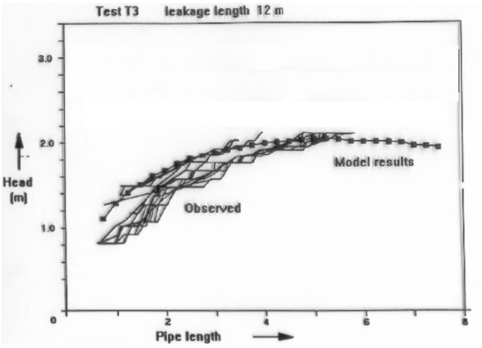


Figure 27: Pipe length versus water head difference based on Sellmeijer model and lab results

These two figures are not the same. The Sellmeijer's method fits the laboratory result well and the Bligh method tends to get a larger leakage length (earth structure foundation width). The difference becomes significant when the water head is larger than 2 meters.

From those two figures, we can roughly conclude that the foundation length required to avoid piping is dependent on soil type and water. The leakage length is in a range of 10 to 60 meters.

Based on the conservative Bligh rule, we choose a mean value of the water head difference saying about 1.5 meters, and assuming a soil grading between fine gravel and coarse sand. From the figure below, we come to the conclusion that the width of a manmade island/peninsula should be equal to or larger than 15 meters. This number is a little subjective but will help to give us a feeling of the width of the required value.

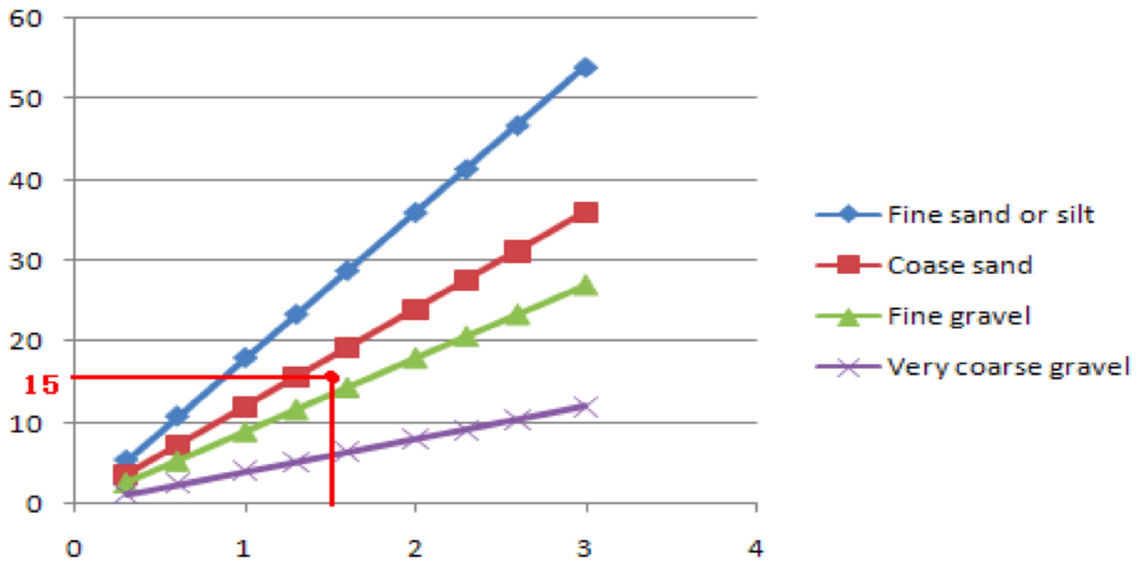


Figure 28: Estimation of minimum manmade island/peninsula width concerning piping problem only

3.2.5.2 Infrastructure and Superstructure

The second requirement for a manmade island/peninsula is that it should be wide enough for the construction of infrastructures above it. There are many superstructures and substructures (buildings, highways, heliport, and park etc), so the width of the manmade island/peninsula should also accommodate these. If we are designing a manmade island/peninsula with a very gentle slope as shown, infrastructures could be built on the gentle inner slopes.

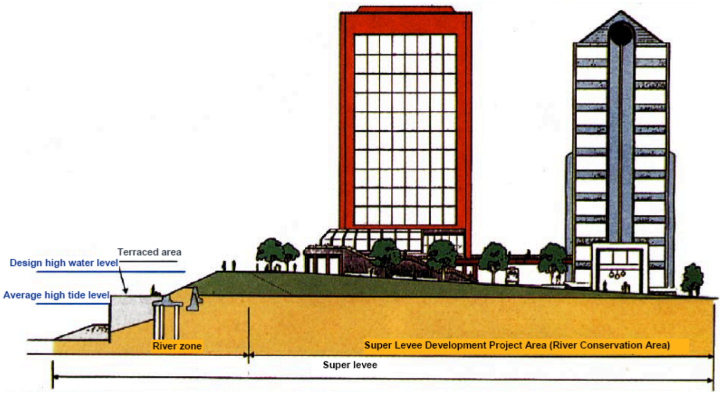


Figure 29: Manmade Peninsula built in Samida Region in Japan (Nagashima 2008)

Accordingly, it is difficult to infer the width of a manmade island/peninsula from this function. We can just roughly estimate that the crest width of the manmade island/peninsula may be more than 20 meters for the construction of infrastructures. Since we know the crest width of the manmade island/peninsula, we can further estimate the foundation width with not so gentle a slope, saying about 1:5.

3.2.5.3 Width and Slope Correlation

All the possible design profiles stated in the beginning of this chapter require a manmade island/peninsula to have a very gentle slope.

Now we will come to more general situations about how gentle the slope should be. As mentioned in the preceding section about the coastal structure angle, two requirements (water drainage and people’s everyday life) should be fulfilled with a gentle slope.

As in the Japanese practice, they adopt 1:300 inner slopes. Following this typical slope angle we can easily calculate that with a coastal structure height of about 2 meters, the width of the manmade island/peninsula can reach about 600. Yet the height can be kept constant and width be increased.

After discussing the manmade island/peninsula width based on the different requirements, we found that the width of manmade island/peninsula varies with the height, slope, area needed to accommodate superstructures and substructures. Emphasis should be stressed that these numbers are pure estimations. The purpose of these numbers (15m for micro instability and piping to 600m due to slope and height) is just to create a feeling of the possible width of the manmade island/peninsula.

3.2.6 Planning and Economic Guidelines

If the manmade island/peninsula is to be built, the advantages should be maximized and its disadvantages should be minimized. For building a manmade island/peninsula, large initial investment is requirement. High capital cost is an essential disadvantage of the manmade island and peninsula construction. In this planning and economic guidelines subsection, emphasis will be given to factors such as investment cost. Generally, the following can be recommended to minimize the investment costs:

(1) The construction of the manmade island/peninsula should work in close relation with the urban development. Urban development scheme should be taken into consideration. If the manmade island/peninsula project can be realized, the chance should be utilized.

(2) Coastal zones should be decomposed into different sections and then, step by step, the manmade islands in different parts should be constructed.

(3) The manmade island/peninsula should be used in an effective and multifunctional way. Space for houses can be allocated on top and infrastructure can be underneath.

3.2.6.1 Planning Guideline

As mentioned in the introduction, emphasis will be given to minimization of the investment cost of manmade island/peninsula during the construction period. Accordingly, a simple economic analysis together with the construction method of the structure will be included. In reality, the situation is far more complicated than suggested.

Since manmade island/peninsula construction is a huge investment in which certain other coastal structures need to be demolished, not all the construction can be implemented at once. It should be constructed zone by zone, and the following is the planned construction method.

Step 1: Section by section

The coastal lines should be separated into different zones according to the situations behind the coastal zone, for example, the presence of houses, farmlands or factories, etc… In different situations, different methods should be adopted to construct the manmade island/peninsula. Here, the focus will be on how to handle the situation if there is development attached to the coast as shown in the figure.

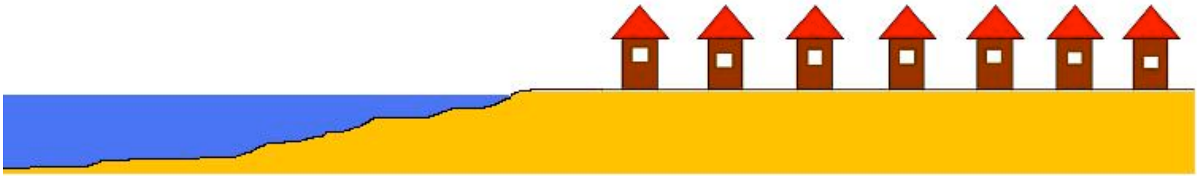


Figure 30: Development Attached to the Coast Before Manmade Peninsula

Figure 31: Seabed Before Manmade Island

Step 2: Strip by strip

After the coastal zone is separated into different sections, the land related shall be expropriated strip by strip. This is due to the fact that different buildings have different end of service lives (some houses are new and some houses are old). In order to save money, the old houses should be demolished first and construction should start in that specific part. Sections need to be separated into different strips according to the service lives of structures on it.

Step 3: Revenue Generated

After constructing the manmade island/peninsula, the new land above the manmade island/peninsula should be used in an effective and multifunctional way; constructing new houses, parks, commercial areas, etc…

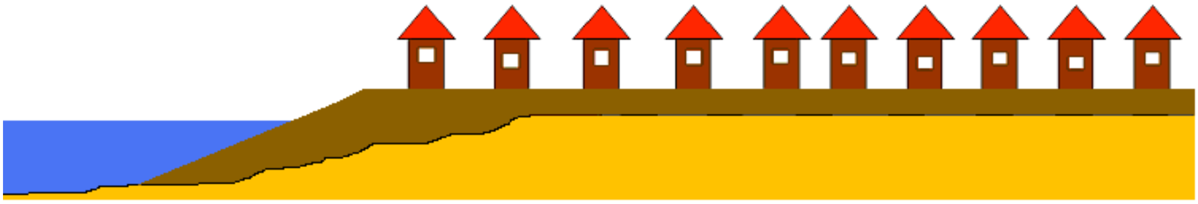


Figure 32: Development After Manmade Peninsula

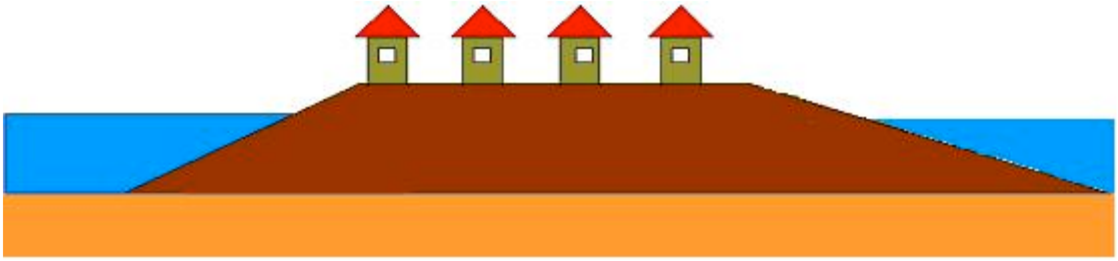


Figure 33: Developmen After the Manmade Island

During this whole process, the overall investment and revenue shall be calculated to judge whether if the manmade island is a feasible project.

3.2.6.2 Economic Guideline

One important aspect that should be kept in mind here is that manmade islands and peninsulas construction is a long term project. The installments will be made at different time periods for different purposes. In the end, the revenue can be determined using a net present value analysis.

In order to give some quantitative values, simplification must be made during the course of the calculations. The assumptions adopted are the following:

Assumptions

1. The interest rate is assumed to be constant during the whole construction period.

2. When dividing different strips, only the service life of the construction is taken into consideration. The influence of the construction method is neglected.

3. The price is constant between different construction materials. P_s is constant.

4. The new constructions above the manmade island/peninsula will only be built after the manmade island/peninsula has emerged.

Investment and revenue will be calculated separately.

Investment

1. Price of the material (sand, clay) needed for constructing the manmade island/peninsula.

$$P_{ts} = P_s \times V_s$$

P_{ts} : Total price of the material;

P_s : Price of the material needed per cubic meters

V_s : Volume of the material needed.

The volume equals to the reclaimed shape times the height of the reclamation.

2. Price of demolishing certain structures (housing, traffic etc).

A rough estimate is made about the money needed for demolishing and relocation in the different sections and in the different strips.

$P_{td} = P_d \times A$

P_{td}: Total amount of money needed for demolishing the current structures.

P_d: Roughly estimated amount of money required for demolishing per unit area.

For houses, the money required for relocation is added, P_{tr}

3. Monetary amount required for constructing the manmade island/peninsula.

4. Monetary amount required for constructing new houses above the super-dike.

Revenue

After the new houses are constructed above the manmade island and peninsula they can be sold. This generates revenue. The presence of the manmade island/peninsula implies that the area is safe and stable. It may also be attractive since it increases the coastline and its functioning. The real estate price also depends on the market conditions.

Within one short section, the method to calculate cost requires:

1. Estimating the manmade island/peninsula's dimensions.
2. Dividing the area into different strips according to the situation behind the manmade island/peninsula.
3. Analyzing the property of each strip, including the dimensions, demolishing price per length, relocation price, the constructing material price at different times.
4. Calculating the overall investment.

5. Calculating the overall income.

6. Comparing the two outcomes above.

Generally speaking, the input includes

1. Dimensions of the intended manmade island/peninsula;

2. The value of the houses under demolition;

3. Material price;

4. Construction price;

5. Price of new land on the manmade island/peninsula;

After case studies on social, environmental, economic, functionality and engineering aspects have been implemented, the design parameters and guidelines were introduced. The next section will highlight the results of the studies.

4 RESULTS AND ANALYSIS

The outcome of the case studies, design and guidelines will be presented to the reader in this chapter. Additionally interpretation of the findings will be analyzed.

The case of extending the coastal line by manmade islands and peninsulas has been studied under five subtopics. In the social case study, the stakeholders involved have been defined. It has been found out that the project even though is to be implemented on coastal zones; has a much wider scope. Developers, users, regulators and other stakeholders are all interconnected. Additionally, the significance of coastline over population has been investigated. The results show that from 1950 to 2025 the ratio of coastal population to coastline is likely to increase from 2247 to 14607 people per km. This is a substantial increase and there should be projects adopted to accommodate and satisfy this coastal population. Then, primary and secondary impacts of extending the coastline by manmade islands and peninsulas have been investigated. Again it has been found out that these impacts affect the whole society and they are interconnected.

During the environmental and economic case studies benefits and costs of implementing the project have been studied. It has been found out that interfering with the coastal processes will have direct effects on the environment. In the economic case study the quantifiable costs and benefits have been stressed. One of the important results is that not everything in the coastal extension project can be quantifiable. Large initial investment, maintenance and relocation costs should be minimized and return on investment should be maximized in order to be able to implement the project with success. In functionality case study, it has been found out that the manmade islands and manmade peninsulas do not have the same functions.

In the engineering case study failure modes and fault trees have been studied with reference to the related literature. It has been found out that the safety levels are likely to be improved with the extension of coastal line by manmade islands and peninsulas. Additionally, with reference to d' Angremond's (2001) studies coastal extension should be realized in leading and marginal edge coasts.

	Manmade Island		**Manmade Peninsula**	
	Short Term	**Long Term**	**Short Term**	**Long Term**
Social	• Coastal activities are limited	• Safer area to live, work, and play • Recreational Area and Attractions • Increased coastline per person	• Inconvenience • Relocation of houses Loss of LNC values	• Safer place to live, work and play • Increased quality of life • Increased coastline per person
Engineering	• Simultaneous planning with construction • Minimise damage the environment • Transportation to the island is an issue of consideration	• Less failure modes • Less maintenance	• Simultaneous planning with construction • Preparing work so as to minimally disturb the regular functionality of city	• Less flood risk • Less failure modes • More maintenance

Environmental	• Disturbance of natural habitats • Disruption of ecosystems	• Possible disappearance of flora and fauna ecosystems • Change in the coastal system	• Disturbance of natural habitats • Disruption of ecosystems	• Possible inability to re-establish loss of environment • Change in the coastal system
Economical	• New developments • Relocation of inhabitants, businesses • Retarded sea and port traffic	• Increase in tourism, recreation, and business • Profits due to reclaimed land •Could result in a return higher than initial investment	• Loss of business • Disturbance in development • Retarded sea and port traffic • Relocation of businesses, inhabitants	• Increase in tourism, recreation, and business • Greater value for land • Attractive area for development • Large demand for new space

Table 4: Summary of Findings of Case Study

Then design and guidelines of manmade islands and peninsulas have been introduced. Profiles of manmade islands and peninsulas have been drawn. It has been shown that these structure’s profiles are likely to change with different geographical conditions they will be built in. Then the guidelines were introduced concerning the angle of slope, height and width of the manmade islands and peninsulas. The angle to satisfy macro stability and prevent overtopping discharge should be gentle. The height calculation of manmade islands and peninsulas has been thoroughly investigated and guidelines were introduced. In reference to Vrijling (2009), the height calculations included variables such as sea level rise, ground subsidence, wave run up and settlement. In guidelines regarding the minimum width of manmade islands and peninsulas, 3 requirements were introduced; limitation of failure mechanisms, infrastructure allowance and slope. Minimum of leakage length was found to be between 10 and 60m. This implies that the minimum width is likely to be determined by infrastructure allowance of slope rather than the leakage length. It was also stressed that the minimum width required in manmade island and peninsula design is a function of angle of slope and height. Yet again we see that these parameters are interconnected.

In Planning and Economic Guidelines Section, it has been stressed that proper zoning before the execution of the project is needed. In Economic Guidelines Section, the methods to make a rough estimate of the costs and benefits of the project were introduced. Installments in differing timelines are discounted to the present value and a net present value analysis is suggested throughout the calculations. The investment costs included construction costs and relocation cost of inhabitants. In light of this it is safe to analyze that it is more feasible to apply the coastal extension in rural areas and then develop the region.

After the results have been highlighted and analyzed, the next section will discuss the implications of results in relation to the research question.

5 DISCUSSION

The research question, “Is extension of coastline by manmade islands and peninsulas feasible in different parts of the world?” has been raised in the introduction of the dissertation. The interpretations have been based on the literature concerning the extension of the coastline. Yet, to assess the feasibility of extension of coastline by manmade islands and peninsulas case studies were investigated in various subtopics.

As stated before, the rational decision upon whether a manmade island/peninsula is applicable can not rely on comparison between cost and benefits only. The decision should also be based on factors discussed throughout the dissertation. Additionally, not every cost and benefit is quantifiable.

One may argue the insignificance of increasing the coastline of one region of earth compared to the total coastline of the world. However, from a regional point, the construction of manmade islands and peninsulas may dramatically increase the coastline of an intended area. As in Dubai, Qatar, Hong Kong, Kazakhstan and the Netherlands coastal extension has both increased the human to coastline ratio and increased the functionality of the coastal zone.

Figure 34: Dubai Coastal Line (map.google.com)

(The figure above shows the satellite images of the Dubai Coastline. The coastline has been increased substantially. Thus, the effective use of the coastal zone is also achieved)

After discussions, the next section will conclude the dissertation.

6 CONLUSION

The following results found and analyzed throughout the dissertation are summarized. These results are effective in satisfying the initial goals and answering the research question raised at the introduction of the dissertation.

Extending the coastline via manmade islands and peninsulas will increase the coastline and safety level in current coastal systems. It is not necessary to extend all coastline of the world. However there are regions where this option is feasible. It is feasible to build manmade islands and peninsulas on trailing edge coasts. Additionally to decrease costs and opposition from the society and increase benefits, extension of coastline by manmade islands and peninsulas should be implemented in rural areas with development potential. The construction of manmade islands/peninsulas is possible with urban planning and can be combined with other coastal systems to increase its efficiency.

This dissertation has investigated the feasibility of coastal extension by manmade islands and peninsulas. The dissertation reviewed the related literature and previous practices regarding the coastal extension. After the literature review, the method adopted consisted of case studies subdivided in social, environmental, economic, functional and engineering subsections. Then, with reference to related literature and findings of the case studies; design and guideline principles were introduced.

In design critical factors such as profile, slope, height, and width were defined and their interconnections were outlined. These parameters were further investigated with reference to the literature. Then planning and economic guidelines were introduced for successful implementation of the project.

The findings mentioned and parameters introduced are powerful tools for the overall assessment regarding the applicability of the project. Additionally, this dissertation is a starting point for researchers who would like to further investigate the topic in the future.

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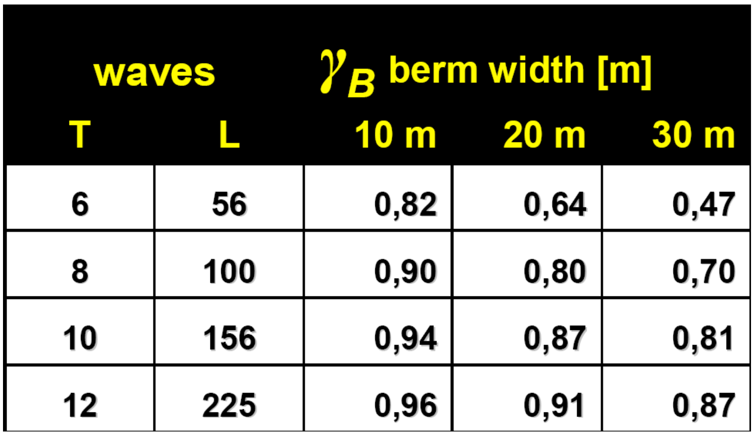
APPENDICES

Appendix 1 The roughness value γ_s

Type of covering	**roughness value**
Open stone asphalt	0.9
Sand asphalt, Asphalt concrete	1
Asphalt impregnated rock	0.8
Pattern penetrated rock	0.7
Concrete block (armourflex, haringman)	0.9
cement impregnated rock, colloidal concrete	0.8
Grass	1
course grave	0.7
armour rock, rip rap	0.55
placed basalt, basalton, hydroblock, pit polygon	0.9
placed natural stone (Doornik)	0.75

Appendix 2 The berm reduction factor γ_B



waves		γ_B **berm width [m]**		
T	**L**	**10 m**	**20 m**	**30 m**
6	**56**	**0,82**	**0,64**	**0,47**
8	**100**	**0,90**	**0,80**	**0,70**
10	**156**	**0,94**	**0,87**	**0,81**
12	**225**	**0,96**	**0,91**	**0,87**

T: wave period [s]

L: wave length [m]

Appendix 3 Population Over Years

1950	1975	2000	2025
2,50	4,10	6,20	8,30
1,80	2,70	3,10	3,10