CF54 Final Report

Development west coast Taiwan

Redesign coastal area between Da'an River and Dajia River

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General notice to the reader:

In the academic programme for Hydraulic Engineering we have in the 4th year (i.e. in the first year of the Master Programme) the requirement that students should do in a group of four to six persons a so-called "groupwork". It is also called "Master Project". During this groupwork they should make a full design of something. The work should be integral, starting with terms of reference, and ending with the real design. This can be a structure, but also it can be a harbour lay-out, a policy plan design, etc. The total time available for the project is in the order of two months and will provide 10 European Credits. It has to be practical and applied.
It is certainly not an M.Sc. thesis assignment (the thesis work is individual, 6 months and more focussed on research or advanced design work on details). But it is also not an apprenticeship, internship or traineeship where the student has to work together with a group of experienced people. For this groupwork they have to solve the problem on their own (of course with guidance).

This report is the result of such a Master Project. This report has been assessed by staff of TU Delft. It has been provided with a passing mark (i.e. a mark between 6 and 10 on a scale of 10), and consequently considered sufficient for publication.

However, this work has not been fully corrected by TU Delft staff and therefore should be considered as a product made in the framework of education, and not as a consultancy report made by TU Delft.

The opinions presented in this report are neither the opinions of TU Delft, neither of the other sponsoring organisations.

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Preface

This is the final report of project group CF54 for the CT4061 Master Project. The project group consists of four students of the Technical University of Delft. Each of the members has its own major; ranging from building engineering to structural hydraulic engineering, so the project group can be considered as a genuine multi-disciplinary team.

The team would like to thank the following persons for their help to make the project and our stay in Taiwan possible. First we like to thank Prof. Jiang from Feng Chia University in Taichung, Taiwan, for being our memorable host, for introducing us to people, for his advice and for his good help. At the TU Delft we would like to thank Mr. Verhagen for offering us this project and his advice during the months before the project and during this project. Furthermore we would like to thank Y. de Haan for her good help to make the project possible and our guardian angels from Feng Chia University, for showing the way around in Taiwan.

Taiwan, 24th of March 2006

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Abstract

In the year 2004 there was a flooding in an area between Da'an River and Dajia River in Taichung County, Taiwan. The flooding was caused by outlets which were clogged up, thus lacking the capacity to discharge the amount of rainwater that the typhoon caused into the sea.

A survey conducted by the project group, showed that the coastal protection is deteriorating, aging and inconsistent. Therefore the safety of the coastal protection is doubtful when extremely high water tables occur. The survey also showed that most of the outlets did not function properly, either they were clogged up, or the outlets were forced open by local inhabitants, using stones or tree-trunks.

The main purpose of this project is to design a new coastal protection and drainage system, which will suffice in their main purpose, but are also sound with the ecological, recreational and spatial requirements.

The alternative solutions consist out of three elements. These elements are the possibility of land reclamation, the possible methods of coastal protection and methods of drainage. There exists a strong relation between the elements.

After the feasibility of land reclamation was considered, four categories of solutions concerning the coastal protection were treated: "do nothing", improvement or replacement of the current dike, offshore constructions and soft solutions. Concerning the drainage system the following categories are treated: allowing flooding (do-noting alternative), decrease of the peak discharge or structural enhancement of the capacity

It was concluded that land reclamation is a feasible option and has to be further elaborated because of the favorable conditions of the foreshore and opportunities for land use. By using a multi-criteria analysis a choice has been made out of the generated alternatives. This analysis has shown that dike improvement and/or the application of soft solutions are preferred for coastal protection. The use of detention and the removal of bottlenecks are the solutions selected for improvement of the drainage of the area. These alternatives are elaborated further. For land reclamation an area of 500 meters width and 2 km's length is selected at the south of the project area.

The coastal stretch has been divided in four coastal protection zones. For each of these zones a design of the coastal protection has been made. The dimensions of the coastal protection of each zone are shown in table 1. The first zone is the land reclamation zone; because the shoreline at this zone is moved seaward the designed dike for this zone is considerably larger than the other dikes. The second zone is a zone with considerable foreshore vegetation. At this zone an ecologically sound dike has been designed with less steep slopes than the current dike and a grass revetment. Development of foreshore in this zone should be aimed at conservation by restricted use and natural development, but recreational opportunities for extensive recreation are available here. The third zone is a recreational zone, here a promenade is designed which is protected by a vertical front seawall. The fourth zone is a zone without foreshore vegetation, the dike designed for this zone is similar to the dike for the zone with foreshore vegetation only the revetment consists partly of placed blocks because the wave attenuating effect of the foreshore vegetation is not present.

It can be concluded for the new coastal protection that it is safer than the existing protection and upgraded to satisfy recreational and ecological needs. But this recreational and ecological needs lead to larger cross sectional surfaces and therefore the new protection will be more expensive than the current protection.

Tabel 1 Dimensions of coastal protection

	Toe level	Crest level	Outer slope	Inner slope	Berm	Cross section	revetment
	[m] + EL	[m] + EL				[m2]	
Existing dike	3.5	6.2	1:2	1:1.5	No	21	concrete
Land reclamation dike	1	8.32	1:6	1:3	Yes	321	Grass/ loose rock
dike with foreshore vegetation	3.3	6.9	1:9	1:3	Yes	108	Grass
dike Without foreshore vegetatio	3.3	6.9	1:9	1:3	Yes	108	Placed blocks/ grass
Sea wall	3.5	7 *	Vertical	-	No	-	Concrete
* including a parapet of 0.5 meter							

A part of the drainage system is modeled using Sobek. First the current system is modeled. From this model it is concluded the current drainage system is sufficient for a rainfall with a return rate of fifty years if it is maintained well. After this the chosen reclamation area is added in the model. Several opportunities for the drainage system are put forward and modeled: decentralized outlets, decentralized outlets with valves, centralized outlets and centralized outlets with valves.

Both the centralizing of the outlets and application of structures with valves will restrict the outflow; but structures with valves are needed to prevent salt intrusion and centralizing of the outlets means a limitation to the maintenance effort. Therefore the application of centralized outlets with valves is chosen. Due to this restricted outflow and because of the impossibility of discharging during high water of the sea extra measures are needed to prevent flooding during a typhoon.

A detention area with a surface of 2.5 hectare is sufficient to restrict this flooding to a predefined area. With the use of an embankment of the canal the detention area can be used for other purposes if there is no heavy typhoon. For the discharge of rainwater into the detention area during heavy rainfall an overflow construction is necessary. During normal operation natural drainage is possible but during typhoon situation artificial drainage is needed for the reclaimed area. Therefore a combined system needs to be placed. To ensure safety of the reclaimed area a high dike surrounding the detention area is needed.

The outlet structure from the canal to the sea has to discharge water to the sea and it has to protect the land against the sea. Therefore a gate with a counterweight is designed. The counterweight is needed to assure discharge with a low head difference. Fences are needed to prevent clogging up by debris.

General conclusions

In this project, possibilities for land reclamation, ecological friendly and safe structures with recreational opportunities have been investigated.

When land reclamation is applied the shoreline is moved seaward so the protective structure will be more massive. Also the level of the reclaimed land is lower and therefore drainage efforts will be higher. To obtain an ecological friendly coastal protection milder slopes are needed so this results again in a more massive structure.

A combination of land reclamation and ecological friendliness will result in an accumulated effect and therefore a very large structure compared with the

current situation. This combined with the fact that additional structures and facilities are needed in the reclaimed area to assure drainage and prevent flooding and salt intrusion means a high effort for land reclamation. It has to be determined if the value of the reclaimed land is high enough to justify these efforts.

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Chapter 1 Introduction

In the year 2004 there was a flooding in an area called Hai Tsien Tsung, which is between Da'an River and Dajia River in Taichung County, see also figure 1.1. The outlets which are normally used to drain the area were clogged up by tree-trunks, waste material and sediments, thus lacking the capacity to discharge the amount of rainwater that the typhoon caused.

Figure 1.1 The area of Hai Tsien Tsung in Da'an County

A survey conducted by the project group, showed that part of the coastal defense is deteriorating and aging, and that on some place repairs had taken place. The safety of the coastal protection is doubtful when extremely high water tables occur, due to the deteriorated parts and inconsistencies in the defense. The survey also showed that most of the outlets did not function properly; either they were clogged up, or primitive measures had been taken to force them open in order to provide enough discharge during the dry season.

The main purpose of this project is to design a new coastal protection and drainage system, which suffice in their main purpose, but are also sound with the ecological, recreational and spatial requirements.

This final report is the last of the three documents generated during the project. The first and second part of this document consists out of a revised part of the progress report and start-up document. The revisions are made according to the availability of new information and new insights. The purpose of this document is to present elaborated alternatives to tackle the problems as described above in the coastal zone between Da'an river and Dajia River.

The first part of this document consists out of a revised part of the start-up document. In chapter 2 the situation description is given, which is the basis of the report. From the situation description follows the problem statement, which is presented in chapter 3, along with the derived purpose statement. To confine the problem, restrictions are given in chapter 4, including the program of demands which is derived from the restrictions.

In the second part of the document the continuation of the project is presented, starting with the generations of alternatives for the several aspects of this project. These alternatives are compared using a multi-criteria analysis in chapter 7 in which also a sensitivity analysis of this method is given. A master-plan for the coastal zone between Da'an River and Dajia River regarding the land-use and the application of the different alternatives on the stretch of coast is presented in chapter 8.

The final part of the document is the result of the last phase of the project. It consists out of the elaboration of the alternatives. In chapter 8 several alternative solutions for the coastal protection are further elaborated. A model of the drainage system is described in chapter 9, leading to an alternative which is further elaborated in chapter 10. Finally the design of an improved outlet structure will be presented in chapter 11. A conclusion regarding the whole project is drawn in chapter 12. Also some recommendations are given in this chapter.

Chapter 2 Situation

This chapter describes the situation of the project area. At first a more general description of the most important aspects of the Taiwan west coast is given. Then more detailed description of the project area which is the coastal area between the Da'an River and Dajia River follows.

2.1 Taiwan West Coast

Western Taiwan consists of plains and basins. There are a lot of small and some big rivers which empty into the Taiwan Strait. This is the stretch of sea between Taiwan and China. The majority of the Taiwanese population lives on the west coast. This area has the most suitable land for agriculture, and the presence of natural resources attract industries.

2.1.1 Climate

The climate in Taiwan can be considered as sub-tropical, with average temperatures ranging from 15 degrees Celsius during the winter to 30 degrees Celsius in summer. The annual weather cycle is a monsoon cycle. In the months September till May there is a north-east monsoon and in the months June till August there is a south-east monsoon. The average wind speeds of these monsoons are respectively 7.5 meters per second and 4 meters per second.

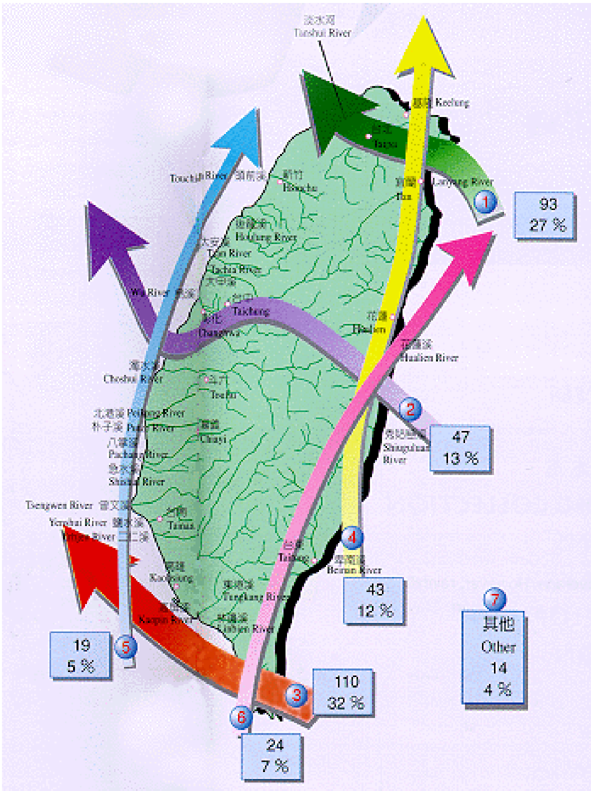

Figure 2.1 Typhoon routes and the number of occurrence between 1897 till 1997[1]

During the south-east monsoon period there are also typhoons. Most typhoons originate above the Pacific Ocean east of the Philippines. They travel westward

[1] http://www.eng.wra.gov.tw/public/data/gh022_p4.htm

and first hit the east coast of Taiwan. They pass over the mountains of central Taiwan before they reach the west coast; hence the force of these typhoons is considerably diminished when they reach the west coast. Although the force is diminished, there is still heavy rainfall to be accounted for up to 300 mm per hour. Occasionally a typhoon originates in the South China Sea. In this case the typhoon travels along the west coast first and causes considerable damage because it hasn't diminished yet, and the people don't expect them. Such a typhoon also causes heavy rainfall.

2.1.2 Taiwan Strait

The west coast of Taiwan is adjacent to the Taiwan Strait. The Taiwan Strait is a connection between the China South Sea and the China East Sea. The overall depth of the strait is approximately 70 meters, the width is about 150 kilometers. The current is mainly wind-dominated. From May till September the south-east monsoon pushes water from the South to the North, from October till April the north-east monsoon pushes the water from the North to the South. These currents can reach a maximum velocity of 1 m/s.

The coast is wave dominated; causing large plains to develop which fall dry during low tide. These plains can grow relatively large with widths of over 1 kilometer.

Figure 2.2 A plain outside the sea dike

2.1.3 Landside

The rivers in Taiwan can be characterized as typical tropical rivers, with a large seasonal variance. The rivers entering the Taiwan Strait fall virtually dry in the dry season, while during times with heavy rainfall they have to cope with large amounts of water; over 5.000 cubic meters per second. The rivers are relatively short and steep, so currents on the rivers are very high. Therefore the rivers have a large capacity to transport sediments ranging from sand to boulders. During the typhoon season the rivers also carry a lot of wood from the mountains which is later deposited on the floodplains on the coast. The river mouths are river-dominated estuaries whilst they have water in them.

Figure 2.3 Estuary of the Dajia River[2]

The land is protected from the sea by concrete dikes and other hard structures, such as block revetments made out of tetrapods. On many places the dike is interrupted for watering outlets and small rivers. Along the dike there are many small harbors, which are used by local people for fishing.

Earthquakes occur regularly in Taiwan. This is because Taiwan is situated on the colliding Eurasian and Philippine plates. The most recent devastating earthquake occurred on 21 September 1999 and measured 7.3 on the Richter scale. The earthquake caused tremendous damage.[3]

2.2 Area between Da'an River and Dajia River

The area of interest is bound between the Da’an River in the north and the Dajia River in the south, just north of Taichung Harbor. These rivers are two main rivers from the mountains in central Taiwan and they belong to the seven biggest rivers in Taiwan. The area has a coastline with a length of circa 15 kilometers, for an overview see figure 2.4, the existing sea dikes are marked yellow. Some of the problems in the project area are related to these rives, like the woody debris on the beach. Some solutions to the problems can stretch beyond the limits boundaries of the project area.

2.2.1 Socio-graphic

Agriculture

Behind the sea dike most of the land-area is occupied by agriculture mostly small scale farms which produce rice or other kinds of crops. There are also some poultry-farms.

Fishery

The entire length of the stretch is used by local fishermen. Their ships and equipment is only fit for small scale fishing. The ports used by the fishermen are rather small (200-300 m^2 per port), and are generally located behind the breaker zone. They lack navigational channels, so the fishermen have to go through the surf to reach open sea.

[2] Google earth
[3] Lonely Planet Taiwan

Population

In the area between the coast and the freeway are also many houses and a lot of small villages with a maximum population of 8.000 people. The total number of inhabitants is on or about 100.000 people. The averaged population density of the whole area is approximately 700 people per square kilometer[4].

Landownership

Most of the area of interest is governmental possession. There are also certain areas, which belongs to the military. They keep an eye out for illegal immigrants from China and are taking care of their area regarding pollution.

Responsibility coastal defense and drainage

The WRA, the Water Resources Agency, part of the ministry of economic affairs of Taiwan is responsible for the coastal defense. This agency executes twice a year a visual inspection with a checklist. After the visual inspection a maintenance plan is proposed to the Taichung County authority, which has to execute this maintenance. The Taichung County authority is also responsible for cleaning the beach of debris. However the maintenance of the coastal protection and the cleaning of the coastal area are very poor at this moment.

There are three parties responsible for the drainage system; the WRA, the Taichung county authority and a farmer association. These parties are responsible for a well functioning dewatering system. All the drainage canals are distributed over these three parties.

2.2.2 Taiwan Strait

Detailed information on tides, wave-records, currents, general wind-speeds and directions are given in Appendix A. It should be noted, that this data has actually been gathered at the site of Taichung Harbor, which is located approximately five kilometers south of Dajia River.

2.2.3 Beach

The section of the Taiwan coast in question is assumed to be an accreting coast. In the current situation a hard solution exists, i.e. the concrete dike. If there was a structural erosion problem at this stretch of coast, the large tidal plains would have disappeared in the lifespan that the current dike exists. The tidal flats aren't eroded, so one can assume that the current coast is at least stable, or even accreting. The sediments required for the accreting coast can come from the large amounts of sediment that both Dajia River and Da'an River carry.

The distance between the concrete dike and the high tide level of the sea is for most of the area of interest only about ten meters. From the top of the dike it can be seen, that there is a sand bar located between the surf zone and the foot of the dike. Because of the small slope of the beach the swash zone is very wide. Therefore the distance between the dike and the low tide level can be several hundreds of meters. The mouths of the smaller rivers in the project area, as described in sub-paragraph 2.2.5, do not cross the sand bar right away, but make a southward turn. They pass through the bar several hundred meters south of the actual river mouth.

[4] http://www.taichung.gov.tw

The area between the coastal protection and the surf zone shows a variety in vegetation. Some areas are completely void of any kind of plants, while other beaches have small mangrove-like vegetation, or even thick bushes starting at the foot of the dike. However the largest part of the coast exists of a sandy beach.

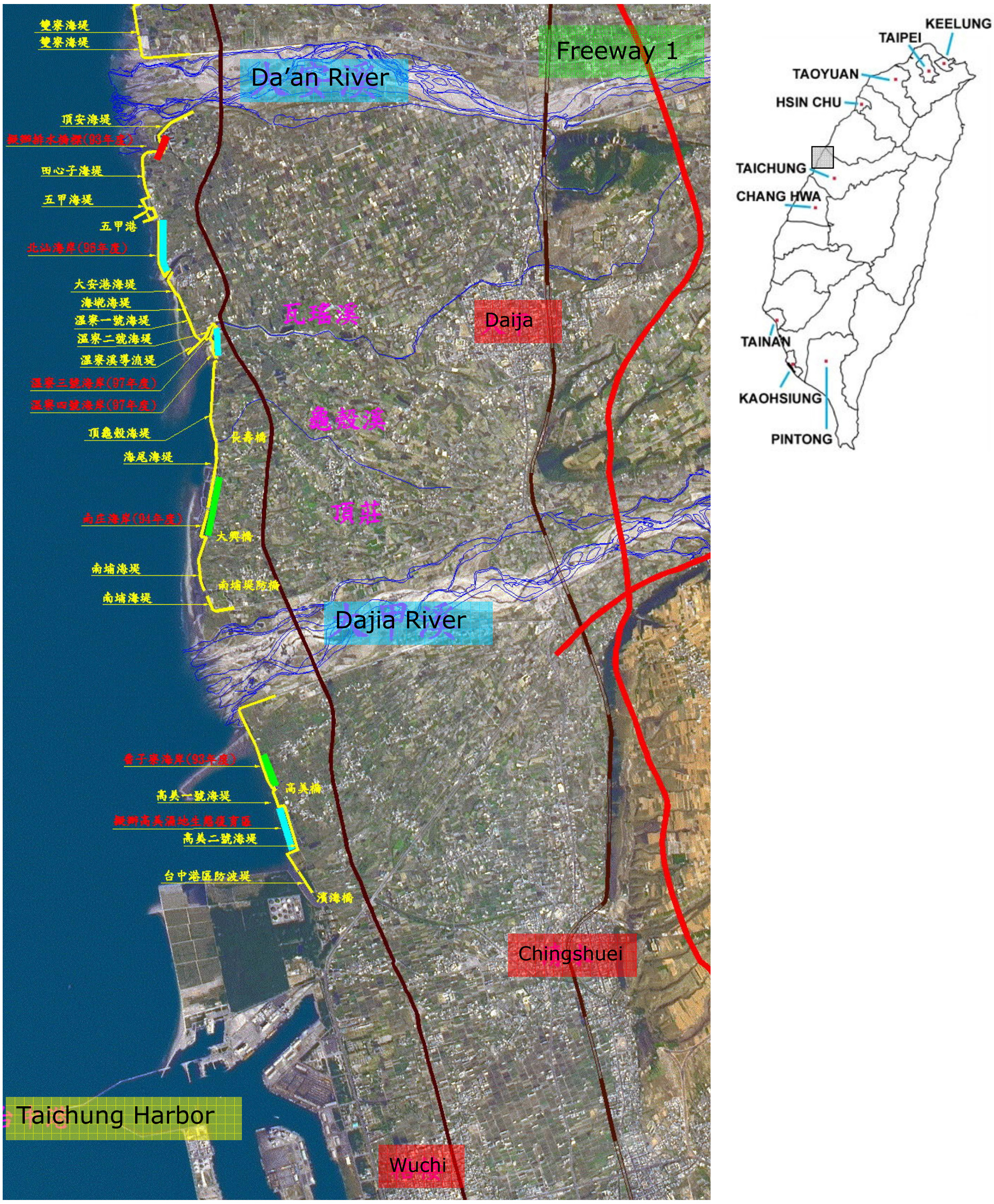

Figure 2.4 Overview of the area, existing coastal defenses are highlighted

Most of the beaches are littered by dead trunks or snags of wood. These trunks come from the higher mountains, and are transported to the coast through the rivers during the season in which the rivers carry water. They are then deposited along the coast. The snags make up huge piles on the beach every year, as can been seen in figure 2.5.

Figure 2.5 Pollution of beach by wood and other material

2.2.4 Da'an and Dajia River

The wet season in Taiwan generally runs from April till September. This is also the period when the rivers have their greatest discharge. During this time the rivers are about eight-hundred meters wide. In the other seasons the discharge decreases to a trickle, and almost the entire bed falls dry. It is beyond obvious that both rivers are not used for any kind of shipping.

The estuaries of the big rivers are difficult to characterize, because of their large seasonal variance. During the dry season, there isn't even much of a discharge to speak of, and the gravel-covered bed only protrudes less than a kilometer from the adjacent coastline, and seems to stop abruptly at the surfzone without being flooded by tide, see also figure 2.4. In the monsoon-season, the estuary can be characterized as river-dominated, with large freshwater discharge and relatively short tideland areas.

The bed of the rivers consists mostly of course sediment like gravel or even larger graded stones and boulders. The sediment consists mostly of gravel, but also finer graded materials such as sand or silt. In addition to the gravel the rivers transport large amounts of tree-trunks coming from the higher catchment-area during the wet season. For Dajia River it is known that it receives 3.15 million cubic meters of sediment per year from erosion caused by typhoons. The yearly sediment discharge of Da'an River is even higher; 3.99 million cubic meters.

2.2.5 Small rivers and canals

Between the two big rivers Da'an River and the Dajia River and smaller rivers and canals a distinction can be made. The rivers are rather small in comparison to Da'an River and Dajia River, and are for the largest part completely normalized by means of concrete structures. These rivers are several tens of kilometers long. The canals are smaller and shorter than the rivers and end up in the sea by a tube through the sea-dike. For the small rivers the sea-dike is interrupted and a river mouth exits. The rivers and canals are polluted with all kinds of waste material and some suffer from pollution coming from farms, i.e. the dump of manure in the water.

2.2.6 Outlets

Locally the sea-dike is interrupted to allow drainage of the small rivers into the sea. Along the rivers and canals dikes exist but they are lower than the sea-dike. The current design return-rate of a rain induced flooding is once every ten years. Sedimentation in the mouth of the outlet occurs and also a lot of trees are deposited along the rest of the coast settle in the mouth of the outlet. Furthermore the waste material of the small rivers settles also in the river outlet. On some places one meter high screens made out of bamboo are placed to prevent sand blown into the outlet by the wind. In figure 2.6 one of the outlets is shown.

Figure 2.6 An outlet, with on the right screens of bamboo to prevent sand from being blown into it

Most of the outlets of the canals are equipped with simple steel gates, which should close automatically during high water levels on the outside of the dike. However, most of these gates are hindered in their performance by either the placement of wood or stones in these gates to keep them open during low water levels, or by the blockage of sand and debris deposited against the steel gate.

Figure 2.7 Two different outlet gate with stones or siltation

2.2.7 Coastal defense

The river-dikes consist of a sand-core covered with stones and/or concrete. Arriving at the coast these dikes are all changing into dikes with a sand core and a concrete cover of approximately 20 cm. At several places this dike is enforced with tetra-pods at the seaside. At other stretches of the coast the main coastal defense is protected by vegetation. The continuity of the dike looks very inconsistent as can be seen in figure 2.8. At several places the concrete dike is lower than other parts. Furthermore at some places hollow cores in the dikes are suspected.

Figure 2.8 Dike interrupted by deteriorated military structure

2.2.8 Recent coastal development

To improve this coastal area several measurements are recently taken, but these are more on the recreational and ecological aspect then on the aspect of safety. A concrete dike is replaced by a pseudo green dike i.e. a dike covered with stones allowing vegetation as shown in figure 2.9. Furthermore there is invested in recreation by constructing a biking-path along the coast.

Figure 2.9 A (pseudo) green dike

2.2.9 Earthquakes

The biggest earthquake in the region on record will undoubtedly be the Jiji-earthquake of 20 September 1999. This particular quake caused extensive damage to the western part of Taiwan, and also triggered several liquefaction events in Taichung Harbor, which isn’t far from this project’s area of interest.

Chapter 3 Problem analysis

3.1 Problem description

3.1.1 Current coastal protection

The current dike is getting older and older; there are a lot of cracks in it. On some places it is interrupted and there are some parts suspected to have a hollow core due to the wash out of sand. Furthermore the current coastal protection doesn't satisfy ecological, environmental and recreational needs of the region.

3.1.2 Dewatering problem

During typhoon season the area experiences heavy rainfall. Due to the fact that the outlets are being clogged with tree-trunks from the mountains, waste material and sediment this water cannot be sufficiently transported to the sea.

The biggest damage occurs during typhoons from the west. These typhoons are stronger and there is less time to take precautions. Furthermore typhoons from the west induce storm-surge; therefore discharge of water to the sea is even more limited.

The combination of heavy rainfall and limited discharge results in flooding of the area just behind the coastal protection.

3.1.3 Sediment

Both airborne and waterborne sediment cause problems. Due to the strong winds sand is transported over the dike and will settle behind it or even in the hinterland. The coast ca be defined as accreting, this can be due to large amounts of sediments transported into the sea. Due to this sedimentation problems can arise with the outlets. The progressive nature of the coast also spawns wide flood plains which are not suitable for recreation at this moment.

3.1.4 Rubbish on the beach

During the wet season the Da'an River and the Dajia River are transporting large amounts of rubbish, i.e. tree trunks and waste material, which come ashore on other places along the coast. Cleaning the beach is not a sustainable solution because the yearly returning large amount of rubbish which requires cleaning.

3.1.5 Economical

The current coastal defense has been designed without the use of a failure-rate, so the return-rate of flooding from see remains unknown. The drainage system has a failure-rate of once in every ten years. This restricts the economic growth of the area; the fact does not attract investors to invest in the area. The land-use in the area is indirectly restricted by the lack of this safety for investments.

3.2 Problem statement

The main problem of the area is twofold,

- the dewatering system is insufficient;
- the coastal protection is deteriorated and is aging. Besides that, it does not meet ecological and recreational requirements.

There are three sub-problems, which are strongly related to the main problem:

- there is not enough space for recreation and there is no sustainable method to keep the current recreational beaches clean;
- the coastal zone is not utilized enough as important area for ecological development;
- the area is lacking economical growth due to the high return rate of the flooding;

3.3 Purpose statement

The main purpose of this project is twofold,

- the enhancement of the dewatering system, so that it can dewater sufficiently, especially during the typhoon season;
- the design of a coastal protection, which is first sufficiently safe and second environmental-friendly and offers recreational opportunities;

There are also three sub purposes, which are of lesser importance but are related with the main purpose:

- to create space for recreation in a sustainable way;
- to increase the ecological value of the coastal zone;
- to improve the economical development of the area.

Chapter 4 Restrictions

This chapter provides the currently known boundary conditions, starting points and assumptions. From these restrictions and boundary conditions a program of demands will be constructed.

4.1 Boundary conditions

These conditions are imposed by the natural and social situation.

4.1.1 Natural boundary conditions

The following aspects need to be accounted for. In the next report they will be expanded when necessary.

- BC-N1 Tide
  For our calculations the Highest High Water level will be used. A detailed outline of occurring tides in Taichung Harbor is given in Appendix A.
- BC-N2 The monthly rainfall
  Exact figures on precipitation from stations in Taichung and Wuchi are given in Appendix A.
- BC-N3 Typhoons and storms
  In Taiwan heavy storms and typhoons occur frequently, with strong winds and extreme rainfall. The exact data is displayed in Appendix A.
- BC-N4 Wind
  In the monsoon season winds are predominately from October to March, and are predominately from NNE, occurring about 80% of the time. Winds over 20m/sec account for only 1.71% of wind activity. The strongest gale recorded had 10 on the Beaufort wind scale. In the summer season winds are mainly from the south and the wind velocities are mostly under 10 m/sec. Typhoons normally occur from July to October. The maximum wind speed recorded reached 13 on the Beaufort wind scale. Sheltered by the Central Mountain Range, the selected area is seldom subject to severe typhoon attack[5].
- BC-N5 Wave climate
  Exact data on the wave-climate are given in Appendix A.
- BC-N6 Currents
  Current along the coast of Taichung Port composes of longshore current, wind-drift current, tidal current and a branch of the Kuroshio-current (an ocean current). According to the preliminary investigation, when wind velocity reached 20 meter per second in the winter monsoon season, the current near the port entrance was about 2.8 knots with the direction of WSW[6].

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[5] http://www.tchb.gov.tw/ENG/e420.php
[6] http://www.tchb.gov.tw/ENG/e430.php?targE=tr3

- BC-N7 Groundwater-level
  The project area is groundwater rich. The average water level at the measuring station in Haichean village, which is situated in the center between Dajia River and Da'an River along the coast, is located at 37 cm below the ground level at the station itself.

- BC-N8 Earthquakes
  Large earthquakes can occur in Taiwan. The heaviest conceivable earthquake that could strike the area of interest has a Peak Ground Acceleration of 40% of the gravitational acceleration, which is about 3.9 m/s^2.

4.1.2 Legal boundary conditions

- BC-L1 Safety hinterland
  The design should be such that it can ensure safety of the hinterland during its lifetime. (from: Water Resource Agency)

- BC-L2 Recreational needs
  The proposed solution must have space for recreational needs. (from: Da'an Township)

4.1.3 Technical boundary conditions

- BC-T1 Standards
  Design conform Dutch Standards, and if available according Taiwanese standards.

- BC-T2 Debris
  The proposed solution must have an adequate ability to deal with washed-up debris, which follows from information from Da'an Township

4.1.4 Executional boundary conditions

- BC-EX1 Safety hinterland
  During construction of the coastal protection the safety of the hinterland must be assured.

- BC-EX2 Hampering activities
  The proposed solution must not hamper the agricultural/fishery activity in the area during construction.

4.1.5 Economical boundary conditions

- BC-EC1 Livelihood maintenance
  The proposed solution must guarantee enough possibilities for local fishermen to maintain their livelihood.

- BC-EC2 Accessibility
  The current level of accessibility of the region must be maintained.

4.2 Starting points

These points are self imposed limitations to narrow the field of interest.

4.2.1 Natural starting points

- SP-N1 Weather-data
  Data from Wuchi weather station are representative for the project area, because it is located near enough, around 15 km south.

- SP-N2 Wave-data
  Data concerning waves and tides from Taichung harbor are representative for the area, because the harbor is located only 5 km south of the mouth of Dajia River.
- SP-N3 Groundwater level
  The groundwater level at the measuring station in Haichean village is representative for the entire area, because it is located in the central zone of the project area. This level is assumed to be stable.
- SP-N4 Slope of the beach
  Because there is no data available, it is assumed, that the beach has an average slope of 0.5%.
- SP-N5 Soil composition
  It is visually estimated that the soil is mainly consisting out of sand.
- SP-N6 Coastline characterization
  The coastline is assumed to be characterized as an accreting coast.
- SP-N7 Wind speed during typhoons
  The wind speed during a typhoon event is 50 m/s. This wind speed is found in a typhoon that is classified as a 'very strong typhoon'. Stronger typhoons do exist, but it is assumed that typhoons striking this coast have already dissipated some of their energy.
- SP-N8 Breaker index
  The breaker index is assumed to be 0.5.
- SP-N9 Fetch
  The fetch of the typhoon over the Strait of Taiwan is 100 kilometers.
- SP-N10 Sea level rise
  The average sea level rise is 0.1 meters during the lifetime of the construction.
- SP-N11 Soil subsidence
  The soil subsidence during the lifetime of the construction will be 0.5 meters.

4.2.2 Social starting points

- SP-S1 Ecological-friendly
  The design has to be environmental/ecological-friendly.
- SP-S2 Ecological development
  The proposed solution must have space for ecological development.
- SP-S3 Residential area
  Loss of residential land-area should be minimized.

4.2.3 Constructional starting points

- SP-C1 Materials
  The use of local available materials is preferred.
- SP-C2 Soft constructions
  Soft natural constructions are preferred.
- SP-C3 Safety
  The new coastal zone should have a higher safety-level for rain-induced flooding.

4.2.4 Executional starting points

- SP-EX1 Labor
  The use of local available labor is preferred.

4.2.5 Economical starting points

- SP-EC1 Agricultural
  Loss of agricultural land-area should be minimized.
- SP-EC2 Economical
  The solution should be economical. The costs should not be disproportionate high compared to the achievements.
- SP-EC3 Economical value
  The solution should be aimed at increasing the economical value of the region.

4.3 Program of demands

From the boundary conditions and starting points stated above the following program of demands is derived.

4.3.1 Technical

- The coastal protection must be designed according to a return-rate for seawater-flooding of 1 per 250 years. (BC-L1)
- The drainage system for the existing land must be designed according to a return-rate for rainwater-induced flooding of 1 per 50 years. (BC-L1)
- The drainage system for newly reclaimed land must be designed according to a return-rate for rainwater-induced flooding of 1 per 50 years. (SP-C3)

4.3.2 Functional

- At least 50% of the area of, or in the direct vicinity of, the coastal protection must be suitable for recreational needs. (BC-L2)
- At least 80% of the area of, or in the direct vicinity of, the coastal protection must be suitable for ecological development. (SP-S2)
- There should be no loss in the capacity of outlets due to blockage by debris. (BC-T2)
- The closure of beaches due to debris during the summer period may only occur rarely. (BC-T2)

4.3.3 Social

- During the execution of construction the ports used for fishing may only be blocked for a short period. Furthermore at least one harbor in the project area should be accessible. (BC-EX2)
- There may be no decrease of fishing harbor capacity after completion of construction. (BC-EC1)

4.3.4 Land-use

- The demolition of residences is not allowed, unless this loss is mitigated. (SP-S3)
- Loss of breeding/living space for local wildlife should be compensated for within the project area. (SP-S1)

Chapter 5 Generation of alternatives

There are many possible alternatives, but all these alternatives merely consist out of three elements. These elements are the possibility of land reclamation, the possible methods of coastal protection and the alternatives for solving the problems with the drainage system. These three elements will be dealt with separately in the following paragraphs; however there still exist a strong relationship between them. The question about land reclamation has implications on the coastal protection, whether it can be improved or it has to be replaced. Also for the drainage system there is a distinct interaction between land reclamation and the chosen coastal protection, because it the drainage system needs space and has to cross the coastal protection. The alternatives presented in the following paragraphs are forming a palette from which the coastal zone can be painted.

5.1 Reclamation area

Renewal or improvement of the coastal protection can be combined with land reclamation. In this case the new coastal protection will be placed in front of the existing coastal protection, thus reclaiming the land between both coastal protections from the sea. This area can be used for many purposes.

Though there is interaction between the type of coastal protection and land reclamation, basically the decision for land reclamation does not depend on the type of coastal protection. Therefore the land reclamation alternative is separately discussed and considered in this paragraph. There are three options to be chosen from. The first option is to do nothing, second land reclamation by the landfill method and third the creating of polders.

5.1.1 “Do nothing”-alternative

If there is no land reclaimed and there is a desire to change the current land use, the existing land has to be reallocated. There are many groups with different interest involved so it will be difficult to satisfy the needs of every group. This will involve complex planning and requires a consistent policy.

Advantages

- No capital costs

Disadvantages

- Limited possibilities for reallocation

5.1.2 Landfill alternative

If there is land reclamation a higher economical value is given to the reclaimed area because this land becomes available for different purposes. Because the newly reclaimed land is available for different purposes, reallocation is made less difficult. Land reclamation has a long term impact on the coastal morphology and the coastal environment. These impacts are difficult to predict. A thorough assessment of the expected effects has to be made. When using the landfill method the sand has to be harvested from other places, so availability of sand is an important aspect.

To determine the needed amount of sand information has to be gathered about the alignment and the condition of the soil of the foreland. Furthermore information about available sand and the impact of excavation or dredging has to be investigated. To investigate the morphological alteration information is needed on the current along the coast.

Assessment

As stated before the main reason to consider land reclamation is the opportunities it offers for usage. Currently the area considered to be reclaimed is a part of the swash plains in front of the coastal protection. Since they are flooded every day when high water occurs, the use of these swash plains is limited to small scale fishing and as far as beaches are present for recreation. Reclaiming this land means it becomes available for vegetation, agriculture or even residence.

Using the landfill method to reclaim land will lead to lower maintenance efforts in the future, because the land is elevated, so drainage and coastal protection will be easier. Also because of this elevation, using the landfill method will lead to less damage in case of flooding, so the risk is lower.

Sand is relatively expensive, thus creating new land by depositing sand induces high capital costs, since a lot of sand is needed. The actual amount of capital costs depends on where the sand has to come from which determines the transport costs and the acquisition costs.

Another disadvantage which relates to land reclamation in general is has to do with the complex and with current knowledge relatively unpredictable processes in coastal morphology. By creating new land the existing current and sediment transport is obstructed and thus changed. This can lead to undesirable side effects. For example land reclamation at one location might lead to erosion at other locations at the coast.

When the sand needed for the land fill method is acquired from the same coastal zone this aspect plays even a bigger part, because this will certainly lead to changes in sediment transport. The dredging area will be filled up by nature again and the sand needed to fill this up must come from somewhere, this could be the coast, leading to erosion. To prevent erosion of the coast the dredging activities should take place as far of the coast as there will be no influence of these activities on the coastal morphology.

Another disadvantage might be the destruction of nature. This is the case when the function of the appointed area for land reclamation can be characterized as ecologically important, which means it has a high biodiversity and biological production. No matter how the reclaimed land is fitted up, it is very unlikely it will have the same biodiversity and biological production.

Advantages

- Opportunities for land use
- Low maintenance cost
- Less damage when flooded

Disadvantages

- Morphological uncertainties
- High capital costs
- Possible destruction of ecological important area

5.1.3 Polders alternative

When using the polder-method the reclaimed land is still below sea level during high water. The land needs to be drained, during the low tide this can be done by using gravity. When drainage is needed during high water usage of pumps is inevitable.

Because the reclaimed area is below sea level the coastal defense becomes more important since a breakthrough of the dike means inundation of the entire reclaimed area. On the contrary low lying land means better opportunities if usage of the area for retention is considered.

<u>Assessment</u>

The more general advantages and disadvantages for land reclamation, being opportunities for land use and morphological uncertainties also apply for this solution; they will not be further elaborated here.

A specific advantage to this solution is the opportunity to use the area for water detention. By creating low lying land at the coast, a natural drain for the area is created so very little efforts are needed to store excess water at this location. Also because it has yet to be developed there is room to develop it in such a way that the damage due to the water storage is limited. However this benefit also has its shadow side. When the reclaimed land or part of it is not used for retention extra measures have to be taken to keep the water out. So, more efforts to guarantee a certain level of safety are required. So, more efforts to guarantee a certain level of safety are required.

The main difference between the polder method and the land fill method is that there is less to no sand needed. Since sand removal at other areas can have negative effects on the environment this difference can be considered a plus for the polder method. This will also lead to lower capital costs, but because more efforts are needed to protect the area from flooding, construction costs will be higher; the overall capital costs will therefore be moderate compared to the landfill method.

Maintenance costs are higher though. This is mainly due to the higher efforts needed to keep seawater out and get rainwater out. Because the land is very low a good drainage systems and pumps are required and this needs maintenance. Also the coastal protection will have to be maintained very well because the risk involved in flooding is higher.

<u>Advantages</u>

- Opportunities for land use
- Opportunities for detention
- No sand removal at other locations

<u>Disadvantages</u>

- Morphological uncertainties
- Moderate capital costs
- Maintenance cost are higher
- More efforts needed to guarantee safety

5.1.4 Conclusion

A choice has to be made between the "do nothing"-alternative and the reclamation of land. If there has been chosen for land reclamation, there are two possible methods to achieve this, namely the land-fill method and the polder method. All the alternatives are listed below in figure 5.1.

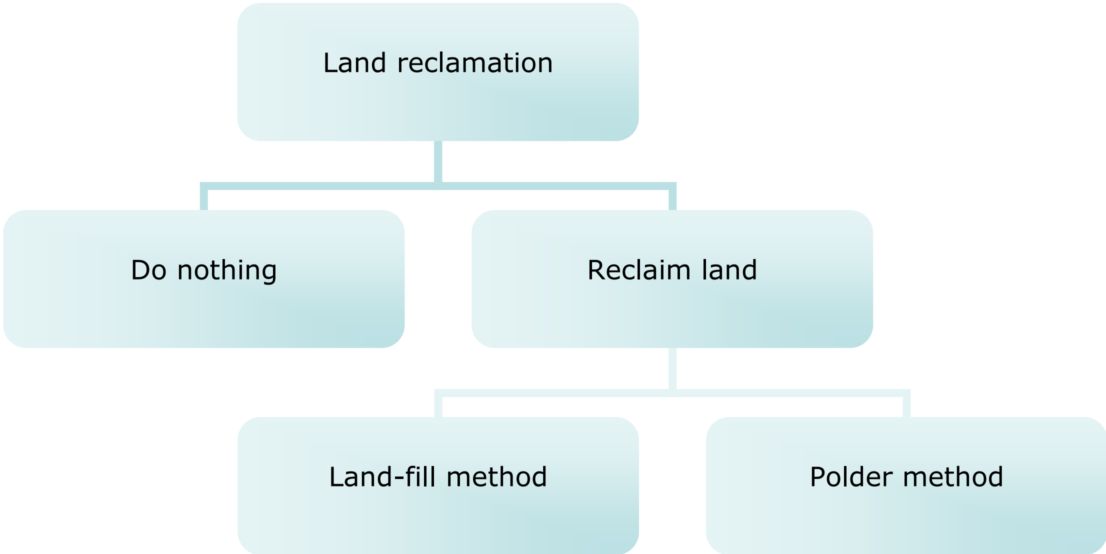


Figure 5.1 Diagram of possible alternatives for land reclamation

5.2 Alternatives for coastal for protection

During the typhoon season the water level and the waves at sea become higher. The hinterland needs to be protected. Alternatives for coastal protection can be subdivided in four categories. First, the "do nothing"-alternative, second, the improvement or replacement of the current dike, third, offshore constructions and fourth, soft solutions. These four alternatives will be elaborated below. For all these alternatives information about the wave climate and the extreme water levels is needed. There are different combinations of the alternative categories possible. Furthermore on each different stretch of coast a different combination can be applied.

5.2.1 "Do nothing"-alternative

In the current situation a concrete dike with a sand core is used for the coastal protection. As shown in the situation description, the current coastal protection does not meet the requirements, partly due to poor maintenance

<u>Assessment</u>

The concrete dike is safe for the largest part of the area, though there are some parts of the dike which are getting old. So replacement or maintenance of these parts is needed to guarantee the coastal protection. Besides this maintenance there are no costs for this solution.

The current dike is not an ecological friendly solution: Concrete is not a material on which animals or plants can settle. Furthermore it is not visually attractive and it does not give opportunities for extensive recreation.

Advantages

- No capital costs

Disadvantages

- Does not meet ecological needs
- Does not meet recreational needs
- Parts of the current dike are old

5.2.2 Improvement/replacement alternative

The current dike can be improved, so that it does meet the recreational and ecological needs to a certain level. However some improvements require such an intervention in the current situation or are not compatible with the current coastal protection, that replacement is necessary. It is beyond obvious that when there is chosen for a land reclamation alternative that there is a replacement of the current coastal protection. There are globally two alternatives possible to improve or replace the dike and also meet the recreational ad ecological needs.

- Promenade

  To meet with recreational needs a promenade can be constructed this alternative is especially suitable in combination with beaches. This can be done in two ways. First a seawall can be placed. The landside of the seawall can be elevated and fitted up like a promenade, i.e. there is place for shops, restaurants and promenade features. Due to the steep wall attention has to be paid to cross-shore sediment transport. Second the existing dike can be expanded with a sand body behind the dike. The sand body must have the same height as the crest of the dike.

- Alternatives for revetment

  A more ecologically sound solution is the green dike. This is a dike mainly covered with vegetation. Another solution for a green dike is adding sand at the seaside of the current coastal protection and making it suitable for vegetation. In case of a dike partly covered with vegetation and partly with hard material is considered as a pseudo green dike.

  Another conventional option is to cover the coastal protection with rock armor. Well constructed rock armor cover will offer ecological opportunities, but this solution is less suitable for recreational use.

Assessment

By improving the dike capital costs will be made, but these costs will be low compared to other solutions than the do nothing alternative. The solution is conventional, there are less uncertainties and it is a very effective alternative to meet the ecological and recreational requirements. The constructions are rather simple and do not take a great effort to construct. In combination with the current dike it may be even easier and less expensive.

A hard solution is less suitable for an eroding coast because of the continuing erosion and the possible instability of the hard solution. For an accreting coast hard solutions can be applied but the possibility of erosion has to be investigated.

Advantages

- Relatively low capital costs
- Conventional and effective solution
- Relatively easy to construct

Disadvantages

- Hard structures can cause or amplify erosion processes

5.2.3 Offshore structure alternative

There are three variants to be considered for coastal protection using offshore structures. All of these variants are directed to dissipate wave energy off shore. Therefore the wave run-up on the main coastal protection; i.e. the dikes is reduced. Also by constructing offshore structures the sediment transport is afflicted. This can prevent beach erosion and sediment can be deposed behind them so a tombolo can be formed.

- Artificial reef
  An artificial reef is a man-made, underwater structure, typically built for the purpose of promoting marine life. Generally this is done by placing objects on the sea bed. A variant of this reef is an artificial surfing reef, made to create wave conditions suitable for surfers. There are many materials suitable and available to create such a reef.
- Detached breakwater
  A detached breakwater is a conventional breakwater constructed parallel to the coastline and is called detached because it is not connected to the coast. Due to the low sediment transport behind the breakwater a salient, see figure 5.2, or even a tombolo will be formed, creating a beach line suitable for swimming. Down drift erosion however must be investigated.
- Floating breakwater
  A floating breakwater also dissipates wave energy, but is attached to the sea bed by chains or cables. Therefore the influence on sediment transport is smaller. If accretion occurs behind the floating breakwater, the floating breakwater can be shifted seawards; the floating breakwater keeps the same function.

Figure 5.2 A salient behind a detached breakwater

Assessment

Although wave energy is dissipated off shore by these structures, which will reduce the wave run-up on the dike, the wind-setup by typhoon winds are not reduced by offshore structures. Therefore the needed crest height of the coastal protection will be lower, but it has to be investigated to what extent.

There will be accretion between the breakwater and the coast due to the lower sediment transport behind the breakwater. In this way a beach will propagate naturally and end up in a tombolo. Down drift the breakwaters the original sediment transport will return and therefore be the cause of erosion.

Especially when land reclamation is applied the effects of offshore structures can prove beneficial to reduce the new dike’s crest height and perhaps create new beaches. In the current situation with the relatively small wave attack and availability of wide tidal flats appliance of offshore structures are unnecessary.

Once the offshore breakwater is established there is little need for maintenance. Only after an extreme storm the breakwater has to be checked. Offshore structures tend to be massive and will therefore be more expensive. Especially in deeper water huge amounts of material are needed.

Special attention has to be paid to the accumulation of debris. Construction of a breakwater, when not submerged can lead to accumulation of debris. This feature can be used as an advantage if the breakwater is designed in such a way that it keeps debris from unfavorable locations like beaches, but debris can also be trapped between the breakwaters; this can cause an accumulation of debris.

Advantages

- Reduction of wave run-up on sea-dikes
- Natural build op of beach levels
- Require little ongoing maintenance
- Blocking of debris

Disadvantages

- Expensive structures
- In existing situation effects are small or not necessary
- Will produce down drift erosion

5.2.4 Soft solution alternative

Improved coastal protection can also be achieved without the use of coastal structures. In this case one can speak of soft solutions. Three alternative soft solutions are described below.

- Higher foreland
  By artificially retreating the main coastal protection line or by beach nourishment the foreland will become higher and therefore reduce the wave height. By reducing the wave load the main construction can be relieved.

- Vegetation
  The planting of vegetation in the foreland and creation of conditions which encourage vegetation growth can also be an effective method of dissipating wave energy in order to relief the main coastal protection.

- Sand dunes
  Created and maintained through the deposition of sand, dunes can be artificially or naturally created. They offer protection against high sea levels and also function as a buffer zone for erosion.

Assessment

Soft solutions are environmentally as well as recreationally sound. There are possibilities for plants and animals to settle and there are no materials which harms the environment. Furthermore soft solutions are visually attractive and offer opportunities for recreation.

It is difficult to predict the sediment transport along the coast. There are complex processes which play an important role in the development of the coast in the first years after taking a soft measure. Therefore the solution is vulnerable in the first years of construction and it is not clear if the solution needs additional protection.

If well designed a soft solution uses natural processes beneficially and an equilibrium state will be reached. Once equilibrium has established there is no need for human maintaining because the nature is able to maintain itself. Therefore it is also a sustainable solution.

A disadvantage is that for most of the soft solutions additional coastal protection is required to ensure the required safety. Only sand dunes are a solution that does not need additional protection. Another disadvantage is the space needed to apply a soft solution. In general a soft solution requires a large area.

Advantages

- environmentally and recreationally sound
- Natural processes are beneficially used
- Visually very attractive solutions
- Sustainable solution

Disadvantages

- Vulnerable especially during first years
- Often requires additional protection
- Complex processes
- Large area needed

5.2.5 Conclusion

There are four main categories of alternatives for coastal protection, which all solve the problem to a certain extent. These alternatives, including their sub-categories are listed in Figure 5.3 on the next page.

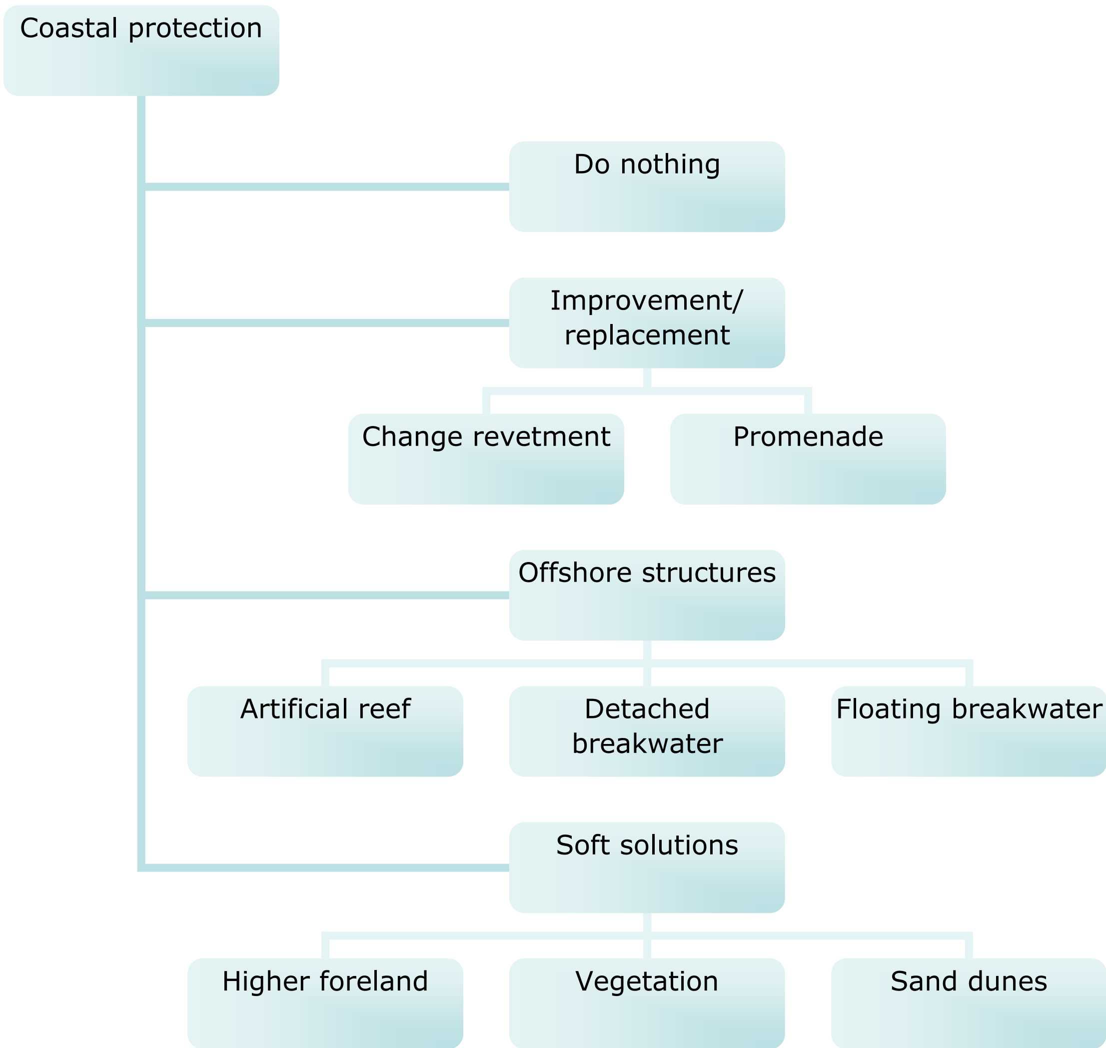


Figure 5.3 Diagram of possible alternative for coastal protection

5.3 Alternatives for the drainage system

During a typhoon situation, which means that there is a high discharge and also a high sea water level, there is a risk for the area behind the coastal protection of being flooded. In this paragraph several alternative solutions will be presented. There are three main conceivable directions in which alternatives can be found. First, one can consider that flooding of the area is allowed, thus the "do-noting alternative". Second, one can search a way to decrease the peak discharge which can be done by either detention areas or by pumping. Third, one can enhance the structural capacity, either by maintenance or by changing the outlet configuration.

Though the main problem occurs during typhoon season the regular situation has to be taken into account as well, i.e. the solutions have to be sufficient all the time.

5.3.1 "Do nothing"-alternative

If nothing is done to the current situation, i.e. flooding of the area is allowed, because the risk is considered to be low enough, evacuation of the people in the flooded area can be considered. This solution means nothing will be changed from the current situation.

With this alternative it is important to what extent flooding can be forecasted. Furthermore there has to be considered how often a flooding is expected to occur and what the damage is, for example to the infrastructure, the environment and properties of the inhabitants.

Assessment

Because with this alternative nothing will be changed and nothing will be built in order to prevent flooding there are no capital costs and there are no extra restrictions to the current land use. However there are of course returning costs because of the damage a flooding invokes. Because of this returning flooding the area will be less suited for use which requires large investments or takes extra investment to prevent damage from flooding. Because of this the economical value of the area is reduced.

For the simple fact that people living in the area don't like it when their property is damaged and because when a flooding occurs large media attention can be expected, which places the area in a negative context, the social acceptability of this solution is poor. This can lead to the need for a better solution in the long run. In this case this alternative means just postponing the real solution.

Advantages

- No capital costs.
- No extra restrictions to existing land use

Disadvantages

- Repeated damage
- Reduced economical value of area
- Poor social acceptability
- A sustainable solution is possibly required later

5.3.2 Detention alternative

It can be considered to appoint detention areas. These are areas where excess water will be stored if necessary. In this way flooding of the more valuable areas can be prevented. The land use of these retention areas has to be restricted. The extent of these restrictions depends on the return rate and the scale of the flooding.

It is important that the capacity of the retention area is large enough to decrease the peak discharge sufficiently during extreme rainfall. This requires information about extreme rainfall, extreme discharges and duration of a peak discharge. Because the capacity is limited and not easy to increase this solution requires good planning. This solution gives only temporary relief since eventually the water has to be discharged into the sea. When the interval between two peak discharges is large enough the excess water can be repeatedly stored and transported to sea.

Assessment

Fundamentally this solution is not directed to prevention of flooding, but it is directed to controlling the flooding. The flooding is controlled in such a way that a beforehand appointed area is flooded. In this way the damage caused by flooding is also restricted to this area. By finding a suitable area the damage is limited. This damage can even be further diminished by fitting the area out right. Of course this will lead to higher construction costs. If the area is carefully selected the construction costs however can remain low compared to other alternatives. The construction costs consist mainly of creating an inlet in such a way that it can process an amount of water which is large enough.

The main disadvantages to this solution are that it is a patch solution. The excess water is only temporarily stored, eventually the water has to be transported to the sea. This means if there are two peak discharges in to short a span of time the problem will be even greater than before. This problem can be reduced by using pumping stations to transport the water to the sea once it is stored in the detention reservoir. Also because the water depth will be limited, a relatively large area is needed to be able to store a large quantity of water. Of course the land use of an area of which it is certain that will be flooded occasionally is more restricted than the land use of an area were no flooding is expected. Finally, because of this it will be difficult to appoint an existing piece of land as a retention area; a difficult consideration of conflicting interests has to be made. Therefore it is favorable to combine this solution with land reclamation.

Combination of this alternative with the pumping alternative is a very good possibility, because it combines the benefits and can reduce the disadvantages of each alternative.

Advantages

- Damage limited to appointed area.
- Area can be adjusted to limit damage
- Low construction costs

Disadvantages

- Patch solution
- Relatively large area is needed
- Limitations to current and future land use of appointed area
- It is difficult to find suitable retention area

5.3.3 Pumping alternative

If there is no space for retention areas, the solution can be found in the installation of pumping stations. With a high seawater level the discharge is limited due to the smaller inclination. The discharge can in this case be increased by using pumps. By using pumps before the peak discharge, this peak discharge can be leveled out. But if a large pumping capacity is installed also the peak discharge itself can be transported to sea before flooding occurs. For this solution also information is needed about the height and the development in time of the peak discharge.

Assessment

When this solution is executed well the flooding will be prevented entirely, so there will be no damage to the area. Also the construction of this solution will be relatively effortless, since the pumps can be made in a factory and only have to be placed. These pumping stations can be placed at coastal defense so the existing land use is maintained. Expansion of the capacity of the pumping stations is relatively easy, because it can be achieved by merely placing extra pumps.

Though the pumps will only be used in rare occasions they will have to be maintained and checked regularly in order to keep them in good condition. This will lead to high maintenance costs. Even though maintained in a good condition there will still be a chance of failure when the pumps are applied, because it is a mechanical solution. Furthermore the risk of failure of the power supply is eminent, because a peak discharge occurs during and after a typhoon. Therefore extra precautions like placing extra pumps or installing generators for emergency power supply must be taken. For this alternative to be effective a large number of pumps are needed, partly because of the limited capacity per pump, but also because in the current situation there are a lot of outlets, each of them needing one or more pumps. The effect on leveling out of the peak discharge will be small in the current situation because there is no retention at the outlets and the effect depends on the steepness of the discharge wave.

Advantages

- No damage to area
- Effortless construction
- No restrictions to existing land use
- Easy to expand

Disadvantages

- High maintenance costs
- Risk of failure
- Large number of pumps needed

5.3.4 Maintenance alternative

The current situation can be optimized by maintenance. This solution direction is not aimed at a one time renovation of the system but means regular maintenance to keep the system in a better condition permanently.

The most obvious way of maintaining the discharge of the drainage system is regular cleaning. There are globally two ways in which the run off of the drainage system is obstructed. First there is the problem of accumulating debris. Second there is the problem of siltation of the drainage system by sediment. Both take place especially in the outlets.

Cleaning of the outlets of debris and sand can be done in a number of ways.

- Flushing
- Dredging
- Raking/ booming
- Trapping

All these cleaning methods have to be done on a regular basis and therefore require scheduling. Also the cleaning needs an integral approach so it is important to establish a clear division of responsibilities.

Another important aspect of maintenance is maintenance of the valves. These must be adjusted and maintained in a good condition to optimize the water drainage also in non-typhoon time. A more sustainable way of keeping debris out is addressing the sources of this pollution. These sources are likely to be found in urban areas. Adjusting the sewer systems in these urban areas will result in less debris in the outlets.

For these solutions it must be investigated if the current drainage system has a sufficient capacity if it is maintained well. Therefore the theoretical capacity and the design capacity have to be determined.

Assessment

Since this solution is directed to optimization of the current drainage system no complex structures or infrastructure has to be altered or built leaving the current land use situation intact. This alternative mainly relies on labor so the costs will be continuous but relatively low but and no capital costs are made except when mechanized cleaning is considered.

Since the current drainage system is divided in parts belonging to three different owners it will be difficult to establish a division of responsibilities, especially when cross border pollution has to be addressed. Cooperation is a must if one wants to effectively optimize the whole system. Even if the responsibilities are clearly divided it will cost a lot of efforts to check the system and checking only gives a still image of the situation, so the quality of execution is hard to maintain. Furthermore the effect to the increase of the system capacity with this alternative is limited to the maximum capacity of the current system. So if the current system is not sufficient even if it is clean other measures have to be taken as well.

Advantages

- Small to no capital costs
- No restrictions to existing land use

Disadvantages

- Division of responsibility is not clear
- Reliability of the execution of maintenance
- Maximum capacity depends on current system

5.3.5 Outlet directed alternative

At this moment there are many small outlets, what means there is always a short route toward the sea. Every outlet suffers from siltation in the current situation, so every outlet needs maintenance. By centralizing the outlets, the number of outlets is decreased.

On the one hand this will lead to an increase of the standard discharge and therefore the problem of siltation is decreased or even eliminated. On the other hand the maintenance is concentrated to one point and therefore easier. Both effects will lead to lower maintenance efforts. Centralization can also make more expensive solutions for example a raking machine feasible. By combining a centralized outlet with a harbor, maintenance of this facility can be combined with maintenance of the outlet so the maintenance effort can be further minimized. Also combining a centralized outlet with a river can lead to decrease in maintenance efforts, since rivers are capable of keeping their own outlets clean to a certain extent.

Combining several drainage canals however can imply longer distances from the source of water toward the outlet itself. This means the drainage system as a whole will have a smaller inclination which means the capacity will be limited if the outlets are positioned at the same level.

Other outlet related solutions are in the course of changing the lay out. A relatively simple adjustment is enlarging the existing outlets so capacity is sufficient even if it is being blocked to a certain extent, or placing fences around them so they won't be blocked by debris from the beach anymore. The problem with these solutions is that the flow velocity is reduced so the chance of siltation is increased. A more sophisticated conceivable solution is the use of breakwaters placed perpendicular to the coast at both sides of the outlets. These can stabilize outlets of rivers and trap floating debris and sediment from the sea in front of them. In this way outlets are kept free from debris and sediment. Therefore outlet capacity is maintained optimal.

Another more sophisticated solution is placing groins perpendicular to the riverbanks in the river mouth. Thus a 'summer bed' is created which will maintain its depth during low discharges. During high discharges in typhoon season the groins will submerge and therefore the whole width of the river will be used.

Also for this solution information is needed of the current drainage system and the design capacity. Furthermore it must be clear which outlets are not sufficient. Every outlet or group of outlets has to be looked at separately.

Assessment

This alternative is aimed at a structural capacity increase. Therefore investments are made to accomplish long term sustainable solutions. This makes the alternative more complex and more expensive. However since the outlets are in the coastal protection zone these investments can be combined with investments made to improve the current coastal protection. Also these solutions will lead to a reduction in maintenance efforts. When it is decided to centralize the outlets the current system of canals has to be altered. This will lead to a change in existing land use which is hard to achieve because there are many interests of landowners or users to be paid attention to. On the other hand this can lead to a better and more efficient division of land.

Advantages

- Sustainable solutions
- Structural increase of capacity
- Decrease of maintenance efforts

Disadvantages

- More complex and more expensive
- In case of centralization there is a change in existing land use

If the capacity of the canals leading to the outlets and the rivers themselves are not sufficient, an increase of the outlet capacity is not sufficient to prevent flooding. In this case the capacity of canals and rivers has to be increased, which can be done in roughly for ways. First the river or canal can be widened, second it can be deepened or the dike and walls along it can be elevated, third the inclination can be enlarged and fourth the bed roughness can be reduced. However, adjusting the capacity of the rivers and the canals is beyond the scope of this project.

5.3.6 Conclusion

There are three main categories of alternatives to solve the dewatering problem; these categories are the "do-nothing"-alternative, alternatives to reduce the peak discharge during typhoon situation and alternatives to structurally increase the discharge capacity. Some of these alternatives can be combined to reduce the disadvantages and combine the advantages of them, for example the combination between detention and pumping as been listed in the previous paragraphs. These alternatives, including their sub-categories are listed in figure 5.4 on the next page.

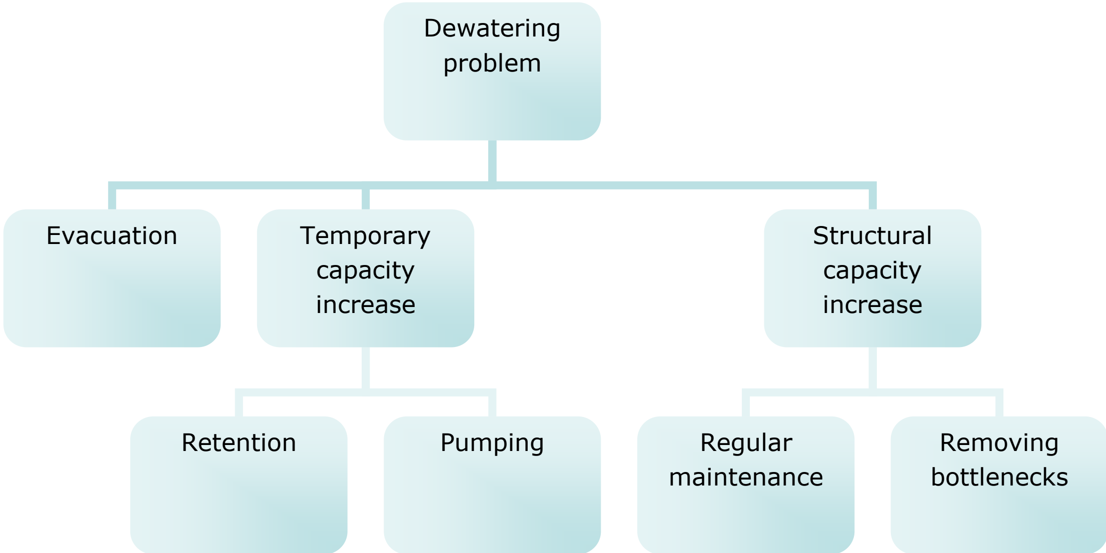


Figure 5.4 Diagram of possible alternative for drainage

Chapter 6 Comparison of alternatives

In this chapter the various alternatives discussed in the previous chapter, for either improvement of the coastal protection or improvement of the dewatering of the area are compared and judged. However before comparing the alternatives it will be discussed if land reclamation is to be applied.

6.1 Land Reclamation

The choice between the different types of land reclamation is independent from the choice whether lad reclamation should be applied. The analysis of which land reclamation method is better is therefore also treated separately. First the choice between lad reclamation will be made; afterwards the choice which method will be used if there is any land reclamation is made.

6.1.1 Yes or no land reclamation

The tidal flats which exist in the current situation can be considered as a valuable ecologic area, with a possible high biodiversity and biological production. These ecological areas will be lost if land reclamation is applied. Land reclamation also requires a large capital investment. These are the main disadvantages of applying land reclamation. However land reclamation offers also advantages, like more space for agricultural, recreational and even ecological development. The existing land has less chance of flooding, because the whole coastline shifts toward the sea and thus the bottlenecks in the drainage system have to be tackled. The current outlets have to be moved along with the coastline and new outlets have to be designed. These advantages enhance the economical value of this coastal zone.

The choice has to made between the conservation of an ecological area on the one hand and the economical growth, due to more safety and space for various development, on the other hand. When applying land reclamation, one can offer nature a new chance. This chance can be seen in an ecological sound design of the coastal protection and more space for ecological development on the land side of the coastal protection, which offers different chances to different types of nature, almost absent in the current situation. There is also the case of the accreting coast. While this has to be investigated, there is a possibility that after land reclamation the coast is still accreting and thus forming new tidal flats. In this case the disadvantage of land reclamation is diminished to a temporal one.

When looking at the advantages and the probably only temporal disadvantage of land reclamation, one can consider land reclamation as a sound solution for the project area.

6.1.2 Land reclamation method

There are two methods of land reclamation discussed in the previous chapter. The main advantage of the landfill method is the increases safety, but the main disadvantage is the costs, however these can be reduced if sand from the Taiwan Strait is used. The polder method is relatively cheaper. Because de main advantage of this method is that the reclaimed land is better suited for retention when the polder method is applied, the best method depends on which alternative for dewatering is chosen. So it can be concluded that if retention is considered a good alternative the polder method will be used, else the land fill method will be applied.

6.2 Multi-criteria Analysis method

Weighing and comparison of alternatives can be done in a number of ways. A commonly used method is the multi criteria analysis. There are different methods for this analysis. The currently used method consists of two main steps which are presented below.

1. Comparative weighting of criteria

Some criteria are judged more important than others for our project area. This is reflected by an appropriate weighting. This is shown in the first table, in which the total weight of a criterion is determined. This table is filled according to the rules below:

If the criterion in a row is:

- more important than the criterion in the column, then score = 2;
- equally important as the criterion in the column, score =1;
- less important than the criterion in the column, score = 0;

and vice versa.

2. Comparative assessment of alternatives

Next the list of feasible alternatives is drawn up. A comparative assessment of the alternative schemes is made by marking how well each scheme is likely to achieve each criterion on a scale of 1 to 5 where 5 means a very good achievement of the criterion. Finally, for each option, the rankings are multiplied by the weighting assigned to the relevant criterion and a total weighted score evaluated this is presented in the bottom row.

6.3 Comparison of alternatives for coastal protection

6.3.1 Weighing of criteria for coastal protection alternatives

To comparatively assess the alternatives for coastal protection the following criteria are used:

- Protection of land
- Recreational soundness
- Ecological soundness
- Low capital costs
- Low maintenance costs
- Public acceptance

First the importance of a criterion is determined by weighing them against each other. This is presented in table 6.1 below.

Table 6.1 Comparative weighting of criteria

	Criterion	A	B	C	D	E	F	Total weight
A	Protection of land	*	2	2	2	2	2	10
B	Recreational soundness	0	*	1	2	1	1	5
C	Ecological soundness	0	1	*	1	1	1	4
D	Low capitol costs	0	0	1	*	0	1	2
E	Low maintenance costs	0	1	1	2	*	1	5
F	Public acceptance	0	1	1	1	1	*	4

As can be seen from table 6.1 protection of land is always considered most important. This is obvious, because a coastal protection is to be designed. Further it can be seen that recreational soundness is the second important feature together with low maintenance costs. Recreational soundness is considered equally important as ecological soundness, but more important than the costs. Though ecologically soundness and recreational soundness are considered equally important for the proposed solution the difference is that recreational soundness is considered more important than low capital costs while ecologically soundness is equally important than low capital costs. This distinction is made because recreation will generate direct and indirect economical benefits and in this way the capital costs can be seen as an investment which will earn itself back over time.

Further it can be seen that with respect to the cost it is determined that low maintenance costs are important, even more important than low capital costs. This is because in the current situation it seems to be hard for the responsible authorities to maintain the structures so a more costly, but maintenance reducing structure is preferred.

Public acceptance is very much related to the other criteria, since when for example the cost will increase this will influence the public acceptance. Therefore public acceptance is weighed equally important as all other criteria.

6.3.2 Assessment of alternatives for coastal protection

The following alternatives are compared:

- **I** Do nothing
- **II** Dike improvement
- **III** Offshore structures
- **IV** Soft solutions

The comparative assessment of the alternatives is presented in table 6.2 below.

Table 6.2 Comparative assessment of alternatives for coastal protection

	Criterion	Weight	I	II	III	IV
A	Protection of land	10	2	5	3	4
B	Recreational soundness	5	2	3	3	5
C	Ecological soundness	4	2	3	4	5
D	Low capital cost	2	5	3	2	2
E	Low maintenance cost	5	3	4	4	2
F	Public acceptance	4	2	4	4	4
		Total weighted score:	71	119	101	115

<u>Protection of land</u>

Of course since the current coastal protection is old the do nothing alternative is ranked lowest for this criterion. With respect to protection of land improvement or replacement of the current dike is seen as the best solution. Because the coast is accreting and there is a large foreshore a hard solution like dikes will lead to a safe coastal protection. A soft solution is also considered a good way to protect the land, but because these are more vulnerable it is ranked just below the dike improvement. Offshore structures can never be used alone and is therefore ranked below the other solutions.

<u>Recreational soundness</u>

Because soft solutions can be generally form a good combination with recreational possibilities this is seen as the best alternative considering the recreational soundness of the coastal protection. Dike improvement can be easily designed in such a way that it is also suitable for recreational purposes for example or biking path can be created and the same applies for offshore structures. The last alternative can improve possibilities for waterfront activities.

Ecological soundness

The same reasoning for recreational soundness also applies to ecological soundness to a large extent. This is because these are related. Ecologically sound solutions will attract people for leisure activities and offer possibilities for recreation. As can be seen from the table, soft solutions are scored best. Because soft solutions mean working with nature they will also be very ecologically sound. Also offshore structures are seen as a bit more ecologically sound than dikes. An artificial reef can be considered and also the possibility to prevent debris from washing up ashore.

Low capital costs

It is sufficient to note that offshore constructions and soft solutions require more capital costs than dike improvement. The capital costs of the alternatives are more extensively discussed in the review of the alternatives in chapter 5.

Low maintenance costs

Since the current dike is getting old, maintenance costs will increase in future, however since the dike is rather simple maintenance costs will stay below the level of maintenance costs induced by the dike improvement or the offshore structure alternative. Soft solutions are considered to take more maintenance efforts, and will therefore increase maintenance costs.

Public acceptance

As far as public acceptance is concerned all alternatives except for doing nothing are equally scored. Because none of the alternatives will cause much re-division of land or harm the local people. On the other hand all solutions will prevent damage to people’s properties and increase the safety of the area.

6.3.3 Sensitivity analysis

To prevent the possibility of the choice being too dependent on the subjectively chosen weight factors a sensitivity analysis has been carried out. This analysis is done from three viewpoints, which can be found in table 6.3.

- From the government, the capitol costs and maintenance costs the most important factors.
- From the local people, safety, public transport and recreational soundness are the most important.
- Equal weighing factors for all.

Table 6.3 Weighing factors for the different viewpoints

Criterion	Normal	Government	Local	Equal
A Protection of land	10	7	9	5
B Recreational soundness	5	2	7	5
C Ecological soundness	4	2	3	5
D Low capital cost	2	9	1	5
E Low maintenance cost	5	9	1	5
F Public acceptance	4	1	9	5
Total	30	30	30	30

Table 6.4 Comparative assessment of alternatives for coastal protection for the different viewpoints

Criterion	I	II	III	IV
A Protection of land	2	5	3	4
B Recreational soundness	2	3	3	5
C Ecological soundness	2	3	4	5
D Low capital cost	5	3	2	2
E Low maintenance cost	3	4	4	2
F Public acceptance	2	4	4	4
Normal	71	119	101	115
Government	96	114	93	88
Local	71	114	102	110
Equal	80	110	100	110

The weighing factors used for the multi-criteria analysis are not real sensitive to changes, as can be seen in table 6.4. Only if costs are an important factor alternative IV, i.e. the soft solutions, will be a less preferable option. In all cases alternative II, i.e. the dike improvement is the best solution. In all cases, except for the government case, the outcome of the multi-criteria analysis is not sensitive to changes.

6.3.4 Conclusion

From the comparison of the alternatives using a multi criteria analysis it can be concluded that alternative II and IV, being dike improvement and soft solutions are the preferred alternatives. Since a combination of the two is feasible and suitable these two alternatives will be further investigated and designed.

6.4 Comparison of alternatives for dewatering problem

6.4.1 Weighing of criteria for dewatering alternatives

To decide which of the alternatives for the dewatering problem is the best these alternatives will be considered by the following criteria.

- Protection of land
- Low maintenance costs
- Low capital costs
- Public acceptance
- Restrictions to land use

The comparative weighting of these criteria is given in table 6.5.

Table 6.5 Comparative weighting of criteria

Criterion	A	B	C	D	E	Total weight
A Protection of land	*	2	2	2	2	8
B Low maintenance costs	0	*	2	1	2	5
C Low capital costs	0	0	*	1	2	3
D Public acceptance	0	1	1	*	1	3
E Restrictions to land use	0	0	0	1	*	1

The main purpose of the dewatering system is the protection of the land. Therefore this criterion gets the highest comparative weight. It can be seen that with respect to the cost it is determined that low maintenance costs are important, even more important than low capital costs. This is because in the current situation it seems to be hard for the responsible authorities to maintain the structures so a more costly, but maintenance reducing structure is preferred.

The costs of a solution are related with the public acceptance; if a solution becomes extraordinarily expensive this solution will not be accepted. If the costs are still reasonable the solution will be accepted. These criteria are equally important.

Restrictions of the land use are considered to be of less importance than the other criteria. Because it is already decided there will be land reclamation there will be new land of which the use has to be determined and the restrictions of the use of this land will be low.

6.4.2 Assessment of alternatives for the dewatering problem

The following alternatives will be considered:

- **I** Evacuation
- **II** Retention
- **III** Pumping
- **IV** Regular maintenance
- **V** Removing bottlenecks

Each alternative is marked how well it is likely to achieve each criterion. This is shown in table 6.6.

Table 6.6 Comparative assessment of alternatives for the dewatering problem

Criterion	Weight	I	II	III	IV	V
A Protection of land	8	1	4	4	3	5
B Low maintenance cost	5	4	4	2	1	3
C Low capital cost	3	5	3	3	5	2
D Public acceptance	3	1	3	4	4	4
E Low restrictions to land use	1	4	2	5	5	4
Total weighted score:		46	70	64	64	73

<u>Protection of land</u>

Since evacuation means that the land is not protected enough this alternative is ranked lowest for this criterion. The best solution for protecting the land is removing the bottlenecks in the current system. Retention is ranked below this alternative because it is a patch solution.

Pumping is considered a less suitable solution because the number of pumps needed in extreme situations is worryingly high and there is always a certain probability of failure of the pumps. In the case of only regular maintenance it is not certain if the system is sufficient, therefore this alternative has a lower rank.

<u>Low maintenance cost</u>

For evacuation and detention low maintenance is needed. Only if there is a flooding maintenance has to be executed. Pumping has high maintenance costs because the pumps will have to be maintained and checked regularly in order to keep them in good condition. Of course regular maintenance induces higher maintenance costs and is ranked very low for this criterion.

<u>Low capital cost</u>

There are no capital cost for evacuation and regular maintenance. The highest capital costs will be made if all the bottlenecks will be removed. Depending on the number and size of the pumps this will give capital costs. But these costs will be distinctly lower than if all the bottlenecks will be removed. To make area suitable for retention will give capital costs for this alternative. These costs are considered lower than the costs for pumping or for removing bottlenecks.

<u>Public acceptance</u>

The evacuation alternative will not be accepted by the public and is therefore marked very low. Detention is considered less suitable because using certain areas as excess water storage is not widely accepted. The other three alternatives are ranked equally because none of the alternatives will cause much re-division of land or harm the local people's interests.

<u>Low restrictions to land use</u>

Because detention gives limitations to current and future land use of the appointed area this alternative is marked very low for this criterion. For the evacuation alternative there is no place for very valuable houses and therefore the land use is restricted. If bottlenecks will be removed this will demand a certain area and therefore this area is restricted for land use as well. Pumping and regular maintenance will give no restrictions to land use.

6.4.3 Sensitivity analysis

To prevent the possibility of the choice being too dependent on the subjectively chosen weight factors a sensitivity analysis has been carried out. This analysis is done from three viewpoints, which can be found in table 6.7.

- From the government, the capitol costs and maintenance costs are the most important factors.
- From the local people, safety and fewer restrictions on land use are the most important factors.
- Equal weighing factors for all.

Table 6.7 Weighing factors for the different viewpoints

Criterion	Normal	Government	Local	Equal
A Protection of land	8	4	7	4
B Low maintenance costs	5	7	1	4
C Low capital costs	3	7	1	4
D Public acceptance	3	1	4	4
E Restrictions to land use	1	1	7	4
Total	20	20	20	20

Table 6.8 Comparative assessment of alternatives for coastal protection for the different viewpoints

Criterion	I	II	III	IV	V
A Protection of land	1	4	4	3	5
B Low maintenance cost	4	4	2	1	3
C Low capital cost	5	3	3	4	2
D Public acceptance	1	3	4	5	4
E Restrictions to land use	4	2	5	5	4
Normal	50	72	68	61	77
Government	72	70	60	57	63
Local	48	61	84	81	84
Equal	60	64	72	72	72

The weighing factors used for the multi-criteria analysis are sensitive to changes of viewpoint, as can been seen in table 6.8. If the costs are an important factor, i.e. the government viewpoint, the current situation is even most favorable, because of the low capitol costs. However if the local viewpoint is taken, i.e. the land has to be protected well and there should be no and only a few restrictions on land use, the alternatives with pumping, regular maintenance and the removal of bottlenecks are almost equal. If the weighing factors are taken equal the difference between the different alternatives almost disappears.

The multi-criteria analysis is thus sensitive to changes in weighing factors, this depend on which viewpoint is taken. Therefore there is no perfect solution in this case and the best solution can rather be seen in the combination of different solution instead of choosing one solution.

6.4.4 Conclusion

There is no perfect solution for the problem of drainage. Depending on the viewpoint taken different solutions apply for most preferable solution. The best solution can therefore is a combination of different alternatives. The combination of retention and the removing the bottlenecks, i.e. improving the outlets, will be further elaborated. If the newly reclaimed area is laying too low for natural drainage during typhoon situation, pumps have to be installed to provide safety against flooding of these areas.

Chapter 7 Coastal area zoning

The coastal area can be zoned in several ways. First there will be looked at the technical part, i.e. the division of the coast in separate sectors in which a combination of alternatives can be applied. Second the coastal zone will be zoned in the type of land-use that can be applied at different places.

7.1 Division of the coast

The area between Da'an River and Dajia River can be devised in different zones. In each zone a combination of alternatives can be applied. For

7.1.1 Reclamation of land

In the preceding chapters land reclamation is chosen as a suitable option which can satisfy ecological and environmental needs and offers land use opportunities in which way the whole area will be upgraded. In this paragraph it will be investigated which location suits best for land reclamation.

<u>The area</u>

To find the most suitable place for a reclamation area two aspects have to be taken into account; the current value of the different parts of the coastal protection and foreshore and the negative influence to other areas in the vicinity due to leeside erosion.

The coastal protection between the Daija River and the Da'an River consists of a concrete dike. This dike is partly converted into a pseudo green dike. The area between the coastal protection and the surf zone shows a variety in vegetation. Some areas show an abundance of many kinds of plants while other areas only have a sandy beach. The foreshores which have abundant vegetation are considered more valuable than the sandy beaches. There is also a part of the coastal protection with a boulevard and some investments to improve recreational possibilities have been done on this coastal stretch.

The dominant direction of the current along the coast is from the north to the south. This implies that on the north side of the reclaimed area accretion will occur and on the south side erosion will occur. By reclaiming area in the north this could cause problems for the outflow of the Ta'an River, which is the northern border of the project area, and will create erosion in the rest of the area. Reclaiming land in the southern part of the area has certain advantages. On the leeside of this area the Dajia River is situated. This is a source of sediment; therefore the erosion on the leeside will be limited. Furthermore there is already reclaimed land southward of the Dajia River as can be seen in figure 2.4. There will be less accretion in the area northward of this reclaimed land but erosion is not expected. It can be concluded that reclaiming the land in the southern part will cause minimum erosion problems.

The southern part of the coastal stretch consists merely of a concrete dike and a sandy beach. There are no possibilities for recreation. Furthermore when compared to the remaining foreshore in the project area this part is least ecologically developed. One kilometer northward the pseudo-green dike begins. But still there is only little vegetation in front of this dike. After one more kilometer more vegetation on the foreshore appears so this part of the foreshore is considered to have more ecological value.

By reclaiming an area with a length of two kilometers just northward of the Daija River little ecological or recreational valuable land will be lost. However the coast northward of this coastal stretch will be influenced: there will be accretion. Therefore the current vegetation in this area can be expanded creating more ecologically valuable land. However it also can have an impact on the composition of both vegetation and the animal-population. This could mean an undesirable alteration in the ecology of this area.

Figure 7.1 The reclaimed area indicated in the project area

The width of the reclaimed area depends on several variables. If the area will be wider, the coastal protection, moving seaward, must be higher. Also with increasing width the influence to the leeside areas will be greater. But if the width is greater a higher amount of land will be reclaimed which can be used for different purposes. A feasible compromise has to be obtained.

The inclination is assumed as proportional with the width of the reclamation area. The height of the dike and the total amount of material needed for this dike however is not proportional to this width; the height of the dike will increase due to the lower seabed but also due to the larger waves which occurs in deeper water. Therefore a larger width of the reclaimed area will bring on an unreasonable high dike. In this report 500 meters of land reclamation will be further investigated. Land reclamation of 500 meters will give enough opportunities for new purposes and it also seems feasible. In figure 7.1 is shown witch part of the project area will be reclaimed.

Conclusions

- A stretch of two kilometers in the south of the project area, just northward of the Daija River will be used for land reclamation. This area has a low ecological value and the lee side erosion is limited.
- Land reclamation with a width of 500 meters seems reasonable and shall be further investigated.

7.1.2 Zoning

The coastal stretch can be divided into four zones. Each of these zones is distinguished by either the presence of a (vegetated) foreshore, or the possibility for recreation. The zones are depicted in figure 7.2 below.

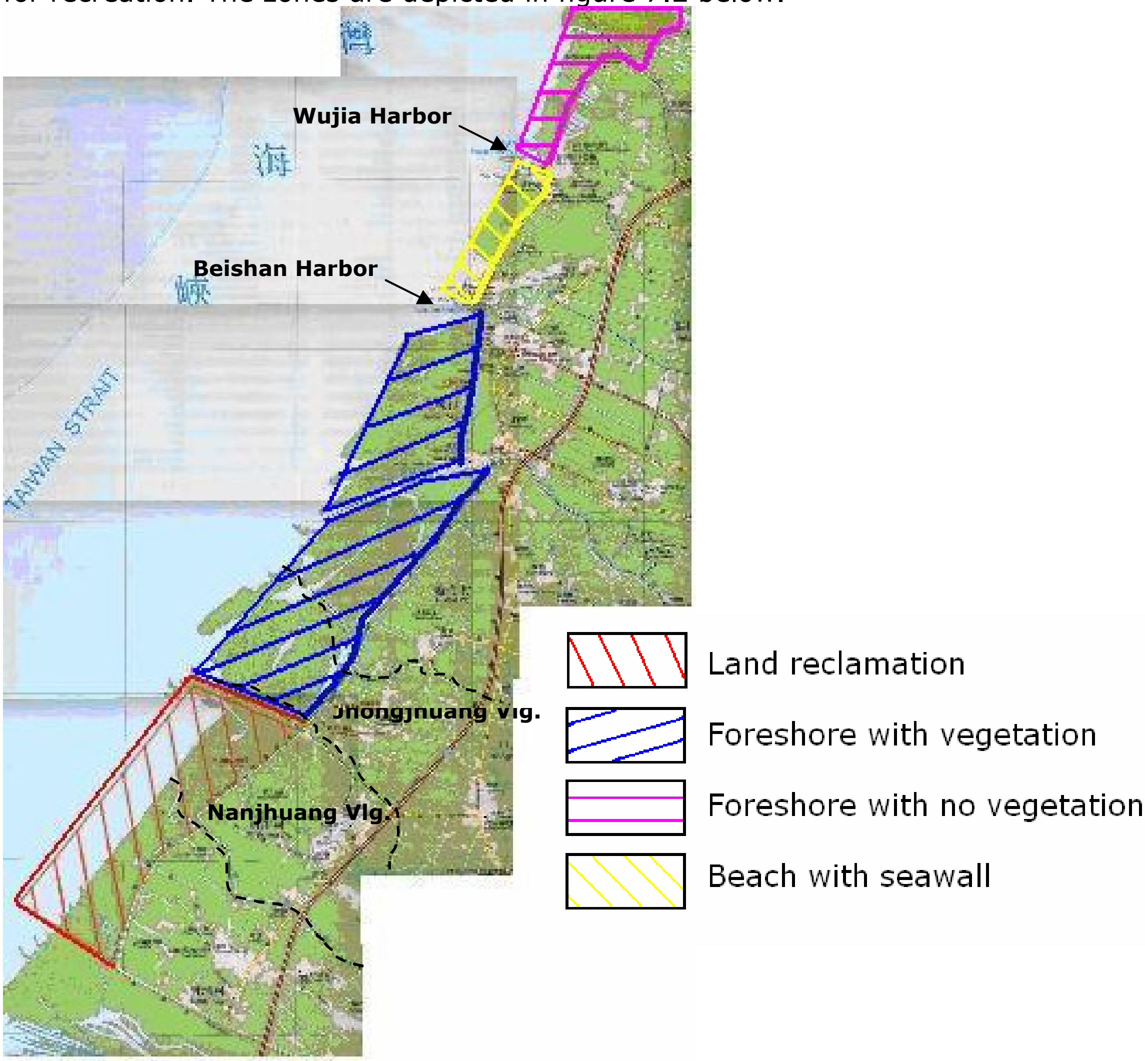


Figure 7.2 Zones of coastal protection

- Red zone
  This is the location of the land reclamation, as outlined in the previous subparagraph. To the south it is limited by the Dajia River and the border to the north coincides with the border between Nanjhuang village and Jhongjhuang village.

- Blue zone
  The blue zone stretches until Beishan Harbor. This stretch of coast already experiences development of vegetation on the foreshore in the form of bushes and at some locations mangroves. This development can be further stimulated, adding to the ecological value as well as the safety, since the vegetation has an attenuating effect on the waves.
- Purple zone
  The purple zone is limited by the Da'an River in the north and stretches southward until Wujia Harbor. This part of the coast has a shallow foreshore. However, it lacks vegetation. This absence of natural developed vegetation probably means the conditions at this part of the coast are not favorable for foreshore vegetation. This means it will cost a lot of efforts and time to create and maintain a vegetated foreshore at this part. In the design of the coastal protection there is no wave attenuation by foreshore vegetation taken into account.
- Yellow zone
  The yellow zone is formed by the stretch of coast between Beishan Harbor and Wujia Harbor. This beach is relatively narrow during high tide and is already fitted out with an adjacent beach resort. To further stimulate the development of recreation in this area this part will have a promenade protected by a seawall.

Each zone has its own distinct type of coastal protection structure attached to it. The location of these four types of protection systems can be seen in the figure 7.3. In the next chapter the design of these protection systems will be presented.

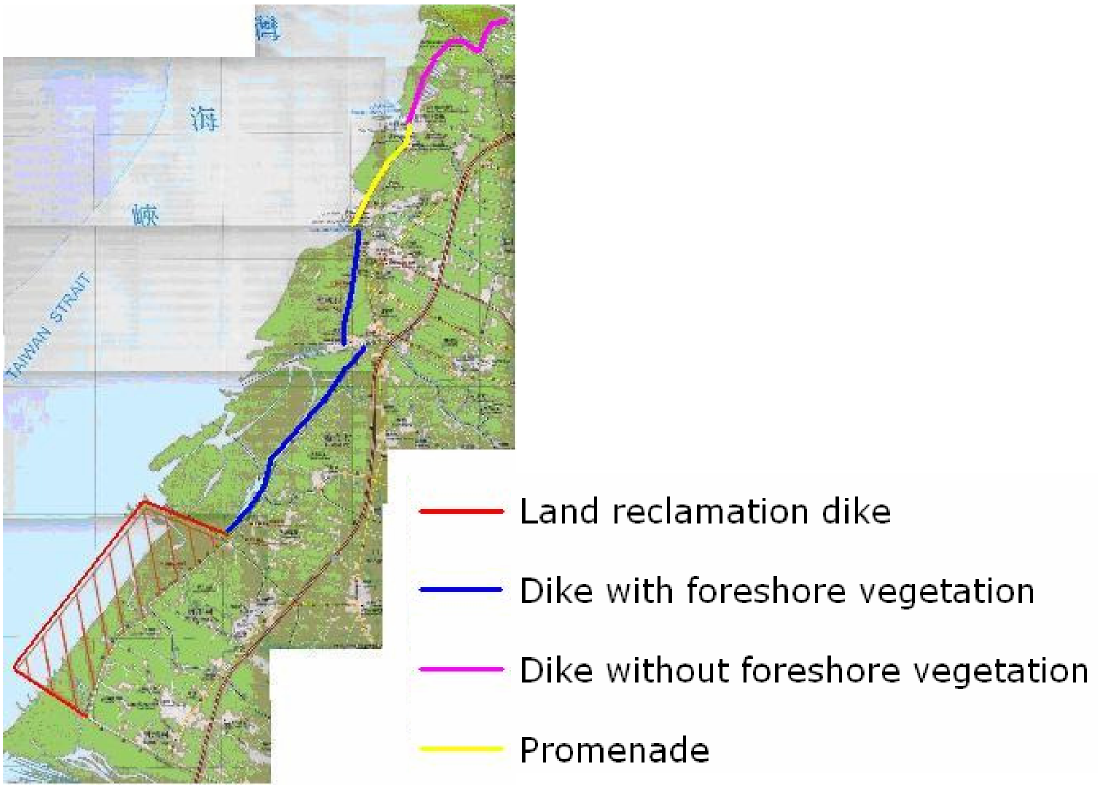


Figure 7.3 Coastal protection system

- Land reclamation dike
  This is the type of dike, of which the design will be described in Chapter 8 paragraph 8.3. Because the dike is located 500 meters seaward of the existing coastal protection the design water depth at the toe is bigger. This will lead to larger waves, because the waves are depth limited. So not only is the base level of the structure lower, also the needed crest level is higher, this leads to a considerable larger cross-section. A cross-section of the dike can be found in Appendix K.

- Dike with foreshore vegetation
  This type of dike is described in Chapter 8 paragraph 8.4. Because of the wave-attenuating effect of the vegetation on the foreshore this dike can be equipped with a grass cover. A cross section of this dike is given in Appendix K.

- Dike without foreshore vegetation
  This is basically the same dike as the previous dike, but with a stronger revetment. If the foreshore lacks vegetation the waves might just be high enough to make it necessary to use a block revetment on the lower part of the dike. Appendix K gives a cross sectional profile of this design.

- Promenade
  The promenade will be combined with the current dike as backfill. The total design for the promenade is elaborated in Chapter 8 paragraph 8.5.

7.2 Land-use

The current land-use of the area can be roughly divided into five categories, namely

- residential areas;
- recreational areas;
- ecological areas;
- agricultural areas;
- fishing areas.

With a new design of the coastal area, these five categories can be planned in a way that fits best. First there will be looked at the five different categories of land-use. In the conclusion a map of the area is shown with the current lay-out of the coastal zone and how it can be.

7.2.1 Residential areas

In the current situation there are some residential areas in the project area, these areas consist out of small cities, villages and communities. These towns are located behind the current coastal protection, but one of the towns has been flooded due to insufficient discharge capacity of the river and drainage system. Outside the towns, there are some houses, but these are rather scattered.

When making a new plan for the development of the coastal area, one can consider allowing residence in the following areas:

- On the old land, like the current situation;
- On the newly reclaimed land;
- On the coastal protection.

The existing land has suffered from flooding, thus one can say that it is not suitable for residential area. However, with changes in the coastal zone, it can be safe to use the existing land for residence. Furthermore permanently removing all the people from the endangered area will cost significantly more than an evacuation if there is a danger of flooding. There is also the question whether removing all residential areas is possible and socially acceptable.

If there will be any land reclamation from the sea, it is less suited for residential area, because the enlarged risk of flooding. This area lies low, so it will act as a drain for the rest of the coastal area, i.e. the existing land. To avoid risk, which is probability multiplied by damage, it is better to reserve this area for other uses, like nature and/or agriculture. If the land is reclaimed using the land-fill method, this problem is not as severe as using the polder-method.

The coastal protection is a fairly save place to have residential areas. In many countries dikes are used for building houses on the slopes of the protection, see figure 7.4. However, building houses on the sides of the coastal protection has several major drawbacks, which are the chance of damaging the coastal protection, the reduced maintainability and the impossibility of dike improvement if needed.

Figure 7.4 A residential building on a primary water defense

It can be concluded that the newly reclaimed area is less suited for residence because of the increased risk of flooding, while the existing land will be better protected against it. In the plan for the coastal zone this has to be accounted for.

7.2.2 Recreational areas

There is recreational development going on in the coastal area. The new plan for the development of the coastal zone management should include these recreational developments and even create more. The current foreshore is reserved for nature, agriculture and fishing. Only at one place some recreation is possible on the beach. In the new plan for the coastal zone the following places for recreation should be looked at:

- Newly reclaimed land;
- Coastal protection;
- Beaches;
- Nature on the foreshore.

The newly reclaimed land is less suited to be used as a residential area; it can be better used for ecological development and agriculture. These can be integrated in the recreational needs. Nature can be used as a recreational area if there are certain facilities, but it may not be a dense recreational area, because the ecological value is then diminished. There has to be a balance between dense recreational areas and ecological areas.

The coastal protection can be the link in a recreational network. It allows people to travel from one recreational area to the other. The coastal protection can be a recreational area itself if the surroundings are diverse enough and the design of the protection attractive. To play the role as link between the several areas, good infrastructure on the coastal protection is mandatory, but also connections between the different parts. In the current development several bridges have been built over the rivers to make the current coastal protection work as link, see figure 7.5. These bridges can be taken into the new plan for coastal development.

The foreshore is a good place for recreational use, either in the form of beach recreation or nature on the foreshore. In the current situation, there is the problem of debris on the beach. This can not be avoided, but maybe it can be diminished. Yet, cleaning of the beaches may remain an issue. By centralization of beach tourism, the problem of cleaning the beach, which is necessary for this type of recreation, is reduced from the whole stretch to only a few places, where additional measures can be taken.

Figure 7.5 One of the bicycle bridges, part of recreational improvement

7.2.3 Ecological areas

Some ecological areas are located on the foreshore, but if any land reclamation will be performed, these will probably be destroyed. However, land reclamation also offers chances for ecological development. Important areas for ecological development are:

- Ecological development on newly reclaimed land;
- Ecological development on foreshore;
- Special attention to the river-mouths.

On the newly reclaimed land, if chosen for such an alternative, some places will not be suitable for residence nor agriculture. For example retention areas will be flooded from time to time, making them ill-suited for some types of agriculture, i.e. paddy-field farming is less sensitive for too much water, but other crops can only with stand the wet soil for a couple of days. However, the change between wet and dry can be the basis for a diverse ecological situation. While designing the various elements of the newly reclaimed area, the ecological development should be kept in mind. With small effort valuable nature can be created.

On some locations the current foreshore is located several meters above sea-level and mainly consists out of sand. Nature has had the chance to develop here and a little forest has arisen, as can be seen in figure 7.6. If land reclamation would be performed here, this nature will be lost. It could be an option to fit the new foreshore with vegetation, so that the new foreshore will be natural to. The creation of nature on the foreshore has several advantages, which are the ability of handling debris to a certain extend and helping the coastal protection with its function. There is no need of removing the debris on the shore if the foreshore is used for nature after the vegetation has fully grown, there is still the need to protect the still vulnerable vegetation the first years. The woody snags can be decomposed by natural processes. If the amount of man-made debris is not too much, nature can grow over it, confining the problem. Only at places where debris has to be removed relative quickly, cleaning shall be necessary. The other advantage of a natural foreshore is that it is able to help the coastal protection with its function. By accumulation of sand by the vegetation on the foreshore, the foreshore will be located several meters above sea-level. With a wave attack the foreshore will be eroded first, which is toughened by the vegetation. Only if the foreshore is eroded away, the coastal protection will be attacked directly.

Figure 7.6 Ecological development on the foreshore.

Rivers need special attention on the ecological aspect, because where salt and fresh water meet, special forms of nature can arise. During typhoon-season the river discharge is very high. One of the solutions to create enough discharge capacity is to widen the river. The extra width could be used for extra ecological development. Some measures, like building breakwaters to fix the position of the mouth, to enhance the discharge capacity of the rivers will probably destroy nature on the tidal flats in the mouth of the river. This has to be mitigated or prevented by choosing other methods, like deepening of the river.

7.2.4 Agricultural areas

Besides some residential areas, the area is mostly used for agricultural purposes. There are two types of agriculture in the area; farming for example Growth of rice and onions and animal farms for example duck farms and pig-farms. Both types of farming will be discussed here.

A characteristic feature of the farming in this area is the paddy-field, used to grow rice. This type of agriculture can be placed on the existing land, like in the current situation, or on the newly reclaimed land. It is also possible to combine this small scale farming with local small-scale ecological development.

Figure 7.7 A small duck farm in the project area

The other type of agriculture is animal farming, mostly duck-farms ad pig-farms. Duck-farms merely consist out of a pool and lots of birds, while pig-farms are stables with relative high density of pigs. It seems to be small scale, but there can be major influence on the surroundings, in the form of noise, smell and eutrophication, due to the depositing of manure in drains. It has to be investigated in which areas this form of agriculture can be allowed, because it has influence on ecological areas and recreational areas.

7.2.5 Fishing areas

Several fishing harbors are located along the coast, which should be maintained. If they cannot be maintained at the current location, mitigating measures have to be taken. Fishing is also performed in the rivers and on the foreshore. With low tide, many fishing nets are visible, see also figure 7.8. Both forms of fishing can be maintained within the new plan for coastal development.

Figure 7.8 Fisher nets by low tide

7.2.6 Conclusion

A general description of the how the area can look like with the new coastal plan is given here. Current residential areas are being preserved, but not expanded to the newly reclaimed areas, because of the risk of flooding. The newly reclaimed area can be used for farming, recreational use and ecological development.

Retention areas are not suited for agriculture except cattle breeding, but are an excellent place for nature and recreation.

The foreshore can be a good place for centralized beach recreation; this reduces the costs and effort of beach cleaning. The beach can also be sheltered with breakwaters for reducing the amount of debris dumped on the beach. The rest of the foreshore can be reserved for ecological development in combination with recreation. The river can decompose natural debris and, if it is not too much, overgrow man-made debris. Furthermore the foreshore can assist in fulfilling the function of the coastal protection. Small scale farming can be allowed on the higher parts of the foreshore. In the river-mouths there is also place for fishing, but for nature this is a very valuable area too. These two functions can be combined.

In picture figure 7.9 the current situation is shown in a smaller area of the project-area. The different relevant areas are highlighted in the picture. In figure 7.10 a possible lay-out is given for the area, given there is some land reclamation.

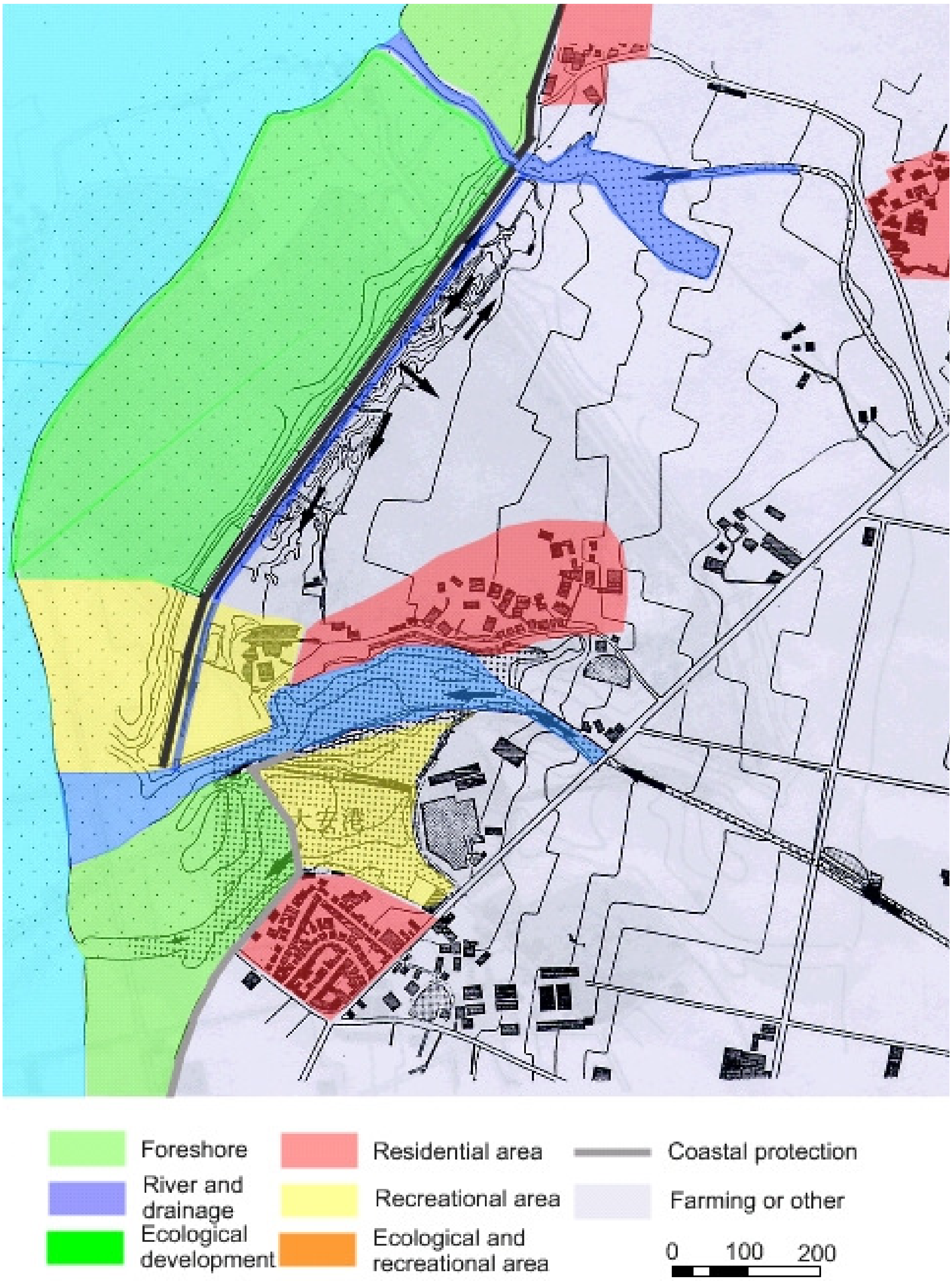


Figure 7.9 Current situation

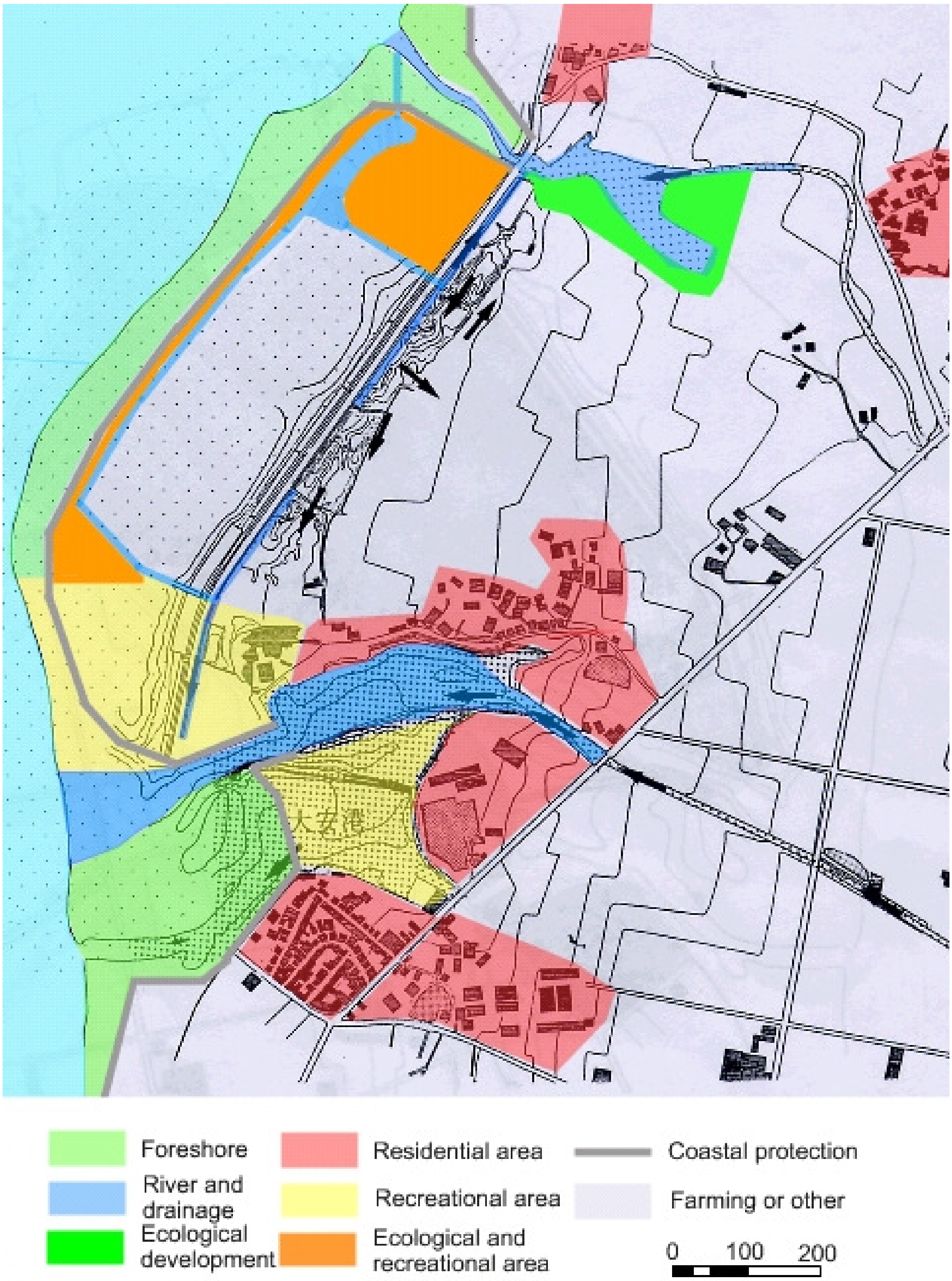


Figure 7.10 Possible land use if land reclamation is applied

Chapter 8 Coastal protection

In this chapter the design of the different elements of the coastal protection is presented. First soft solutions, being creation of sand dunes and foreshore development are elaborated on. In the then following paragraphs the design of dikes on different locations and the design of the seawall is presented.

8.1 Soft solution

In the previous chapters soft solutions were defined as solutions for coastal protection where no man made structures are used. Three variants were given: creation of sand dunes, elevating the foreshore and using vegetation. Creating or developing of sand dunes will form a natural structure able to protect the hinterland. In the other variants the foreshore is developed in such a manner that it helps dissipate wave energy and thus relieves the coastal structures i.e. reduces the run-up and wave attack on these structures. In this case dikes or seawalls are still necessary.

8.1.1 Sand dunes

Dune growth depends on the wind direction relative to the dune axis, the ability of the dune to trap and hold sand and the limits of the sources of sand. When looked at in broad outlines the project area seems to have favorable conditions for creation of dunes. There is a lot of sand supply from the large rivers to the north and the south of the project area, there are large swash plains and the climate is rather windy. These conditions will lead to a considerable wind-blown sand transport.

The critical wind speed for sand transport on beaches is typically in the order of 5 to 6 m/s. At the project area during the largest part of the year there is a NE monsoon wind with average wind speeds of around 8 m/s. However it will be difficult to give a good approximation on the sand transport rates because the soil moisture plays an important part. The tidal flats only fall dry during a specific period per day and it is hard to determine when the soil is still wet and when it will be dry in order to know what critical shear velocity must be used at what time also in wind blown transport, also the process of grains hit loose from the surface due to rain drops can play an important part. Though there are favorable conditions for wind-blown sand transport, creation of sand dunes is limited because the governing wind direction is parallel to the coast while sand dunes depend on sand transport caused by onshore winds. Because dunes will develop in the direction the wind blows, under the NE wind, the dunes to the south will develop first and then the dune row will gradually move to the north. But when in the south part of the dunes are eroded they will not grow anymore, because the area will be at the lee side of the developed dunes in the north.

Because typhoons cause high water tables and high waves, erosion of dunes during typhoons is expected to be very large. Because the onshore component of the wind is too small it is not likely the dunes growth perpendicular to the shoreline will be sufficient to cover for these losses.

Strong evidence present in the project area which proves creation of dunes is not a good option in the project area is the presence of sand fences near Wujia Harbor. According to local officials these sand fences are placed about three years ago yet no significant sand deposition was seen. Normally sand fences should fill up within a year after construction when conditions are favorable.

8.1.2 Foreshore development

In the case of the project area, the foreshore consists of wide tidal flats partly covered with vegetation. Also there are a lot of small rivers entering the ocean at the selected coast. These are ideal conditions for foreshore vegetation. At some locations along the coastline there is already a considerable amount of foreshore vegetation ranging from plants to trees. Because of the interaction between salt and fresh water these areas are ecologically important. When thinking of developing the foreshore in a natural way there are several options ranging from a passive approach to actively changing the foreshore.

The following variants will be discussed below: natural development, influence the boundary conditions for vegetation and planting of vegetation. To really develop the foreshore and perform maintenance requires a lot of research and is beyond the scope of this project. For example research about species and sewing has to be done. Because the natural balance is vulnerable, incompetent human intervention might eventually lead to destruction of foreshore vegetation.

Because the main purpose of all these variants is ecological enhancement of the area and for this project the main point is coastal protection, the variants will only briefly be discussed. However it must be noted that the foreshore offers excellent possibilities to enhance coastal protection, because it attenuates waves, can prevent undermining of the dikes and can offer revetment material for maintenance of dikes.

8.1.3 Spontaneous natural development

When the vegetation has no immediate function for the coastal protection or for erosion prevention and there is a sound condition for vegetation this option is actually very much ecologically sound and of course economically interesting. In figure 8.1 below the natural development from swash plain to salt marshes to forest vegetation is depicted. Natural occurring material has the best chance of surviving because it is adapted to the circumstances. Furthermore the chance on 'disturbing' herbaceous vegetation is diminished. The problem with the spontaneous natural development is that it is hard to predict the rate of development and the location because coincidence plays an important part in the distribution of seedlings. By a combination of sewing and natural development however some steering can be done.

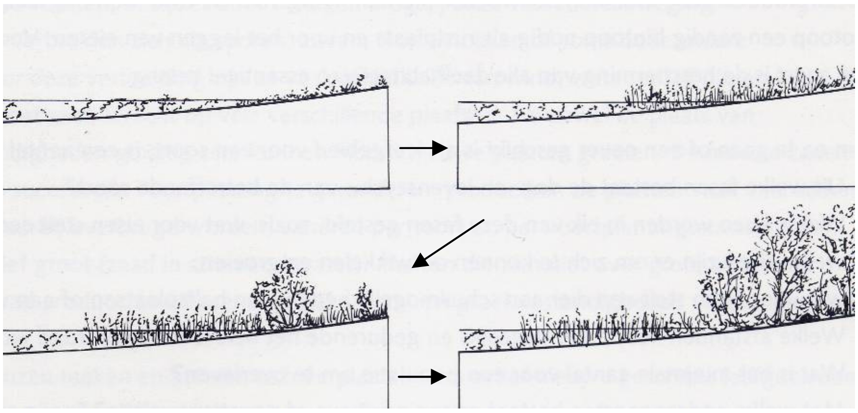


Figure 8.1 Natural foreshore development

8.1.4 Influence boundary conditions

The next option is to create the right boundary conditions for vegetation to develop. These boundary conditions consist of the tide, erosion or sedimentation, soil condition, salinity, climate and the function the tidal flat has for human and animals.

The influence of the tide is very important on the development of vegetation. The size of the area which inundates during high tide and the water depth are significant factors which determine the optimal growth locations. Erosion, sedimentation and soil conditions determine the height of the flat lands and the location of trenches and gullies. The salinity has a tight coherence with the tide, but also with river discharges. It determines the growing process of vegetation to a great extent. The climate has great influence on the animals living in vegetated areas and is also a boundary condition for certain vegetation species to be able to survive. For example mangroves which grow excellent in salt soil are not resistant to frost. Finally the function of the foreshore creates a boundary condition for vegetation development. For example when the foreshore is used for agriculture this has large consequences for the kind of vegetation. For example: in the project area at one location there is a duck farm located at the foreshore. Of course in and in the direct vicinity of this pond no vegetation is allowed by the owner.

To influence the boundary conditions can be done in many ways, depending on the goals and preferred timescale of development. By raising the flats with sand or shells the influence of the tide i.e. the inundation rate and salinity is influenced. This will have far-reaching consequences for the natural processes of the area. The process of erosion and sedimentation can be influenced by creating small scale dams of dead material like wood. Also temporary structures like dams of wood, concrete, stone-filled cribwork and floating structures can diminish the wave attack on the foreshore to create better conditions for vegetation growth.

8.1.5 Plant vegetation

A very active approach to foreshore development is to turn to restructuring by planting and sewing. This is a very delicate business and a lot of aspects have to be taken in account. It has to be determined which species will be planted at what location i.e. how near to the mean high water line. But also timing, order and depth of planting is very important. Planting always has to be accompanied with a sound management and maintenance plan. When boundary conditions are good, planting can be a rapid way of development of the foreshore, but the first two years after planting the vegetation is very vulnerable and unfortunately there are lots of examples where foreshore development by planting eventually fails.

8.1.6 Wave dissipation

Although there is a general agreement on the wave energy dissipating effect of foreshore vegetation, there is little quantitative data available. Especially in shallow water vegetation has influence on wave attenuation. This is because bottom friction is an important factor for wave attenuation in shallow water. Vegetation gives a higher bottom roughness and thus more bottom friction. In deeper water this bottom friction plays a minor part in wave energy dissipation and is therefore generally neglected.

The wave attenuating effect of foreshore vegetation is still a research subject and no guidelines are available which take into account this effect. A research done by the University of Cambridge (Möller and Spencer, 2002) on the wave dissipating effects of marshlands at the coast of England on two locations shows an average wave height attenuation of 0.1% to 0.5% per meter foreshore. In case of our project area with a vegetated foreshore of over 500 meters at some locations this would mean halving to a total dissipation of wave height. However the considered waves in this study are very small. Another important conclusion from this study is about the cross shore division of wave attenuation along the foreshore. It is concluded that the first ten meters of foreshore vegetation contributes the most to the overall wave attenuation.

Mangroves are another type of vegetation which can contribute to wave attenuation to a great extent. This plant is especially effective during storm surge, because then the canopies will submerge which will dissipate the wave energy significantly. Although there are large mangrove forests at foreshores at many locations around the world contributing to coastal protection in a great deal, about the wave attenuation little comprehensive data is available let alone reliable models. Research is also complicated because of the inaccessibility and muddiness of these forests.

It can be concluded that although foreshore vegetation has a positive influence on safety of coastal protection by significantly reducing wave heights, for the design of the coastal protection in our project area there is too little data and research available to quantitatively account for it in the dimensions, i.e. crest height determination, of the coastal protection.

8.1.7 Recreation

Though the foreshore offers great recreational opportunities, in the current situation this aspect is not taken advantage of. Presences of recreational opportunities apply primarily to the parts of foreshore vegetation areas which are almost permanently dry. Especially for more extensive recreational forms aimed at experiencing peace and nature these areas are suitable and recreational purposes can be combined with a sound ecological management. Accessibility and attractiveness are key aspects of the eventual recreational use. Since there is already a biking path along the coast which passes the project area accessibility is assured. Specific recreational utilities should be located near this already present infrastructure which is and should in a new coastal design be more combined with the coastal protection. At strategic places walking paths should be made in the foreshore. At one place in the project area there is currently a project executed which entails the construction of a water park at the foreshore. In this case it seems the foreshore is first elevated and present vegetation is eliminated to then construct the park. This is a method which can be applied when currently no vegetation is present, but even then it should be thoroughly investigated if no potential habitat is destroyed. Generally it would be better to conserve the readily available nature and take advantage of the recreational opportunities it offers without intervening too much in the existing situation.

8.2 Analysis of elements of a dike

When designing a sea-dike, one can roughly discern three important design-elements: The revetment, the "berm" and the slope. These three elements combined determine the crest-height and the cross-section of the dike. In the following sections the influence of these three elements on the design will be investigated. The influence on the dimensions can ultimately be quantified in the wave run-up formulae, which determine the height of the dike. These formulae are described in Appendix C.

8.2.1 Revetment

The function of the revetment is to protect the underlying core from erosion. It can also reduce the wave run-up to maintain the safety required. Besides that there is a need of limiting the required maintenance; the damage should always be less than the economical tolerable damage. Finally the revetment has an esthetical and environmental contribution to the entire dike.

In this case five different kinds of revetment will be looked at:

- Loose rock
  This is a top layer of dumped materials, placed on a geo-fabric or a granular filter. The stone class will be determined according to the Van der Meer-formula described in Appendix D paragraph D.1.
- Placed blocks
  These are blocks or columns made out of natural stone or concrete, placed on top of a filter. Placed block revetments will be designed according to the Pilarczyk-formula[7]. A description of this formula with some of the values used for the constants is given in Appendix D paragraph D.2.
- Asphalt
  This is a watertight top-layer, usually without a filter. Asphalt revetments are used when wave-attack is severe. Regular inspections for cracks and fissures are mandatory.
- Concrete
  Just as the asphalt revetment, concrete covers constitute watertight and smooth top-layers.
- Grass
  A well-maintained cover made out of grass or any other kind of vegetation with good cover, placed on a clay top-layer can make up a good revetment, but only if the wave-attack is not too severe (H <~0,75m)[8]. If waves are higher, a different kind of revetment has to be used, while on the upper parts of the dike a grass revetment can still be used.

All these revetments will be judged on their ecological, recreational, and financial value in the paragraphs below.

<u>Ecology</u>[9]

When looking at revetments in an ecological context a couple of governing principles have to be addressed:

- Substrate
  Bituminous materials or materials with furnace slags in them do not yield a good surface for nature to grow on.

[7] http://blackboard.tudelft.nl/courses/1/ct4310/content/_373685_1/Pilarczyk.pdf
[8] http://blackboard.tudelft.nl/courses/1/ct4310/content/_373684_1/dik0630.PDF
[9] Innovatief denken en doen in kustverdediging; Ecologisch ontwerp kustverdedigingsconstructies

- Smoothness
  Smooth seamless covers, such as asphalt or concrete revetments, don't offer many possibilities for settlement.
- Placement
  The holes and cavities in open or semi-open revetments allow for ecological development, but this decreases as the stones are placed more closely together.
- Size
  Larger stones (>20cm) offer a wider gradient in a-biotic conditions. Therefore the use of larger elements is recommendable.

Cost

In general the cost of a revetment involves the expenses made during construction, and the costs made because of inspection and maintenance afterwards during use. When looking at the construction of revetment it can be noted, that the more labor-intensive revetments, such as placed block revetments, are also the more expensive. Closed layer revetments, however, need special equipment for construction. Furthermore, they need regular inspection during use.

Recreation

Regarding recreation the governing factor in assessing the value of a revetment is the esthetic value and the accessibility. Therefore important features are the color, the monotonousness, and the smoothness of the revetment.

8.2.2 "Berm"

A "berm" in the front slope of the dike is an effective measure to limit the height of a dike. The effectiveness of a "berm" in reducing the run-up height depends on its length and its altitude relative to the still-water level. A "berm" has the greatest effect, if it is located on this still water level during storm conditions. Therefore, when designing a dike, one of the starting points will be to put a "berm" on this water level if it is applied at all. The width of the "berm" may be no longer than 25 percent of the wavelength. What the optimal "berm" width is can only be determined by looking at the effect the "berm" has on the required earthmoving and land acquisition.

Ecology

The effect of a "berm" on the ecological value of a dike is actually a matter of what kind of cover is applied on the "berm". Therefore, it is more a matter of revetment characteristics, than characteristics of the "berm" itself, since the width or height of the "berm" have no real impact on the ecological development.

Cost

As already mentioned, a "berm" can be an effective measure to limit the dike's cross-sectional surface, and thereby limit the costs for earthmoving and land acquisition. However, some boundary conditions that exist on this stretch of coast can cancel out the effect of a "berm", making it useless in limiting the crest height.

Recreation

The "berm" can easily be converted into a second walkway or bikeway next to the crest. It can also be fitted up with other recreational features like benches etc. The wider it is, the more room there is for this kind of recreation.

8.2.3 Slope

The choices for the steepness of the outer and inner slope of a dike are for a large part at the discretion of the designer. The outer slope determines the character of the interaction between wave and dike, while the inner slope only has to deal with the discharge coming from overtopping waves. The inner slope also has to allow for people to get on or over the dike.

Ecology

The ecological development will profit from less steeper slopes, since steeper slopes create less surface area for certain ecotopes which require a certain depth-bandwidth[10]. Therefore, less steep slopes will generate more ecological value.

Cost

Less steep slopes need more earthmoving. The base of the entire dike-profile will also bee wider, resulting in more need of land-area. Yet, the run-up height decreases with decreasing slope, so a larger slope may lead to a cheaper dike.

Recreation

Again, less steep slopes are preferred, due to their accessibility. It is easier for instance to climb a 1:8-slope than a 1:3 slope.

8.2.4 Process description

To determine the dimensions of a dike, the following sequence will be used:

1. Determine exceedence lines for tide, waves, and wind speeds.
2. Calculate wind set-up, gust-bumps, sea level rise.
3. Determine the design water level and the water depth at the toe of the dike.
4. Calculate design wave-height.
5. Choose a slope.
6. Choose a revetment.
7. Choose a "berm".
8. Determine the maximum settlement of the soil during the lifetime of the structure
9. Determine the crest-height: Design crest-level = design water level + run-up + subsoil settlement.
10. Check the acquired profile on safety and soundness.
11. After the profile of the dike has been established, attention can be paid to details, such as the exact dimensions of filter layers or toe-protections.
12. If the design lacks sufficient safety, or doesn't live up to requirements defined in the program of demands, the process can be repeated starting from step 5.

[10] Designing island shores and ecotopes, ministerie verkeer en waterstaat

8.3 Coastal protection land reclamation

The design of the coastal protection which is applied at the places where new land will be reclaimed is done with the process as described in subparagraph 8.2.4. This design can be divided in seven parts, which are the definition of waves and water levels, the choice for the slope, revetment and "berm", the design of the revetment, calculation of the crest height and a check on the safety of the coastal protection.

8.3.1 Determination of waves and water levels

The design water level consists out of the highest possible astronomical tide, the gust bump, the storm surge and the sea level rise. The highest possible astronomical tide during the lifetime of the structure is 5.86 meters above MWL or EL + 3.23 meter. For the relative sea level rise during the lifetime of the structure a value of 0.1 meters has been assumed. Local information on gust bumps is not available, but a maximum value of 0.5 meters is assumed.

The highest significant deep sea wave height is taken from Appendix A measures 7.29 meters with a significant wave period of 12.17 seconds. The wave set-up is calculated using the CRESS-software. Using this program, a maximum set-up during ideal typhoon conditions of 1 meter is computed.

The design water level is the aggregate of the highest tide, the storm surge, the gust bump, and the sea level rise, which is in total EL + 4.83 meter. The vertical location of the toe of the new dike depends on the inclination of the beach and the amount of seaward land reclamation. The new dike will be located 500 meters in front of the current coastal protection. The toe of the current dike lies 3.5 meters above EL, with an average beach inclination of 0.5% the toe of the new dike will lay on 1 meter above EL. The water depth above the toe of the new coastal protection will be 3.83 meters.

The local water depth limits the highest possible wave height at the toe. The 7.29 meter high deep sea waves will break long before they reach the dike because the shallowness of the beach limits their height. With an assumed breaker index of 0.5 the highest possible significant wave at the toe of the dike becomes 1.92 meter.

The peak period of the waves T_p is roughly the same as the significant wave period. However, for further calculations the spectral wave period $T_{m-1,0}$ has to be used. This spectral wave period is 11.06 seconds.

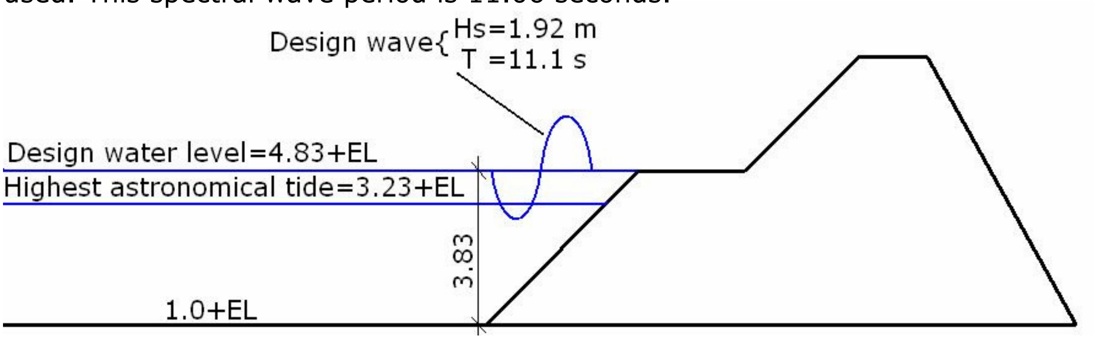


Figure 8.2 Schematic representation of relevant water levels in front of dike (units in meters)

8.3.2 Choice of the slope

The choice of the slope of the dike will have its effect on several aspects. As the steepness decreases, so does the surf similarity index ξ. This means lower wave run-up, and less wave attack on the revetment. Also, it has already been mentioned a less steep slope has more ecological and recreational value.

The only disadvantage of lower steepness is the increasing width of the base of the dike. When the effects of the "berm" are discarded, a dike with an 1:3 slope is roughly 30 meters shorter than a dike with a 1:8 outer slope. The development of the crest height and base width is summarized in the table below. These values for required crest height are calculated according to the TAW-guidelines on wave run-up and wave overtopping, see Appendix C, with the on-site circumstances for a dike with no "berm" and a maximum overtopping of 0.1 liter per meter per second. The crest height in this table and the tables after that is not the real level of the crest, but merely its height above the dike's base. The base width is calculated using a standard crest width of 3 meters and an inner slope tangent of 1:3.

Table 8.1 Slopes with accompanying geometry

Outer slope	Crest height	Base width
1:3	11.61 m	73 m
1:4	11.61 m	84 m
1:5	11.61 m	96 m
1:6	11.02 m	102 m
1:7	10.02 m	103 m
1:8	9.27 m	105 m

One can see that up to slopes of 1:5 the crest height doesn't change. This is because the waves on these slopes don't break, and the calculated overtopping is limited by the maximum. From a slope of 1:6 and onward, the crest height decreases, but with it the base width increases. This increase of base width will go at the expense of reclaimed land. Therefore, a slope of 1:8 is chosen to be used for now, for it offers the greatest ecological and recreational value, while in the meantime it also has a smaller crest height. Later on in subparagraph 8.3.4 when the effects of a "berm" will be included, the crest height can be reduced even further, along with the base width and the cross sectional surface. However, when optimizing the cross section of the dike, it might be more desirable to change the slope slightly. This optimization will be done according to cost, and might result in a slightly steeper slope. This doesn't' mean that the recreational and ecological criterions are discarded. A slope slightly steeper than the 1:8 slope can still mean a huge improvement compared to the present situation.

8.3.3 Choice of a revetment

When designing a dike that has both ecological as well as recreational value, grass revetments are preferred. However, at the location of this dike the significant wave height is almost 2 meters. A grass revetment will not be able to withstand a storm for sufficient time with such a wave height present. Therefore, a different revetment must be chosen.

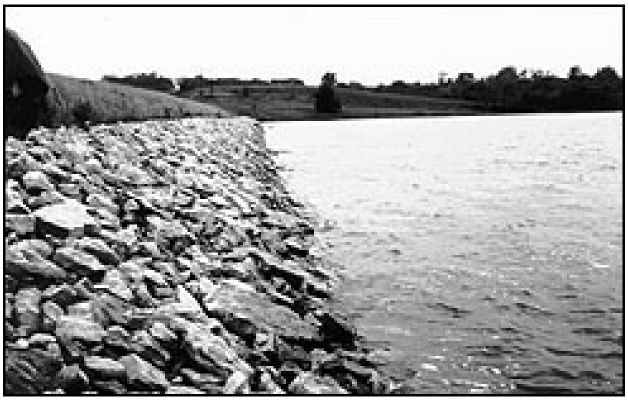


Figure 8.3 Example loose rock revetment

In this case a loose rock protection will be chosen. This solution is preferred over a placed block revetment, because the loose stone revetment is cheaper to build and easier to maintain. Furthermore, the cavities between the rocks offer for more ecological development than the relatively small seems between place blocks. This revetment warrants a friction reduction value for wave run-up γ_f of 0.7.

What kind of stone size has to be used, and how this armor has to be connected to the core of the dike can only be determined after the complete profile of the dike is know. A more detailed design of the complete revetment will be made in subparagraph 8.3.6.

8.3.4 Choice of a "berm"

A "berm" only has a crest height reducing effect up to a certain point. The TAW-guidelines in Appendix C on wave run-up and overtopping are limiting the "berm" reduction factor γ_b to a minimum of 0.6. So while greater "berm" widths may yield smaller reduction factors, there is no point of applying these widths, as the reduction factor to be taken is still 0.6. Also, in the formulas for run-up or overtopping with non-breaking waves, the "berm" reduction factor isn't used at all.

This results in the fact, that for steeper slopes, on which the waves don't break, a "berm" has little to no effect. However, in the case of the 1:8-slope described in subparagraph 8.3.2 a "berm" will have a positive effect on the crest height, the base width and the cross sectional surface. The effects of different widths are depicted in the table below. These values are for a horizontal "berm" located on the still water level, where the "berm" has the most effect. The outer slope has the same value above and below the "berm". For the rest the circumstances are like those on-site. Units are in meters.

Table 8.2 "berm"-width with their accompanying geometry

"berm" width	Crest height	Base width	Cross-section
16 m	6.75 m	93.3 m	332.2 m2
17 m	6.70 m	93.6 m	331.7 m2
18 m	6.64 m	94.1 m	331.5 m2
19 m	6.59 m	94.4 m	331.4 m2
20 m	6.54 m	94.9 m	331.5 m2
21 m	6.52 m	95.7 m	333.8 m2
22 m	6.52 m	96.7 m	337.7 m2

The halt of decline of the crest height at "berm" widths of 21 meter or higher is due to the maximum reduction factor being reached. A "berm" wider than 20 meters adds no more reduction, and only adds to the cross sectional surface. Since the cost of the dike depends on base width, i.e. land acquisition, and cross sectional surface, i.e. earth moving, the optimal "berm" width for this slope is 19 meters.

If this process of cross section optimization would be applied to a dike with steeper slopes, smaller base widths and cross sectional surfaces might be obtained, while the crest height might increase. To see if the decline in base width and cross sectional surface continues for all steeper slopes, table 8.3 is devised.

Table 8.3 Different outer slopes and the accompanying optimal geometry

Outer slope	Optimal "berm" width	Crest height	Base width	Cross-section
1:3	5 m	9.99 m	68 m	349 m2
1:4	10 m	8.91 m	75 m	343 m2
1:5	13 m	7.92 m	79 m	325 m2
1:6	15 m	7.32 m	84 m	321 m2
1:7	18 m	6.85 m	90 m	324 m2
1:8	19 m	6.59 m	94 m	331 m2
1:9	17 m	6.51 m	98 m	339 m2

As can be seen, the base width will always increase with the decrease in slope steepness and the decrease in crest height. The only value that can really be optimized is the cross sectional surface, which shows a minimum at a slope of 1:6. Therefore, the tangent of the slope used for this dike will be 1:6. This slope will have a "berm" 15 meters wide, located on the still water level. With these features, the required freeboard with a maximum allowable overtopping of 0.1 liters per meter per second is 2.99 meters above the design water level.

8.3.5 Determination Crest height

The information on the exact soil composition in the area between Dajia River and Da'an River is not available for this project. For the design of this dike the assumption will be made, that the maximum settlement of the dike during its lifetime will be no more than 0.5 meters. This is of course a subject that has to be investigated more deeply in future studies.

The total crest height is the total of the design water level, the required freeboard, and the expected settlement of the soil. The required crest height is thus EL + 8.32 meter.

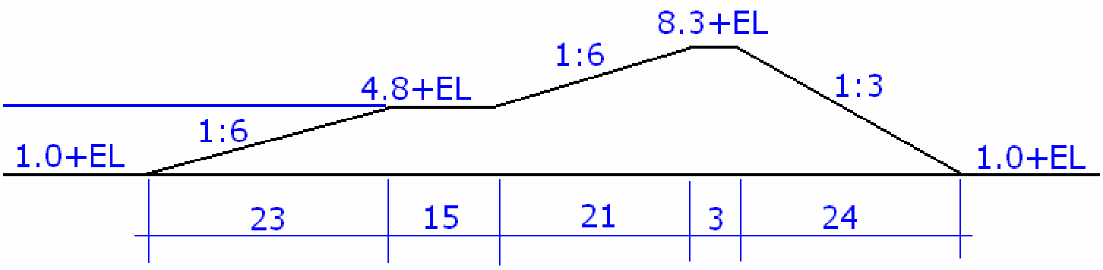


Figure 8.4 Cross section profile dike (units in meters)

8.3.6 Designing the revetment

For this part of the coastal protection a loose rock protection is chosen. According to the Van der Meer-formula, see Appendix D paragraph D.1, the required stone size is 0.68 meter for the median nominal rock diameter D_{n50}. The accompanying nominal diameter D_{50} is 0.82 meter, and a weight of 868 kg, so rock with a grading of 300-1000 kg will be applied. The thickness of this armor is 1.5 times the D_{n50} of the rock, which turns out to be 88 cm. This requires a minimal dumping quantity of 1325 kg per square meter.

The core of the dike will simply be made out of the widely available sand, so a transition between core and revetment has to be made in the form of a filter. This filter will consist of a layer of stone, with a stone class of 90-180mm, with a thickness of 20 cm. This layer of rock lies on top of a geo-textile with a maximum O_{90} of 600 µm, and a high permeability. A good choice for a geo-textile would be a Terram woven polypropylene W/8-8. The exact process of designing this filter is described in Appendix D paragraph D.3.

The toe of the revetment is the transition from revetment into foreshore, and also supports the revetment itself. It will consist of a concrete structure that actually supports the horizontal force coming from the weight of the revetment. In front of this armor will be the actual toe. Appendix D paragraph D.4 gives the design considerations and calculations necessary to determine the rock size of this toe. The result of that is a toe made out of loose rocks with a stone class of 60-300 kg.

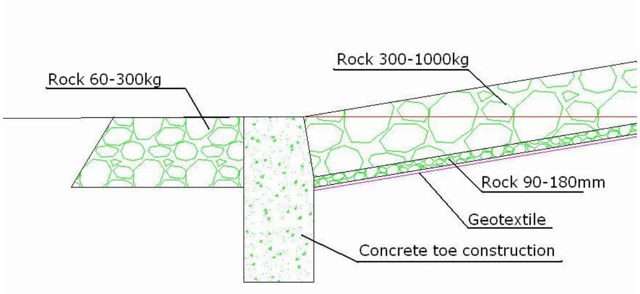


Figure 8.5 Loose rock revetment with toe construction

The wave attack on the upper half of the upper part of the outer slope has already diminished enough to allow for the application of a grass revetment on this part of the slope. A grass revetment is much smoother than loose rock, but according to the TAW a different smoothness this high up the dike doesn't have an effect on the overall roughness-factor of the slope. This kind of grass revetment will also be applied on the inner slope.

It is important to look at the transition from the loose rock revetment to the grass cover. If this transition isn't designed properly, openings between the two covers might develop, leading to exposure of the dike's core material. To ensure no discontinuities in the cover, the filter and the geo-textile will extend several meters underneath the clay layer of the grass revetment.

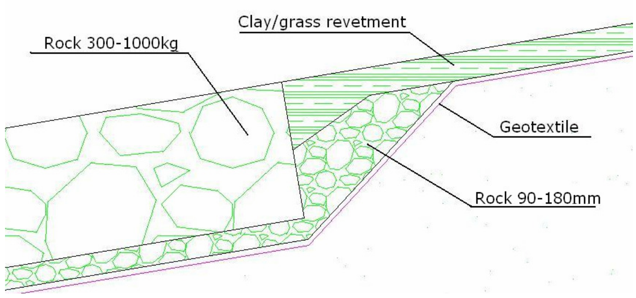


Figure 8.6 Transition loose rock – clay revetment

To give the dike a better accessibility and to improve its recreational value, the crest of the dike will be designed with an asphalt cover. This makes it important to look at the transition from asphalt to grass revetment on the inner and outer slope. Just as in the case of a transition from loose rock revetment to grass revetment, there should be no discontinuities that can allow exposure of core material. An overlap of the asphalt on top of the clay layer should be sufficient to prevent this exposure.

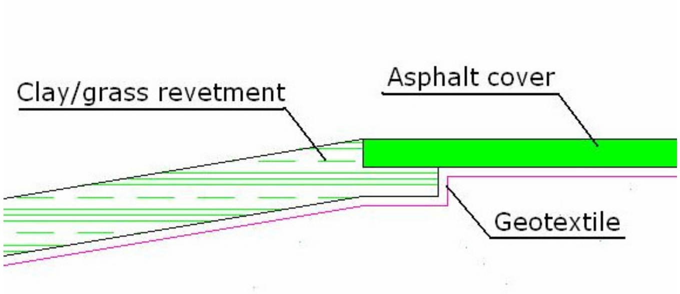


Figure 8.7 Transition clay revetment – asphalt cover

8.3.7 Check on safety

Macro stability

With the use of the program CRESS and its slope stability assessment feature the stability factor F has been computed for various slip circles and centre points. When using this program a number of assumptions are made for the input:

- The soil in and underneath the dike consists out of homogenous cohesion-less sand, with a dry volumetric weight of 16 kN/m^3, a saturated volumetric weight of 20 kN/m^3, and an internal angle of repose of 30^o.
- The maximum water level on the seaward side of the dike is the still water level, which lies 3.84 meters above the toe of the dike.
- The water level on the landward side of the dike is on the same level as the base of the dike.
- The phreatic water level inside the dike in the landward slope is 2 meters above the base of the dike.

The overall outcome of these simulations is that for larger slip circles the stability factor F is above 1, and the macro stability of the entire dike is guaranteed. However, circles that only go through the seepage part of the dike give F-values close to 1. The micro stability of these parts should be investigated closer.

Micro stability

The degree of stability of the slope on place where groundwater flows through the slope depends on the angle of the slope itself and the angle of repose of the soil. Another important factor is whether there is porous flow or seepage through the slope. This last case is the more likely to occur with this dike during storm conditions, so the inner slope has to be checked for stability under horizontal seepage.

A slope under an angle α made out of soil with angle of repose ϕ is considered stable, if it satisfies the following condition:

$$\phi \geqq 2\ \alpha$$

With an angle of repose of 30^o the maximum allowable angle for the slope becomes 15^o, which corresponds to a slope with a tangent of about 1:3.5. The current value for the tangent of 1:3 is too big. Therefore, the angle of the slope is reduced, and the new tangent becomes 1:4.

Earthquakes

The dike has to be able to withstand loads coming form the earthquakes that regularly strike the area. However, when designing the dike on earthquake-loading, it is assumed there are no extreme water levels present, since the chance that an earthquake will strike simultaneously with a typhoon is negligible. The load coming from an earthquake is actually an acceleration of the soil. In the guidelines on seismic design[11] the stability of slopes is evaluated by using ordinary slip circle analysis modified by adding a lateral force, equal to the mass of the soil inside the slip circle multiplied by a coefficient k_h, which is a fraction (usually 0.5) of the ratio between the earthquake acceleration and the gravitational acceleration g.

The incorporation of this coefficient for the lateral force in the available models used to evaluate slope stability goes beyond the scope of this project. It will suffice to say, that with this kind of loading the stability of the inner slope might become precarious. This is partly because the grass revetment on the inner slope is impervious. Water pressures inside the dike might spike during an earthquake, pushing the revetment away. To prevent this pressure build-up a draining filter between the sand and the clay is applied in combination with a gravel filter at the toe of the inner slope.

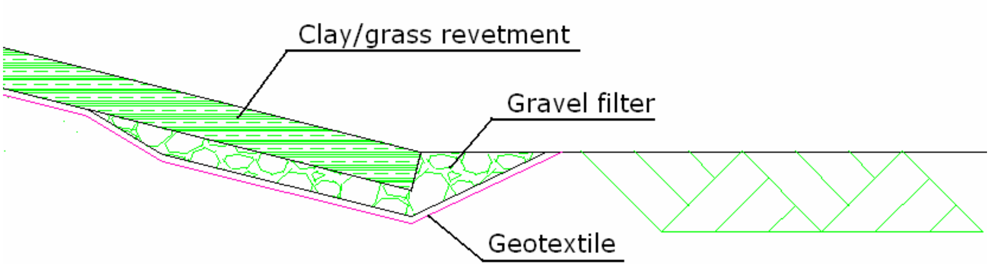


Figure 8.8 Toe construction inner slope with filter

Another remediation technique to strengthen the soil inside the dike is necessary to give the dike enough strength to withstand extreme earthquake loading. A favorable remediation technique in this case is compaction of the sand in and underneath the dike.

As it has been mentioned before when making assumptions on the settlement of the soil, our knowledge on the composition of the soil is extremely limited. The only indication that there is any kind of stratification in the soil is the presence of wells behind the dike, which can spout water well above the ground level. This might indicate that there is a soft impermeable layer somewhere below the well. How deep or how wide this layer truly is, is yet unknown, but it may be wise to investigate this in future studies. A weak soil layer can lower the stability of the dike, can cause more settlement, and can amplify earthquake accelerations. If such a layer is found not deep below the site of the future dike, it is best to remove this layer and replace it with soil that gives more stability to the dike on top of it.

8.3.8 Conclusion

Now that the total design for the dike has been made, checked and altered, a total view of the cross section of the dike with all its elements can be made. This cross section is depicted in Appendix K.

[11] Seismic design guidelines for port structures, PIANC

8.4 Improving current coastal protection

The design of the coastal protection which is applied at the places where the old coastal protection has to be replaced is done with the process as described in subparagraph 8.2.4 and used in the previous paragraph. This design can be divided in seven parts, which are the definition of waves and water levels, the choice for the slope, revetment and "berm", the design of the revetment, calculation of the crest height and a check on the safety of the coastal protection. The same design principles as in the previous paragraph will be used.

8.4.1 Determination of waves and water levels

The design water level consists out of the same elements as the design water level for the dike in front of the land reclamation. Since the conditions concerning tide, storm surge, sea level rise and gust bumps are the same, the design water level is also equal to the design water level used for designing the land reclamation dike: 4.83 + EL. The highest significant deep sea wave height is taken from Appendix A measures 7.29 meters with a significant wave period of 12.17 seconds.

The vertical location of the toe of the new dike depends on the inclination of the beach and the location of the new dike in relation to the old dike. The new dike can be built on two locations: in front of or behind the existing dike. Building the new dike on the location of the old dike is not an option, since the safety of the hinterland would not be guaranteed during demolition and construction. Placement of the new dike behind the existing protection is also not preferred, because that would mean loss of land. The best option is to construct the new dike in front of the old one. After construction is completed, this old dike can be removed.

The base width of the new dike is yet unknown, but judging by the width of the dike designed for land reclamation, a width of 50 meters seems a good estimate. With the toe of the current dike laying at EL + 3.5 meter and an average beach inclination of 0.5%, the toe of the new dike will lie on EL + 3.25 meter. Thus the maximum water depth above the toe will be 1.58 meters.

The local water depth limits the highest possible wave height at the toe. The 7.29 meter high deep sea waves will break long before they reach the dike because the shallowness of the beach limits their height. With an assumed breaker index of 0.5 the highest possible significant wave at the toe of the dike becomes 0.79 meter.

The peak period of the waves T_p is roughly the same as the significant wave period. However, for further calculations the spectral wave period $T_{m-1,0}$ has to be used. This spectral wave period is 11.06 seconds.

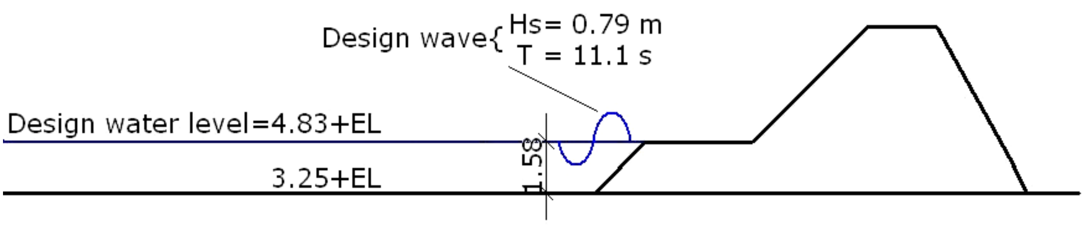


Figure 8.9 Schematic representation of water levels in front of dike (units in meters)

8.4.2 Choice of the slope

The same assessment as made in subparagraph 8.3.2 can be made here. Less steep slopes are preferred, because of their higher ecological and recreational value. However, because the waves are so small, even an 1:8 slope doesn't cause the waves to break. When "berms" wouldn't be applied the crest height of an 1:8 slope is the same as that of an 1:3 slope: 4.96 meters above the base of the dike.

Yet, the steeper slopes don't get the preference, since one of the objectives of this project is to make a coastal protection that is ecological and recreational valuable. A slope with a tangent of 1:8 is chosen, with the remark that it might change slightly after optimization with a "berm".

8.4.3 Choice of the revetment

On the sea dike in front of the land reclamation the wave attack was too severe to allow for a grass revetment. In this case however the wave height is much lower, but not yet low enough to allow for a grass revetment. The highest allowable wave height according to the Dutch standards is 0.75 meters, and the waves on this slope are only slightly higher: 0.79 meters. However, this kind of revetment is still desired over other kind of revetments, and the difference between allowable and actual wave height are not so big. Therefore, vegetation which can reduce the wave load will be placed on the foreshore if the situation allows for it.

If the situation doesn't allow for it, the revetment will have to be fit out with a stronger armor on the locations where the wave impact is most severe. Therefore, a placed block revetment will be used from the toe of the dike up to one meter above the "berm". Above this revetment the grass cover will begin. The placed block armor is preferred for this dike, since it provides more recreational value to the design. Unlike the land reclamation dike, this dike is more likely to attract recreation, since it is located nearer the population centers, and is more likely to have beach in front of it.

Since it is not determined yet what kind of blocks will be used, little can be said about their roughness. That is why a value of 1 will be used for roughness factor γ_f.

8.4.4 Choice of a "berm"

Again the effect of the "berm" is limited to a maximum reduction coefficient of γ_b = 0.6. This factor is completely discarded when the waves on the slope are not breaking. With the smaller waves in front of this dike this happens up to slopes of 1:6. Slopes steeper than this gain no reduction in crest height from a "berm".

When the same optimization process is applied as has been done for the land reclamation dike table 8.4 is obtained. The values in this table were obtained using the TAW-guidelines as outlined in Appendix C paragraph C.2, using an overtopping criterion of 0.1 liter per meter per second and a roughness factor γ_f of 1.

Table 8.4 Different outer slopes and the accompanying optimal geometry

Outer slope	Optimal "berm" width	Crest height	Base width	Cross-section
1:3	0 m	4.96 m	36 m	93 m2
1:4	0 m	4.96 m	43 m	109 m2
1:5	0 m	4.96 m	49 m	123 m2
1:6	7 m	4.55 m	51 m	117 m2
1:7	8 m	4.18 m	53 m	112 m2
1:8	9 m	3.90 m	55 m	110 m2
1:9	10 m	3.69 m	57 m	108 m2
1:10	11 m	3.52 m	60 m	108 m2

In this case the optimal combination between "berm" and slope seems to exist with an 1:9 slope with a 10 meter wide "berm" located on the still water level. The required freeboard for this configuration is 1.61 meters above the design water level.

8.4.5 Determination crest height

The information on the exact soil composition in the area between Dajia River and Da'an River is not available for this project. For the design of this dike the assumption will be made, that the maximum settlement of the dike during its lifetime will be no more than 0.5 meters. This is of course a subject that has to be investigated more deeply in future studies.

The total crest height is the total of the design water level, the required freeboard, and the expected settlement of the soil. The required crest height is thus EL + 6.94 meter.

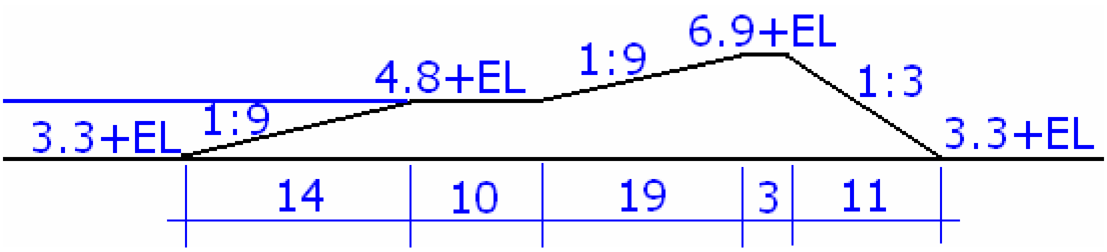


Figure 8.10 Cross section profile dike (units in meters)

8.4.6 Designing the revetment

The grass revetment will simply consist of a clay layer 0.3 meters thick with grass planted on top of that layer. The core of the dike will be made out of the widely available sand, with the cay layer directly on top of the sand. A filter construction won't be needed. To ensure a good quality grass with a high density of roots the cover should get little to no fertilization. Regular inspections should also be in order, since holes in the cover are the starting points of erosion during storm conditions.

If the foreshore doesn't have sufficient wave-attenuating vegetation on it, part of the grass cover with the heaviest wave attack will have to be replaced with a block revetment. This part of the revetment that consists of placed blocks will be designed according to the Pilarczyk-formula, as outlined in Appendix D paragraph D.2. This formula gives a thickness of the elements of 0.30 meters. This layer will be embedded in a 20 cm thick filter layer of loose rock, class 90-250 mm. This layer will rest upon a geo-textile. The determination what kind of geo-textile has to be used depends on the core material of the dike, and since the core of this dike is no different form the land reclamation dike, the same kind of geo-textile can be used.

The toe of the revetment is the transition from revetment into foreshore, and also supports the revetment itself. This transition will again consist of a concrete construction supporting the revetment with a toe in front of it made out of rock. This toe will be made from a smaller class than the toe for the land reclamation dike, due to the smaller wave attack and the smaller size and weight of the revetment supported by the toe. Using the design process outlined in Appendix D paragraph D.4 a stone class of 10-60 kg is obtained.

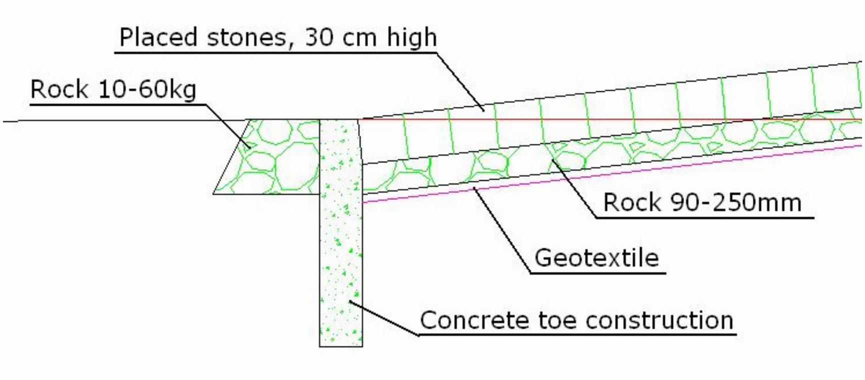


Figure 8.11 Placed stone revetment with toe construction

This dike will not only have a road on the crest. To allow for more recreational use, the “berm” will also get an asphalt cover. Again it is important to look at the transition from asphalt to grass revetment. This transition is the same as the grass/asphalt transition on the land reclamation dike, so basically the transition consists of an overlap of the asphalt over the clay of two meters.

8.4.7 Check on safety

Macro stability

With the use of the program CRESS and its slope stability assessment feature the stability factor F has been computed for various slip circles and centre points. When using this program a number of assumptions are made for the input:

- The soil in and underneath the dike consists out of homogenous cohesion-less sand, with a dry volumetric weight of 16 kN/m^3, a saturated volumetric weight of 20 kN/m^3, and an internal angle of repose of 30^o.
- The maximum water level on the seaward side of the dike is the still water level, which lies 1.58 meters above the toe of the dike.
- The water level on the landward side of the dike is on the same level as the base of the dike.
- The phreatic water level inside the dike in the landward slope is 1 meters above the base of the dike.

Just as in the case of the land reclamation dike the safety factor for the overall stability safety factor is far above 1. Only slip circles that intersect nothing but the revetment have safety factors approaching 1. Thus the micro stability of the slopes should be looked at more closely again.

Micro stability

The check on micro stability is the same as the one performed for the land reclamation dike, see also subparagraph 8.3.7. The outcome of the check is also the same: the current value for the tangent of the inner slope of 1:3 is too big. Therefore, the angle of the slope is reduced, and the new tangent becomes 1:4.

Earthquakes

The same that has been said about earthquake loading in subparagraph 8.3.7 applies here. The most vulnerable parts of the dike will be the impervious revetments that can not drain away the spike in water pressure created by the earthquake. Therefore, these revetments will be fitted out with filters to be able to cope with these pressures. Also, it is important again that the sand in the core of the dike is compacted during construction to give more strength and to prevent liquefaction from occurring during earthquakes.

8.4.8 Conclusion

Now that the total design for the two dikes has been made, checked and altered, a total view of the cross section of both dikes with all the elements can be made. These cross sections are depicted in Appendix K.

8.5 Promenade

In this paragraph improvement of the current coastal protection by creating a promenade is investigated. This solution is especially suitable when there are possibilities for waterfront activity like a beach. In the project area there is one such location, which is called Da'an Beach Resort.

8.5.1 Location

There are three options to create a promenade. It can be created seaward of the current coastal protection, landward of the current coastal protection or at the current location of the existing coastal protection. In all cases it can be decided to what extent the current coastal protection is maintained or upgraded. Since the current coastal protection is getting old and needs maintenance it is preferred to create a promenade seaward of this coastal protection and protect this promenade by a new structure. The old dike is then more or less used as backfill. Another advantage is that when there are buildings and infrastructure right behind the existing coastal protection as is the case with Da'an Beach Resort they can be maintained, which is not the case when the promenade is constructed there.

The main disadvantages of creating the promenade seaward of the current coastal protection is the decrease of the current beach width and the increase of the water depth in front of the new coastal protection during high tide or storm surge. Increase of the water depth in front of the new coastal protection will increase the needed volume of the new coastal protection and also increases the wave height leading to more cross shore sediment transport which could lead to beach erosion, especially when a 'hard' vertical structure i.e. a seawall is constructed to protect the promenade. In case of the project area however the shoreline is located relatively high up the beach. The slope of the foreshore is very gentle and thus the beach is very wide at low tide and the water depth will increase only marginally when the shoreline is moved seaward. Because of these circumstances the disadvantages of a 'hard' and vertical or near vertical structure will not play an important part. Moreover the coast is accreting so with limited seaward erection of the promenade beach erosion is not expected.

8.5.2 Shape and crest height

In the current situation at the Da'an Beach resort there is a small scale promenade at the seaside of the coastal protection which lies approximately at the toe level of the dike. During high water tables and or storm surge this will be flooded and the pavement and permanent structures on it will be damaged. At the site it can be seen this has happened over the years. Another disadvantage of the current situation is that there is no clear transition between the promenade and the beach. There is also a lot of sand being blown onto the promenade.

In order to create a more sustainable promenade with a clear transition between the beach and promenade it would be better if the promenade is protected by a seawall with sufficient crest height. The promenade should be elevated to the same height to maintain the sea view. Of course stairs should be designed as part of the structure to assure beach access.

There are different types of seawalls which can be chosen from. The simplest form is the vertical seawall, other forms depicted in figure 8.12 are: curved-face, stepped-face or rubble mound seawalls.

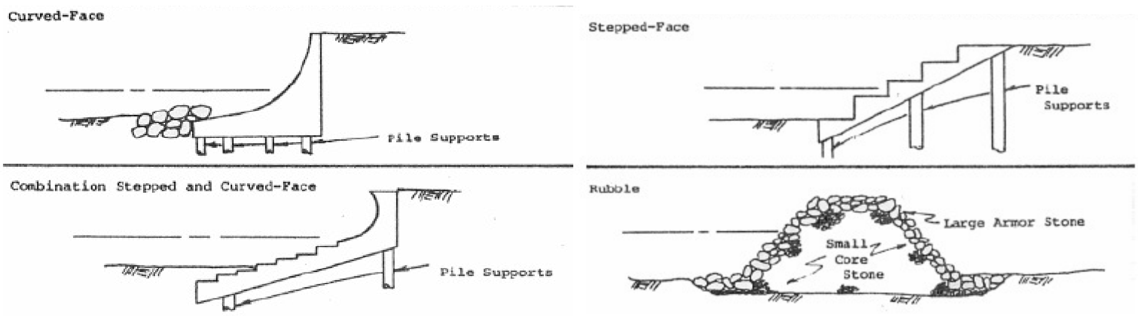


Figure 8.12 Shapes of seawalls[12]

The rubble mound alternative is not recreational friendly, so this alternative can be discarded. The stepped-face and curved-face alternatives are designed to absorb wave energy. However in the current situation due to the relatively high and gently sloped foreshore the wave attack is too mild to justify these more complex structures. Therefore a simple vertical or near vertical seawall will suffice in the circumstances of the project area.

Now a vertical seawall has been selected it has to be decided if this vertical element is constructed using sheet piling or a massive gravity wall. When a sheet wall is constructed the stability depends on anchorage in the backfill material, usually sand. The stability of a massive concrete wall depends on the gravitational force imposed on the wall. This is depicted in figure 8.13.

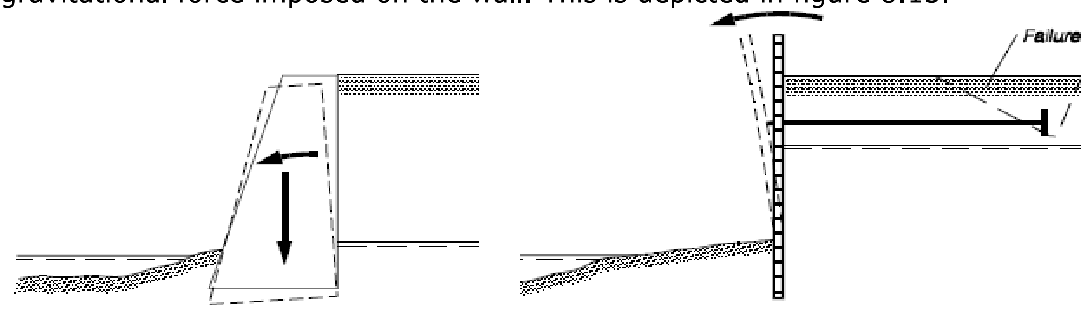


Figure 8.13 Stability of gravity wall and sheet wall

[12] US Design Guide EM 1110-2-1614, 1995

Generally a massive gravity wall is easier to construct whilst a sheet pile wall is a more complex structure. The main advantage of a massive wall is the easy and fast construction; it eliminates the expense of pile driving. The main disadvantages are the needed amount of concrete or quarry stone, and the increased chance of settlement. It can be concluded that especially for relatively high walls and bad soil conditions a sheet pile wall is preferred because it will be cheaper. But it also depends on the availability of heavy material such as concrete or quarry stone. Since in the current situation the coastal protection has a height of only 2.5 meters and the height of the new seawall is not expected to be much higher and also the soil conditions are assumed to be good in this case a massive wall is preferred.

Another advantage interesting in the case of recreational use is the aesthetic possibilities a massive wall offers. It can be either made using cut stone or concrete with an architectural lining as can be seen in figure 8.14. This will also make the surface more rough, resulting in a decrease of the reflection factor for incoming waves thus reducing scour potential.

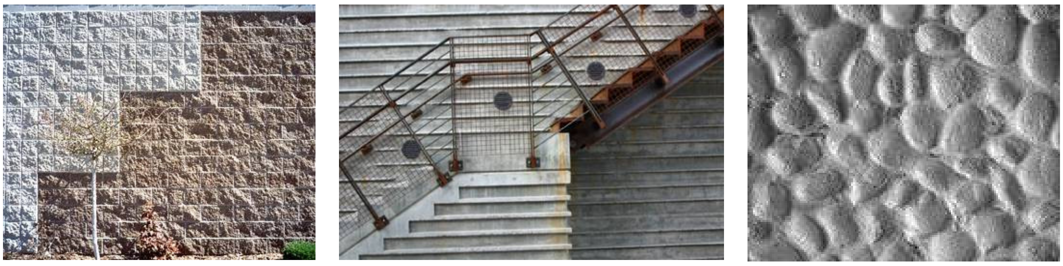


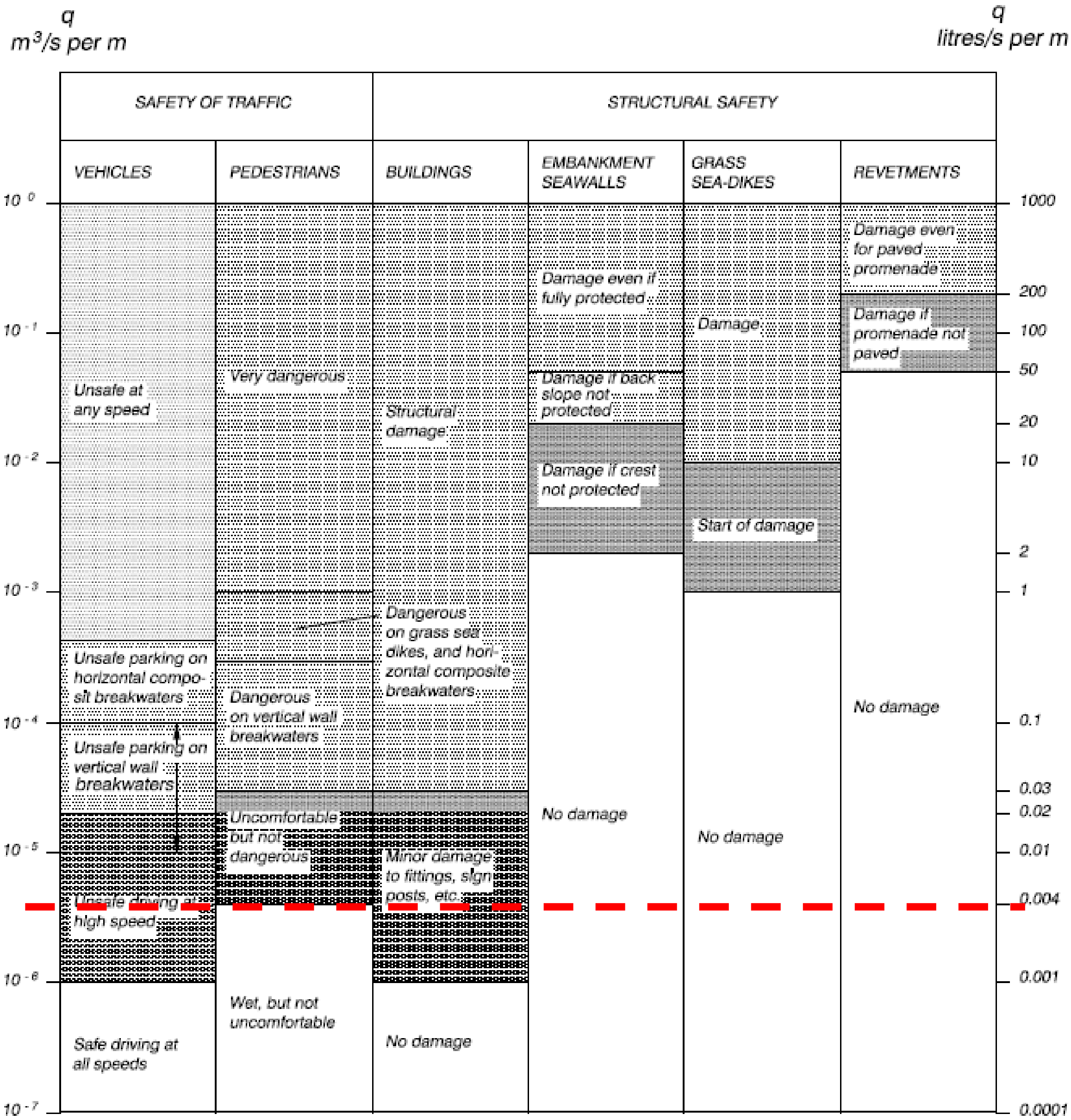
Figure 8.14 Architectural concrete

The crest height is either determined by wave run-up or the wave overtopping criterion. A vertical structure acts like a mirror reflecting the waves. For a smooth vertical structure the reflection factor draws near to 1. Because a standing wave can thus be created the wave height just in front of the structure will be doubled. So the run-up criterion requires a freeboard of twice the significant wave height, which is 2*0.7 is 1.40 m.

To determine the overtopping rate for a simple vertical seawall with no fronting revetment and a small parapet at the crest, the formula presented in Appendix C can be used. It must be noted though that waves hitting a vertical structure will produce a lot of spray which also can be blown over the structure. This increases the overtopping rate. This is not taken into account with the formula presented in Appendix C. As a rough guideline for overtopping criteria table 8.5 can be used, in which the result of various field studies, models and tests is condensed.

Two states can be distinguished being the serviceability limit state and the ultimate limit state of the structure. Since the main purpose of the promenade is recreation the governing conditions in the first state is safety for pedestrians. It must be noted that the values in the table are average overtopping discharges so individual wave overtopping can be much higher. To stay on the safe side the limit for ‘wet, but not uncomfortable’ is chosen, which equals an average overtopping discharge of 0,004 l/s/m. Because under normal circumstances the winds in the project area mainly blow along the shoreline and with higher wind speeds the promenade will not be used for recreation, the wind blown spray is neglected in the serviceability limit state. In the ultimate limit state the winds will be so extreme the promenade has to be closed down. In this state the governing condition is possible damage to the seawall. Again to stay at the safe side as a limit, 1 l/s/m is chosen. In the ultimate limit state increase of overtopping by onshore winds should also be considered, but since in this state the overtopping limit is 250 times as high as the overtopping limit in the serviceability state the overtopping limit in the serviceability state will be normative.

Table 8.5 Critical Values of Average Overtopping Discharges[13]



From the calculation in Appendix C it follows that to comply with the overtopping criterion a freeboard of 1.65 m is needed so the overtopping criterion is stricter than the run-up criterion and is considered normative. When the seawall is constructed 10 meters in front of the existing dike, creating a promenade of 15 meters wide, the construction crest height of the seawall should be 7 m +EL. This is including a small parapet, so with a parapet of 0.5 m the promenade is constructed at 6.5 m +EL. In table 8.6 the different components leading to the needed crest height are presented.

[13] USACE Coastal Protection Manual, Part VI, Chapter 5, table VI-5-6

Table 8.6 Calculation of construction crest height

Highest High water Level	3.23 m + EL	
Sea level rise	0.10 m	
Gust bump	0.50 m	
Wind setup	1.00 m	+
Design water level	4.83 m + EL	
Free board needed for overtopping	1.65 m	+
Design crest height	6.48 m + EL	
Expected settlement	0.50 m	+
Construction crest height	6.98 m + EL	

To prevent toe instability due to scour the base of the seawall is placed slightly below seabed. For a rough first estimate of the scour dept the design wave height is used. This is 0.7 m, so the foot of the seawall should be 0.7 meter below seabed. Since the seabed is at 3.50 m +EL the seawall is placed at 2.80 m +EL.

8.5.3 Stability and failure

Now the crest height is determined the required structure cross section is calculated. Also the structure has to be checked on stability. The failure modes treated below are depicted in figure 8.15.

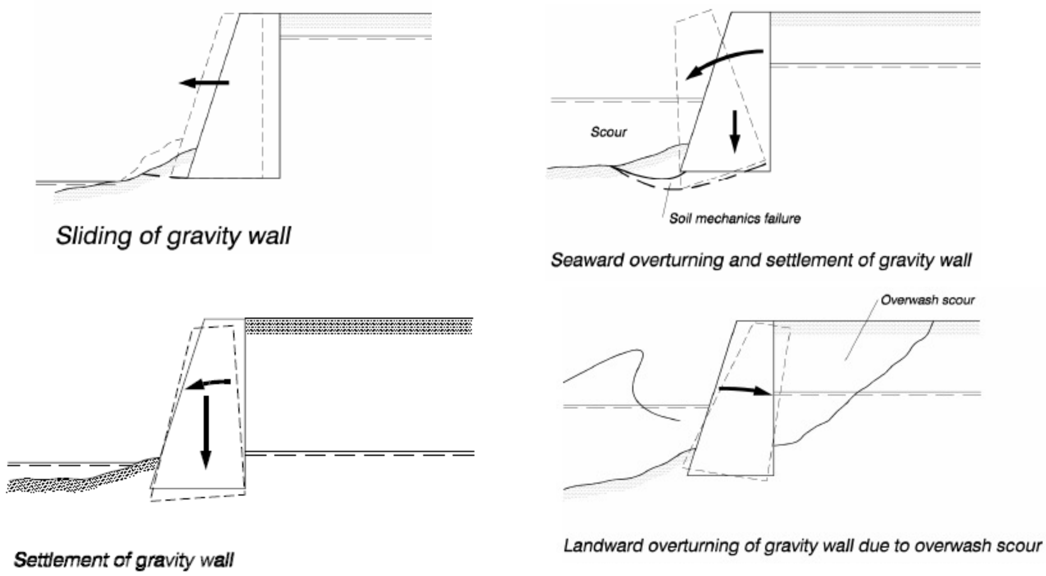


Figure 8.15 Common failure modes for seawalls

<u>Sliding and overturning</u>

Since the project area concerned is a seismic active region in the stability calculations earthquakes should be taken in to account. For the calculation of the stability guidelines described in: '*Seismic design guidelines for port structures'*, Pianc, 2001, are used. In these guidelines three analysis methods are treated with increasing complexity and accuracy: simplified analysis, simplified dynamic analysis and dynamic analysis. The simplified analysis is conventional practice for evaluating seismic stability of retaining walls. It is based on pseudo-static approaches. A seismic coefficient is used to compute an equivalent pseudo-static inertia force. The actual dynamic behavior of retaining walls is much more complex. In the simplified dynamic analysis, simplified relationships between ground motion intensity and seismically-induced deformations are used. These relationships are derived by numerical studies based on the sliding block method of analysis. Dynamic analysis procedures use finite element or finite difference techniques. In this method the response of the foundation and backfill soil is incorporated in the computation of the structural response.

Which analysis is considered adequate depends on the importance of the structure and the amount of effort needed to restore the structure if damaged by an earthquake. In the Pianc design philosophy two earthquake levels; L1 and L2 are considered. An L1 level earthquake event is likely to occur within the lifetime of the structure, while an L2 level earthquake event only occurs rarely. An acceptable level of damage also has to be established. Depending on the importance of the structure the acceptable level of damage during an L1 or an L2 level earthquake event is determined.

The promenade seawall treated in this chapter is a small scale structure with only regional importance and disruption is not expected to lead to disproportional damage to economy or property. It is considered an ordinary structure. Since normal high water is below the toe of the structure it is also relatively easy to restore the structure. This leads to an acceptable level of damage of near collapse for an L2 event and a serviceable state for an L1 event. Since no detailed earthquake records are available at this time, in this report the structure will be designed according to an L2 event. The safety factors for sliding and overturning should be above one. As an L2 event the highest conceivable earthquake for the region is used (Natural boundary condition BC-N8). A simplified analysis is considered sufficiently accurate.

Calculation

The most important starting points for the calculation are given below, for a more extensive deliberation on all used coefficients the full calculation presented in Appendix F paragraph F.2 is referred to.

One of the most important and also most restricting starting points of the calculation is the use of the Mohr-Coulomb criterion. In this analysis a straight sliding surface is assumed whilst a circular sliding surface could lead to a higher active soil pressure. However for sandy soils this approach is considered accurate enough. Another starting point of importance is that though the structure base is 70 cm below sea bed level the sliding resisting passive earth thrust of the sea bed soil is not taken into account. This is done because of the scour potential of the soil just in front of the structure under wave action. Further starting points are given in table 8.7 below.

Table 8.7 Starting point values

Sign	Definition	Value
k_h	horizontal effective seismic coefficient	0.24
k_v	vertical effective seismic coefficient	0
γ_d	unit weight dry backfill soil	16 kN/m^3
γ_c	unit weight concrete structure	24 kN/m^3
φ	internal friction angle backfill soil	30°
δ	friction angle structure-backfill	20°
μ_b	friction coefficient structure-foundation	0.5
q	surcharge	15 kN/m^2

In Appendix F the calculation using the pseudo-static approach of the simplified analysis is presented. The safety factors for overturning and sliding are calculated for different geometries of the structure. The geometry of a gravity seawall with a vertical front is determined by the height, the base over height ratio, b/H, and the angle α of the back of the wall with horizontal, see figure 8.16. Since the height is determined by the overtopping criterion and is set at 3.7 m. The b/H ratio and α determine the cross section. Using a spreadsheet the stability of the seawall is calculated. This is done for a number of combinations of b/H and α. In table 8.8 below the results are condensed.

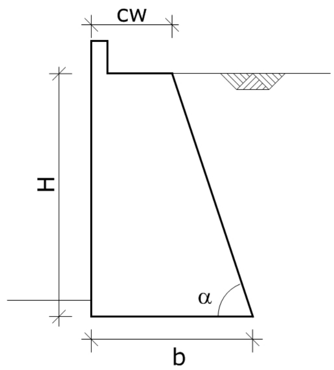


Figure 8.16 Geometry of gravity seawall with vertical front

Table 8.8 Cross section and safety factors for different geometries of seawall.

alpha b/H	50 0.87	55 0.96	60 1.05	65 1.13	70 1.22	75 1.31	80 1.40	85 1.48	90 1.57	deg rad
0.50	***	***	***	3.65 0.95 0.90	4.35 0.98 0.87	5.01 1.00 0.86	5.64 1.02 0.85	6.25 1.04 0.85	6.85 1.06 0.85	
0.55	***	***	***	4.34 1.10 0.93	5.04 1.12 0.91	5.70 1.14 0.89	6.32 1.15 0.88	6.93 1.17 0.88	7.53 1.20 0.89	
0.60	***	***	4.26 1.23 1.00	5.02 1.25 0.97	5.72 1.27 0.94	6.38 1.28 0.93	7.01 1.29 0.92	7.62 1.31 0.92	8.21 1.33 0.93	
0.65	***	***	4.95 1.38 1.03	5.71 1.40 1.00	6.41 1.41 0.97	7.06 1.42 0.96	7.69 1.43 0.95	8.30 1.45 0.95	8.90 1.47 0.96	
0.70	***	***	5.63 1.54 1.06	6.39 1.55 1.02	7.09 1.56 1.00	7.75 1.56 0.99	8.38 1.57 0.98	8.98 1.59 0.98	9.58 1.61 0.99	
0.75	***	5.47 1.69 1.13	6.32 1.69 1.08	7.08 1.70 1.05	7.78 1.70 1.03	8.43 1.70 1.02	9.06 1.71 1.01	9.67 1.73 1.01	10.27 1.75 1.02	
0.80	***	6.16 1.85 1.16	7.00 1.85 1.11	7.76 1.84 1.08	8.46 1.84 1.06	9.12 1.84 1.04	9.75 1.85 1.04	10.35 1.86 1.04	10.95 1.89 1.05	
0.85	5.89 2.01 1.24	6.84 2.01 1.18	7.68 2.00 1.13	8.44 1.99 1.10	9.15 1.98 1.08	9.80 1.98 1.07	10.43 1.99 1.06	11.04 2.00 1.07	11.64 2.00 1.07	
0.90	6.58 2.18 1.26	7.53 2.16 1.20	8.37 2.15 1.15	9.13 2.13 1.12	9.83 2.12 1.10	10.49 2.12 1.09	11.11 2.12 1.09	11.72 2.14 1.09	12.32 2.16 1.10	
0.95	7.26 2.34 1.28	8.21 2.32 1.21	9.05 2.29 1.17	9.81 2.28 1.14	10.51 2.26 1.12	11.17 2.26 1.11	11.80 2.26 1.11	12.41 2.27 1.11	13.01 2.29 1.12	
1.00	7.95 2.50 1.29	8.90 2.47 1.23	9.74 2.44 1.19	10.50 2.42 1.16	11.20 2.40 1.14	11.86 2.39 1.13	12.48 2.39 1.13	13.09 2.40 1.13	13.69 2.42 1.14	

Cell entry:

cross section A [m2]	
Safety factor overturning	**Safety factor sliding**

*** combination of alpha and b/H not aplicable under given H

sliding and overturning factor below 1

sliding factor below 1

sliding and overturning factor above 1

As can be seen from table 8.8 above, for the given geometries the safety factor for sliding is always lower than safety factor for overturning. As the b/H ratio is decreased the safety factors get closer to each other and eventually when the structure is relatively slender the safety factor for overturning will be governing. In the range of the calculation however the safety factor for overturning is higher, which is preferred, because overturning usually leads to complete collapse of the structure, whilst sliding can under certain circumstances be allowed.

With increasing angle α the safety factor for sliding decreases until an angle of approximately 80 degrees is reached, then it increases again. This is because the dynamic active earth thrust acts at a friction angle to the normal of the back of the wall. So with a smaller angle α the horizontal component of this force is also smaller. But since the weight of the concrete is higher than that of the backfill the vertical gravitational force will increase with an increasing angle α under the same b/H ratio. This leads to a higher frictional force between the concrete structure and the rubble foundation. The latter effect overtakes the first effect when the angle α approaches 90 degrees.

The smallest cross section needed to ensure sufficient safety is when b/H=0.6 and α=60°. Because the width at the top of the structure is in this case very small (less than 1 cm) the chance on partial failure by breaking off of the tip is too high. Also a parapet has to be applied. Considering this a configuration of b/H=0.65 and α=60° is chosen. The geometry of this configuration is depicted in figure 8.17 below.

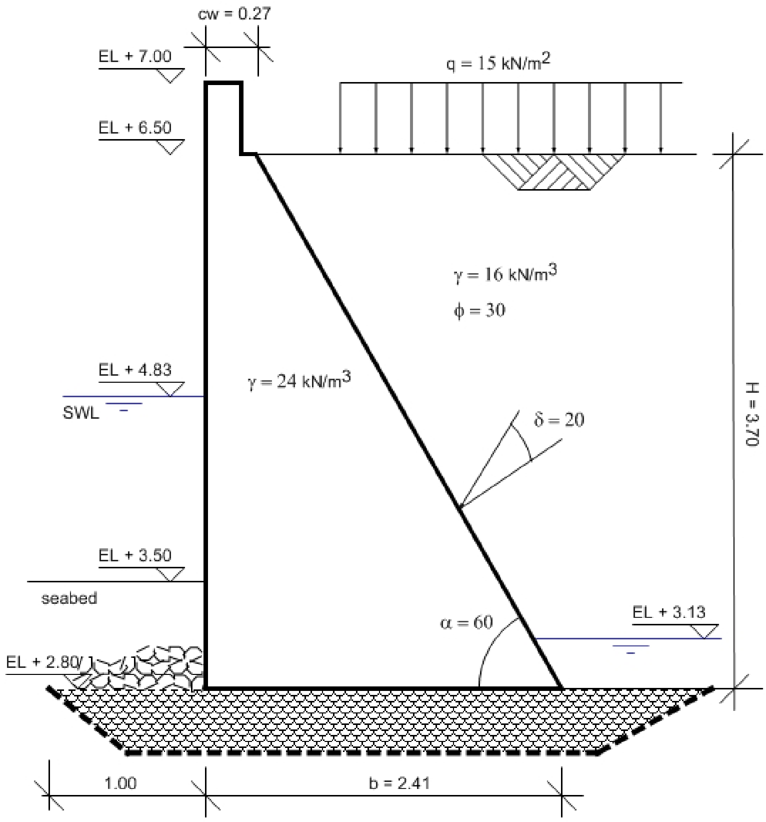


Figure 8.17 Cross section of seawall

A static analysis, with k_h = 0 and full surcharge q taken into account, shows that the safety factors for overturning and sliding under normal non earthquake circumstances are respectively: F_{so} = 2.69 and F_{ss} = 2.07.

The safety of the structure can be increased in some ways. First the sand of the backfill can be compacted, thus increasing the internal friction angle. When the angle of internal friction is increased to 40 degrees, the safety factors for overturning and sliding will respectively increase to F_{so} = 1.56 and F_{ss} = 1.2.

A way to increase the safety factor for sliding is increasing the roughness of the concrete base of the structure, in this way the friction coefficient will increase.

When the friction coefficient is increased to 0.6 the safety factor for sliding increases to 1.24.

In this calculation the backfill soil is assumed to be completely dry and the unit volume weight is set at 16 kN/m^3. Because the soil could become wet and it is not sure the unit volume weight of the actual backfill soil will not be heavier, it is investigated how the stability of the structure is changing when the unit volume weight of the backfill soil is increased. It turned out the stability is not very sensitive to the weight or the backfill soil. When the weight is set at 18 kN/m^3 the safety factor for sliding decreases to 1.02 and when it is set at 20 kN/m^3 (saturated river sand) the safety factor for sliding is 1.01. From the calculations it follows that the proposed cross section is likely to satisfy the seismic performance requirements at L2 earthquake motion.

Scour and toe instability

For stability of the entire structure it is of utmost important to ensure the stability of the structure toe. A potential undermining process of toe stability is scour. Scour occurs when the hydrodynamic shear stresses on the bottom are high enough to initiate sand transport. These shear stresses can be developed by waves, currents or a combination of both. Scour can develop rapidly over a short time span for example under storm surge conditions but also a more gradual loss of seabed material can occur. At a vertical front structure located in the vicinity of the shoreline as the seawall considered in this chapter, scour can occur along the seaward toe of the structure because it can be exposed to energetic breaking waves that produce downward-directed flows and high levels of turbulence which will scour the bed. There are also known cases where the construction of a seawall resulted in gradual loss of beach material, eventually leading to complete loss of the beach. Since the considered coast is an accreting coast with a large amount of sand supply from nearby rivers, the latter problem is not applicable here.

The incident scour potential has to be accounted for, but there are some positive circumstances at the project area. Since the shoreline is rather high compared to the water level waves are depth limited. The design wave height, which occurs under typhoon condition, is therefore only 70 cm. Also the coast is not only accreting, but there is also a lot of wind blown transport of sediment currently leading to sand deposition in front and even behind the dike. When the seawall is constructed a significant amount of this sediment will be deposited just in front of the seawall. Thus a buffer for scour is likely to be present there.

Understanding the physical processes involved in scour is difficult because the shear stresses responsible for scour are by waves and or currents. There are some rather simple rules of thumb used in engineering practice. In this case, because of the positive circumstances mentioned above these rules of thumb are considered accurate enough to use when designing features to prevent toe instability. The most common solution to prevent scour is constructing an apron at the seabed in front of the vertical structure. This apron can be made of quarry stone or larger material. Because in the case of the seawall designed in this chapter the seawall is constructed at a recreational area, it is preferred not to have a visible apron of stones in front of the wall, but to let the beach be directly connected to the seawall. Therefore the base of the structure is lowered below the seabed. As a rule of thumb scour can be predicted by the significant wave height. The depth of the scour hole is just as big as the significant wave height, which is in this case 70 cm. So the structure base is place 70 cm below seabed.

As an extra measure to prevent toe instability the bed layer is extended in front of the structure as a rule of thumb, the relation proposed by Eckert, 1983 is used in which is stated the length of an apron in front of a vertical wall should be about the same size as the wave height. To prevent washing away of the bed layer a layer of quarry stone is placed on top of the bed layer in front of the seawall. Since a scour hole will only develop during a storm surge which may occur only several times a year, but in Taiwan in a distinct season, it is preferred to manually fill up the scour hole after a storm rather than depending on natural processes for filling up of the scour hole. Between the bed-layer and the sandy under layer a geo-textile or a layer with granular material is needed to prevent washing out of the sand.

A totally different scour problem is overwash scour. This occurs when the overtopping of the structure is so high it will lead to erosion of the backfill. In case of this seawall however the overtopping criterion is rather strict, leading to a high freeboard and a low average overtopping discharge. Furthermore the promenade will have to be paved so the greater part of the excess water will run off the structure. Sufficient slope of the promenade and drain holes in the parapet must be provided to assure this run off.

Settlement

As far as settlement is concerned, the assumption is made the settlement of the structure will be no more than 50 cm during the lifetime of 50 years. Settlement will decrease the crest level, leading to higher overtopping rates; therefore the expected settlement is incorporated in the construction height. The current knowledge on the composition of the soil is rather limited. Comments on the soil condition are given in subparagraph 8.3.7.

Before construction a well outlined on site geotechnical investigation has to be performed. Special attention for the seawall has to be paid to differences in settlement and liquefaction potential. Differential settlement can lead to damage to structures and pavement of the promenade, but also cracks in the seawall itself. When the soil is liquefiable, measurements have to be taken to reduce the chance of liquefaction of the subsoil of the seawall during an earthquake.

8.5.4 Functional requirements

Since the promenade is a recreational object attention has to be paid to the functional division and fitting up of the structure. As mentioned before a good dewatering is important, so the pavement should have a sufficient slope and drainage has to be assured. Another functional requirement is the construction of a balustrade of sufficient height on top of the parapet to ensure safety from falling off the structure. Very important is also the accessibility of the promenade. Therefore in the final design stairs and ramps of sufficient capacity should be implemented as well as at the seaside as at the landward side.

Chapter 9 Drainage system model

The drainage system of the area between Daija River and the Chung Shan S. road 2.5 kilometers northward of the Daija River is modeled using Sobek. Not all the drainage canals of the above mentioned area are being modeled but only four bigger drainage canals. The data which is needed as input for the model, i.e. precipitation data and tidal data, is partly gathered from the rainfall runoff mode in the Sobek model and partly obtained from gathered data. The goal of the simulation is to have a prediction of the run-off in the area during a typhoon for alternative drainage lay-outs, which can be used to determine the consequences or new lay-outs and to design outlets for the chosen lay-out. The distance between the calculation points is not chosen to be optimal, but is chosen by the limitation of the Sobek license in use.

9.1 Current situation model

First the current situation is modeled. This is done because the model has to be calibrated to a certain level of accuracy.

9.1.1 Model

The current situation of the project area is modeled. The cross-section for this model is estimated from a site survey and on some places adapted to prevent flooding of the area in the model. The adaptation is necessary because not all drainage canals in the selected area are modeled, therefore the modeled canals will have a higher discharge than they have in reality. The model is used to get a rough estimation of the run-off discharge of the whole area, the missing drainage canals are not important for the total discharge or for the delay in time. In figure 9.1 an impression of the area is given as well as the lay-out of the model is. In this figure the outlets are on the left side. More precise data is given in Appendix G.

Figure 9.1 Model in Sobek and their representative names

9.1.2 Input data

The model needs two types of data. The first type is the precipitation in the area and the according run-off discharge to the canals. For the precipitation in the area the rainfall during a typhoon with a return rate of 50 years is used. There are two types of areas defined, namely unpaved areas and paved areas. Unpaved areas have the ability to retain some of the precipitation, i.e. some part will infiltrate into the soil and will be partly discharged later as base flow. If the precipitation is bigger than the infiltration capacity of the ground, the water will run over the surface to the drainage canal. In paved areas there is no or a very small capacity of infiltration and the water will run off quickly into the drainage system. There is no retention in paved areas and almost no delay in run-off. Using Sobek Rainfall Run-off model the run-off discharge is determined for the unpaved and paved areas; a graph of these discharges is given in figure 9.2 and figure 9.3.

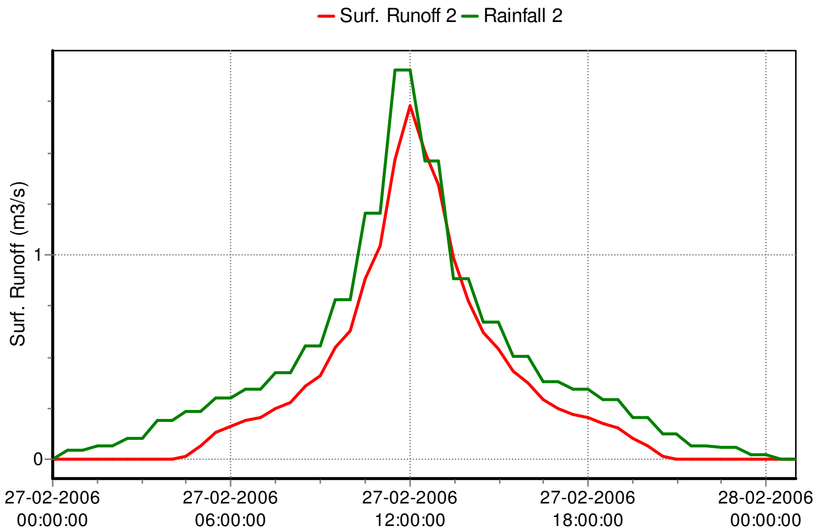


Figure 9.2 Discharge of unpaved area per 10 ha

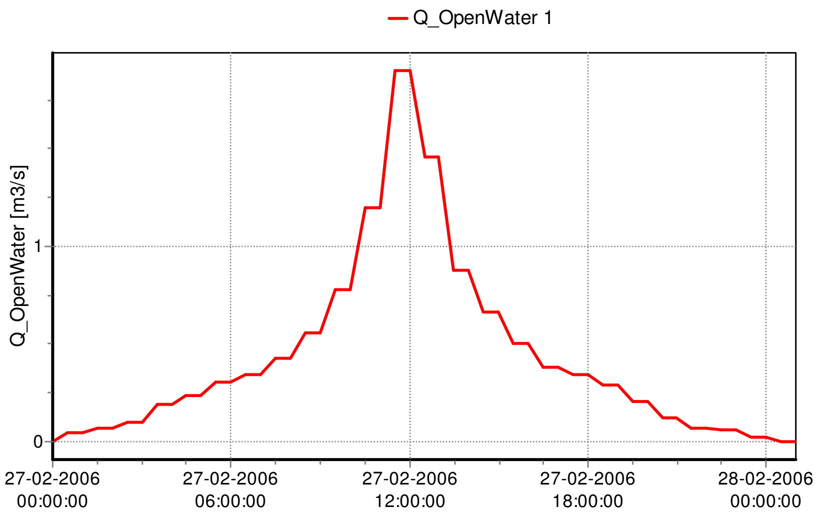


Figure 9.3 Discharge of paved area per 10 ha

In order to estimate the ratio between unpaved and paved area and the size of the catchment areas a map with a grid is used, see Appendix G paragraph G.2. Each area of the grid is given a certain degree of pavement and for each area a surface run-off discharge is determined. The lateral discharge can be calculated for each section of the drainage system. The data concerning the different sections is also given in Appendix G paragraph G.2. This lateral discharge is applied to the drainage system at certain points.

The second type of data the model needs is the water level at the boundary nodes. The water level used in the model is Mean High Water, thus creating the most unfavorable combination of large discharge due to the typhoon and low discharge capacity due to high water. In the current situation the bed-level of the canal mouth is also on this water level; Mean High Water. So in the current situation there is no influence of the tide on the canal-outflow. If canal mouths are moved seaward, for example in the case of land reclamation, the tide has to be taken into account, of which the water levels are shown in figure 9.4.

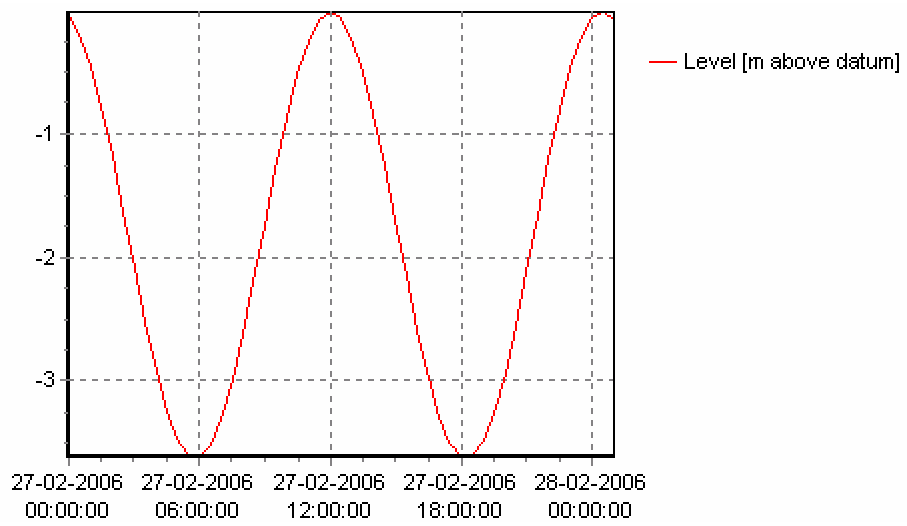


Figure 9.4 Water level, MHW is taken as reference level

To obtain data about the discharge not hampered by any outside water-levels, there is also a simulation run with a fixed water level of 0.5 meter above the datum. This is not a realistic simulation, although the obtained data can be used for estimating the needed capacity of a detention area or pump.

9.1.3 Results and conclusions of the current situation

First the current situation is modeled with Sobek as showed in **Error! Reference source not found.**. For every canal branch which is modeled in Sobek, water levels and discharges are obtained for the situation with a once in 50 year rainfall. The maximum water levels of canal 4 during a design discharge are shown in **Error! Reference source not found.**.

The dimensions of the cross-sections, maximum discharges and maximum water levels are shown in table 9.1 . Discharges of the different canals depend on the catchment area, the inclination, the width of the profile and the river length. Canal 3 has the highest discharge and the highest water levels. Canal 1 has almost the same discharge but a lower water level due to a larger inclination which is the cause of a higher discharge velocity. The larger inclination is also cause of the disproportionate distribution of the bifurcation of canal 1 and canal 2. Canal 4 has a smaller profile, so the water level will be higher if the same discharges occur as in the other canals.

The model shows that in this situation no flooding of the canals will occur. It can be concluded that the current system satisfies for rainfall which occurs once in 50 years. Canal 3, the canal with the highest water level has still a freeboard of

0.25 meter. If the outlets are maintained well and therefore guarantee the maximum discharges they are able to process there would be no flooding. Maintaining well means that all the outlets are cleared of debris and sediment and also the valves will function well.

Table 9.1 Discharges and water levels in the current situation

Canal	Q_{max} [m^3/s]	h_{max} [m]	Profile [width * height]
1	26.3	1.28	3 by 2 meters
2	21	1	3 by 2 meters
3	28.5	1.74	3 by 2 meters
4	18.8	1.38	2.5 by 1.5 meters

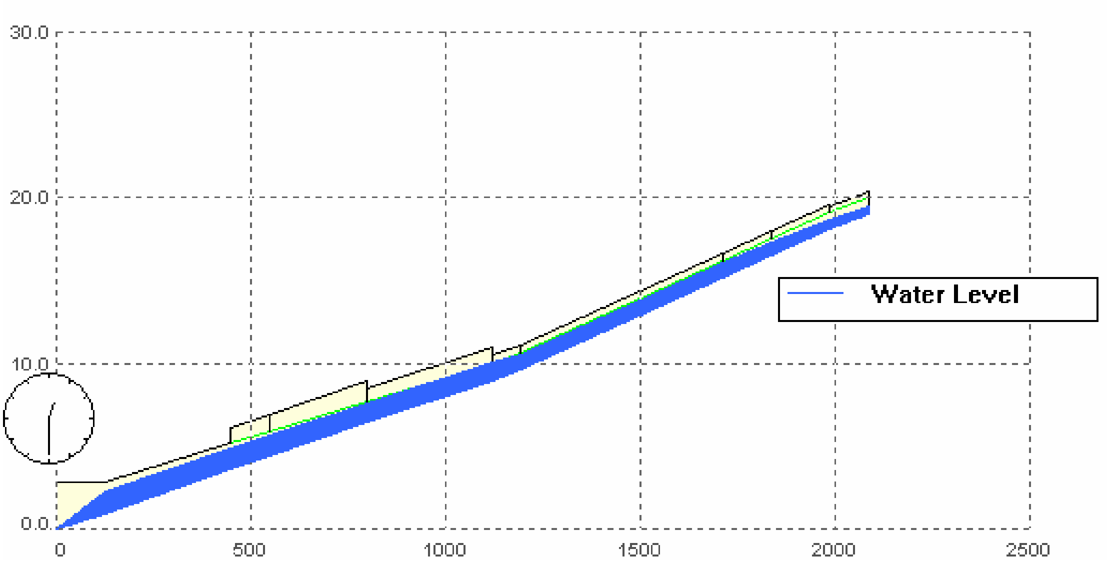


Figure 9.5 Maximum water level river 4

9.2 Land reclamation and decentralized outlets

In the previous paragraph the model of the current situation was presented, in the following paragraphs the models of the new situation with land reclamation will be presented. The current drainage system at the existing land will not be altered, but it will be extended for the new situation. In this way a system with decentralized extended outlets is obtained. In this paragraph these decentralized extended outlets will be treated.

9.2.1 Model

In the model the situation with land reclamation is now simulated; this means that the drainage canals have to be extended to the new shoreline, while they are not being centralized. In this case the current canals will remain of the same size and form. The extension of the drainage canals implies two things for the model. First, the new canals are supposed to have the same inclination as the current foreshore, thus for every 200 meter it will drop 1 meter. This has consequences for the ability of discharging during high tide. Second, the cross-profiles of the new canals have to be determined. A continuation of the old cross-profile, which is a concrete trench, or a trapezoidal form can be chosen. The latter has two advantages over the first, it offers more capacity for the detention of water and second the shores of a trapezoidal shaped canal can be used for ecological development. An advantage of the concrete trench is the limited use of space. On the newly reclaimed land, the trapezoidal form has been chosen; to avoid a bottleneck and improve the ecological function. The schematization of the new model is given in figure 9.6 and the cross-profile of the new canals is given in figure 9.7.

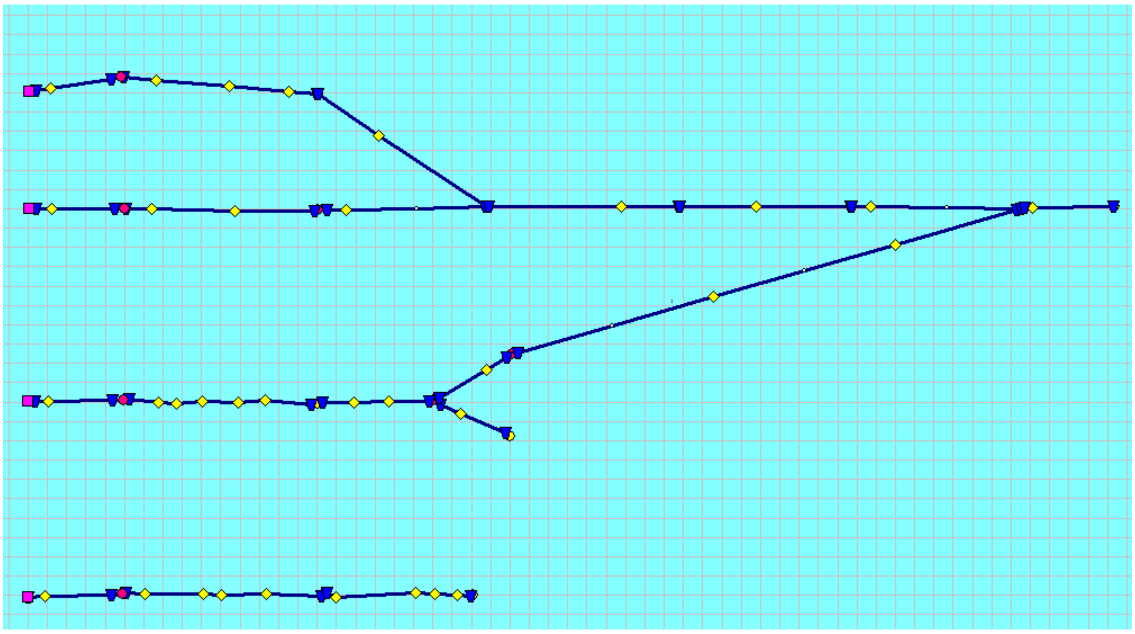


Figure 9.6 Land reclamation and decentralized outlets modeled in Sobek

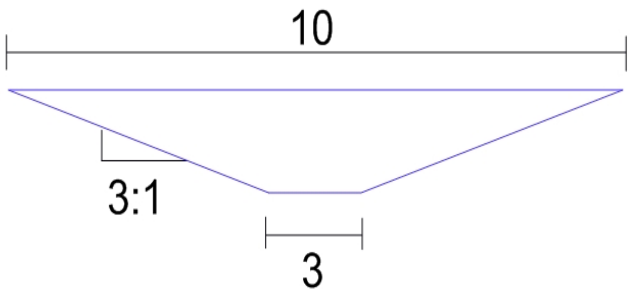


Figure 9.7 Cross profile new canals

9.2.2 Results

After extending the existing canals and by applying the new cross profile a change in the backwater-curve can be seen. In figure 9.8 the new maximum water levels of the fourth canal are shown. As can be seen in this figure there is no flooding in the newly reclaimed area, this is the stretch between 2100 and 2600 meter in **Error! Reference source not found.**. However due to the change in backwater-curve there is a flooding upstream. The maximum discharges and new maximum water levels for the situation where land reclamation and decentralized outlets are applied are shown in table 9.2. Note that there is a slightly increase of the discharges for every canal due to the land reclamation.

Table 9.2 Discharge and water level in decentralized situation

Canal	Q_{max} [m^3/s]	h_{max} [m]
1	27	1.28
2	21.5	1
3	29	1.75
4	19	3.35

For the other canals there is only a small change in the backwater curve and therefore a small increase of the water depth of the canal upstream. Therefore there will be no flooding upstream. There is also no flooding in the newly reclaimed area for the three other canals.

By not applying gates of any sort in the outlet canals, there is a low restriction on the outflow; during normal tide the rain-induced discharge can be handled for three of the canals. However during regular operation and high tide the sea water can enter the drainage canal and therefore it will create salt intrusion. The outlet has to be designed to withstand springtide conditions to protect to this salt intrusion.

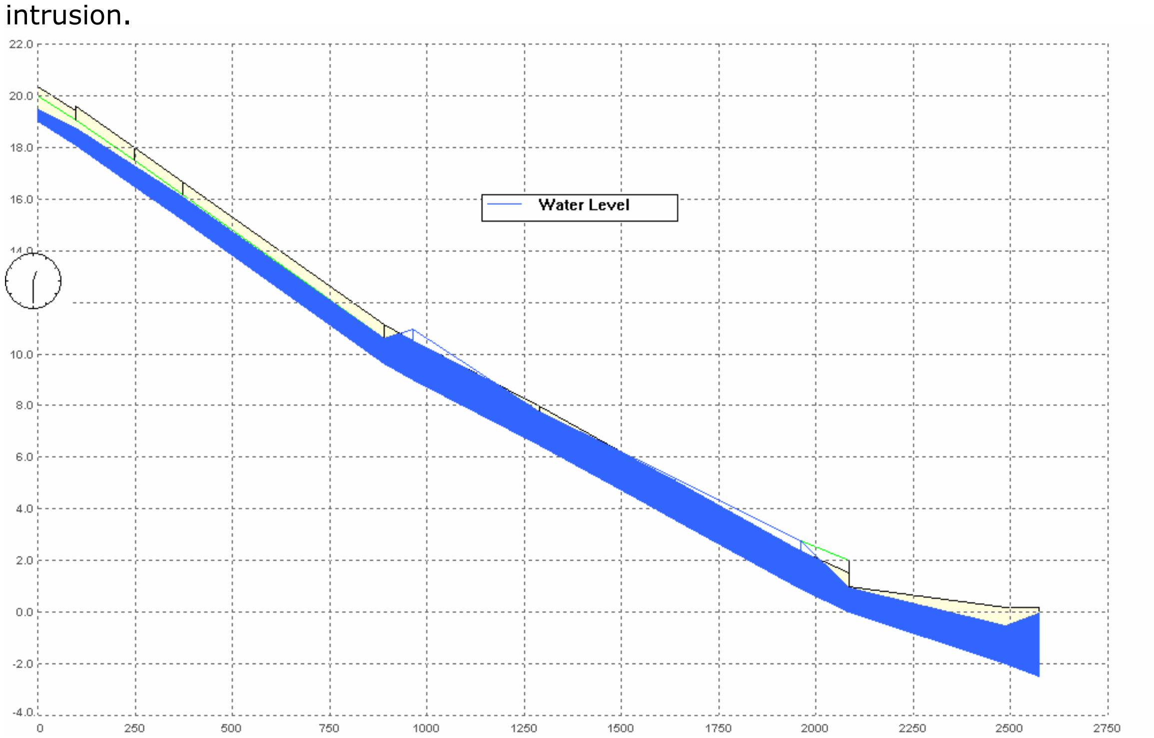


Figure 9.8 Flooding of the fourth canal

9.2.3 Conclusion

- Sufficient discharge capacity for rainfall from a 1:50 years typhoon with normal tide for the first three canals, the chosen profile offers enough space for retention, if embankments of the canals are higher than EL + 1 meter, but possible flooding with spring tide.
- Canal 4 will flood upstream, additional measures like widening of the new profile, increase of the upstream profile, retention or pumping has to be applied for this canal. No flooding is occurring in the newly reclaimed area.
- Outlets need a construction to prevent the sea water from penetrating the canals during high tide.
- The number of maintenance needed outlets is not reduced; the existing problems are shifted seawards.

9.3 Land reclamation and decentralized outlets with valves

To prevent the disadvantage of an open connection to the sea, one can apply a construction with valves in the outlet canal. The construction with valves prevents the sea water from entering the outlet canal. However there is also a disadvantage using this kind of structures; a bottleneck is created in the outlet canal, therefore the discharge can be hampered.

9.3.1 Model

The model is slightly adapted in comparison to the model described in . The differences are the use of nodes to model the structures with valves and a change in outlet canal dimension to create detention area. The cross-profile used for the drainage canal is given in figure 9.9. Note that there is a separate section for the flow and wide plains for the detention of water. This is a first estimation of the cross-profile.

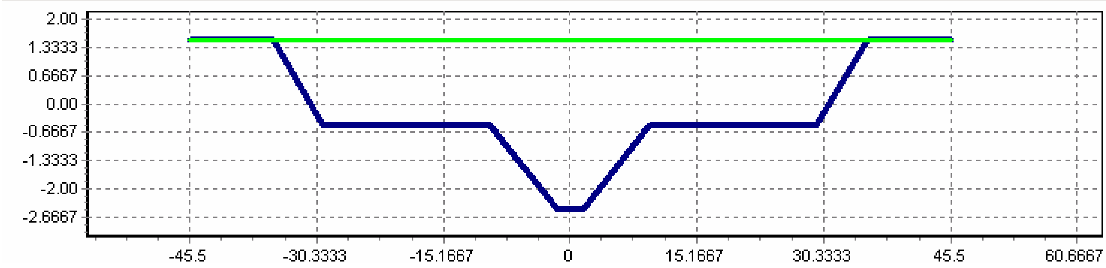


Figure 9.9 Cross-profile, note that horizontal and vertical scales are different

9.3.2 Results

A structure with valves will give a restriction to the outflow, thus forming a bottleneck. This induces an increase of the inside water level as can been seen in table 9.3, which causes flooding upstream in the third and the fourth canal. In figure 9.10 this flooding is shown for the third canal. The increase of the water level can be minimized in several ways: Increase of the detention area, enlarging the structure, enlarging the existing canal or the use of a pumping station.

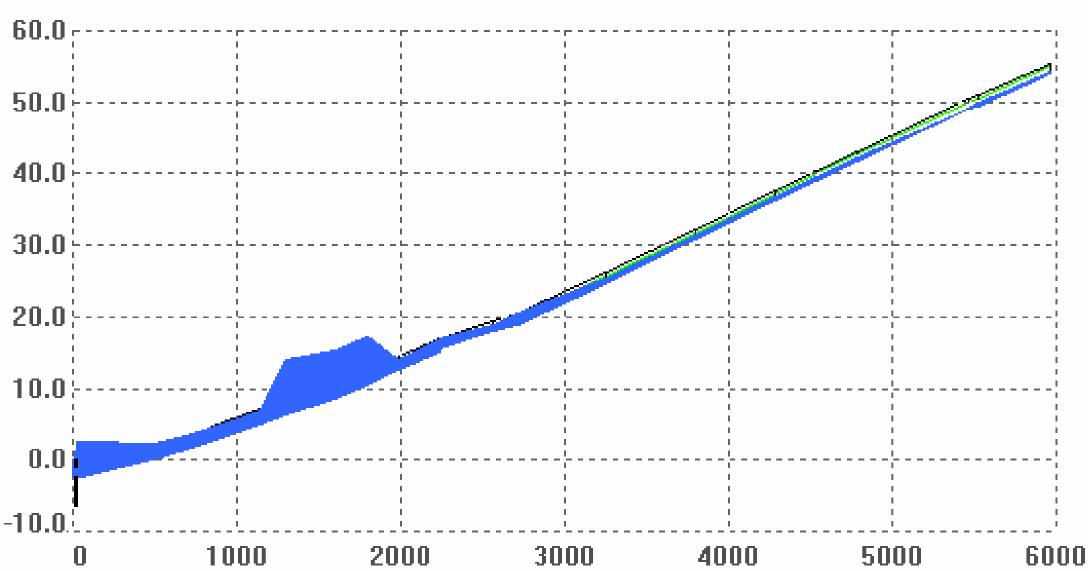


Figure 9.10 Flooding of the third canal

Table 9.3 Maximum discharges and water levels improved design outlets

Canal	Q_{max} [m^3/s]	h_{max} [m]
1	27	1.5
2	21.5	1.1
3	29	3.5
4	19	3.3

9.3.3 Conclusion

- A structure with a valve will form a restriction to the outflow and can therefore be the cause of flooding upstream. Therefore extra measures must be taken to guarantee a sufficient outflow of the canals or the storage of the excess water.
- The hinterland will be prevented from flooding from the seaside during springtide.

9.4 Land reclamation and centralized outlets

Instead of keeping the decentralized system of outlets, one can choose to centralize the outlets when land reclamation is applied. The inclination of the drainage canals is decreased, which implies that the needed cross-profile has to be increased. The coastal defense has to be interrupted at one place instead of four places to discharge the water of the canals. Furthermore there is only one outlet to the sea which has to be maintained, i.e. cleaning of debris and sediment from the sea and the regular maintenance. By increasing the standard discharge, i.e. combining the standard discharge of four smaller canals, the outlet can maintain itself better by flushing away the sediment and debris. However the outlet has to be enlarged to handle the discharge, which increases the needed investment.

9.4.1 Model

In comparison to the original model, the drainage canals are extended to one point. This implies longer canals then by using a decentralized layout and thus a smaller inclination. In this paragraph no structures with valves or culverts are applied, so there is still inflow from the sea in the reclaimed area during high tide of the sea. The layout of the centralized outlets is shown in figure 9.11. To compensate the smaller inclination of the canals a bigger cross-profile has been chosen. As it is with the decentralized layout, also for the centralized layout a choice can be made between various forms of cross-profiles, i.e. continuation of the concrete trench or applying a trapezoidal cross-profile. By applying a trapezoidal cross-profile the shores can be used for ecological development and can also form an ecological link, because all the drainage canals are coupled. The existing drainage canals are again not changed.

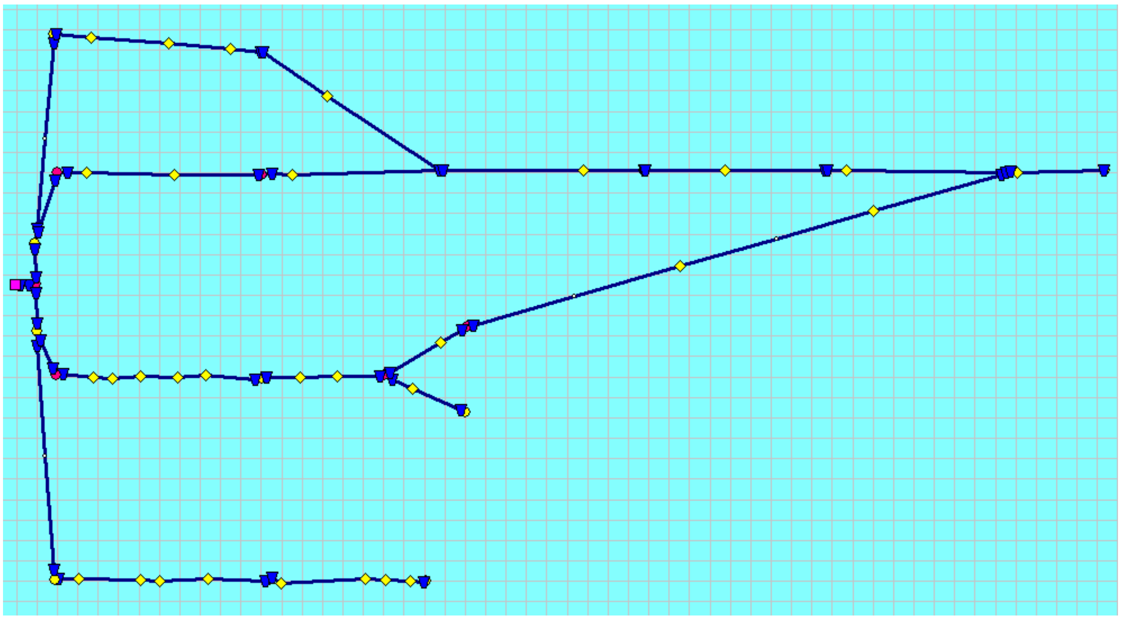


Figure 9.11 Land reclamation and centralized outlets modeled in Sobek

9.4.2 Results

In table 9.4 the results for this alternative are shown. Note that there is a significant increase of the cross profile. Due to the long canals the inclination has been reduced. The cross-profile has been adapted to maintain enough discharge capacity. Long canals and a big cross-profile are able to discharge the typhoon-induced rainfall, but are consuming also lots of space. In normal operation, the sea can enter through the outlet canal; its influence reaches approximately to the old place of the outlets. Therefore the salt intrusion can be considered rather large.

Table 9.4 Results with centralized outlets

Canal	Q_{max} [m^3/s]	h_{max} [m]	Profile [a,b]
1	27	1.34	20 by 5 meters
2	21.5	1	20 by 5 meters
3	29	1.76	20 by 5 meters
4	19	1.53	20 by 5 meters
Centralized	96	2.48	20 by 10 meters

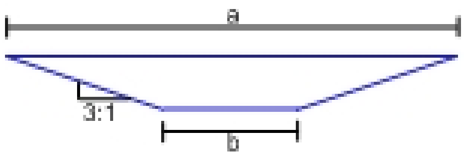


Figure 9.12 Cross profile new canals

9.4.3 Conclusion

- A larger cross-profile is needed to discharge the rainfall with a return rate of 50 years in comparison with the decentralized solution. This is due to the smaller inclination of the canals.
- There is a possibility of flooding of the reclaimed area if embankments are to low.
- The centralized outlet has to be much larger than the decentralized outlets.

- The locations where canals merge can form new bottlenecks and need attention during design.
- The number of outlets is reduced, thus decreasing the needed maintenance.
- Standard discharge is enlarged, increasing the capacity of self cleaning.

9.5 Land reclamation and centralized outlets with valves

To prevent the disadvantage of an open connection to the sea, one can apply a construction with valves to an outlet canal. The construction prevents the sea from entering the outlet canal. However there is also a disadvantage using this construction, the valve forms a bottleneck in the outlet canal and the discharge can be hampered.

9.5.1 Model

The model is slightly adapted in comparison of the model described in figure 9.11. The differences are the use of structures with valves and a change in the centralized outlet canal dimension to create some detention area. The cross-profile used for the drainage canal is given in figure 9.13; note that there is a separate section for the flow and wide plains for the detention of water. This is a first estimation for the cross-profile.

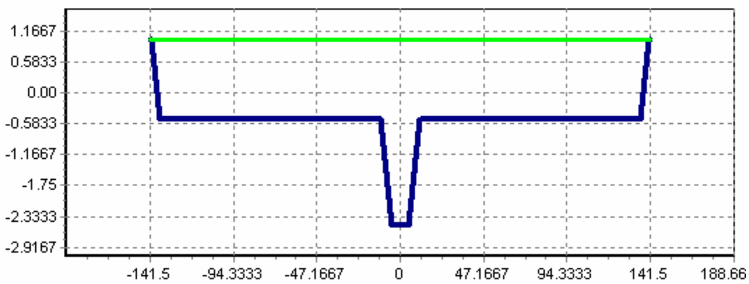


Figure 9.13 Cross section improved design centralized outlet, with detention areas

9.5.2 Results

In table 9.5 the results for this alternative are shown. As can be seen in this table there is a small increase of the water level due to the placed structures. This is only the case if the centralized outlet is changed into an outlet with retention area. In this situation there is no flooding in the whole area and the reclaimed area is also protected from the sea during spring tide of the sea.

Table 9.5 Results with centralized outlets fitted with a culvert

Canal	Q_{max} [m^3/s]	h_{max} [m]	Profile [a,b]
1	27	1.36	20 by 5 meters
2	21.5	1.1	20 by 5 meters
3	29	1.77	20 by 5 meters
4	19	1.57	20 by 5 meters
Centralized	96	2.48	See figure 9.13

9.5.3 Conclusion

- In comparison to the centralized alternative without a structure with valves a larger profile or a retention area is needed for the centralized outlet to provide sufficient discharge for rainfall with a return rate of 50 years.

- There is a possibility of flooding of the reclaimed area if embankments are to low or retention area is to small, but reclaimed area is protected against the influence of the sea.
- There is less salt intrusion compared to a solution without a structure with valves.
- The centralized outlet has to be much larger than the decentralized outlets.
- The locations where canals flow into each other can form new bottlenecks and need attention during design.
- The number of outlets is reduced, thus decreasing the needed maintenance.
- Standard discharge is enlarged, increasing the capacity of self cleaning.

9.6 Conclusion

Five alternatives have been discussed in the subparagraphs above, which can be divided into three different categories, "do nothing", decentralized and centralized. In the latter two, land reclamation is taken into account and in the "do nothing" category land reclamation is not taken into account. In comparison to the current situation or the "do nothing"-alternative the decentralized approach is the one with the least modifications, while the centralized approach needs more modifications and the most space for the canals. However when combining the standard discharges of the different canals, the centralized approach gives a higher standard discharge in the outlet, which has certain advantages like solving the problem of sedimentation and the debris which is washed ashore.

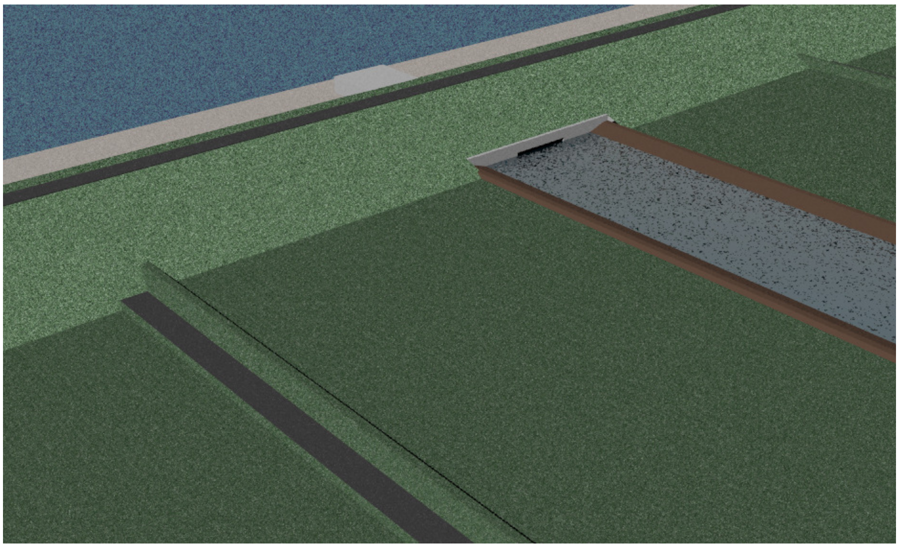


Figure 9.14 Possible layout for a centralized outlet

Another division between the alternatives can also be made, namely the division whether a culvert with a valve is placed in the coastal protection, or that the drainage system can discharge without a structure. Discharge without a structure means that there is no bottleneck i.e. there is no restriction of the outflow during typhoon-situation. However during normal operation the sea can enter the drainage canals, causing a rather large salt intrusion, i.e. making the water not suitable for irrigation purposes. Also the embankment of the drainage canals has to be adapted to the levels of springtide otherwise the whole reclaimed area will be intruded with salt water. If there is a structure with a valve used, there is a restriction to the outflow of the water, which causes a rise in the inside water-levels. To store the excess water, space has to be reserved for detention. The advantages of an outlet structure with valves are the better protection of the hinterland against sea induced flooding and the possibility to use the water in the canals as a source for irrigation.

Centralization compared with decentralization

Advantages

- Less maintenance is needed due to fewer constructions and a flushing effect

Disadvantages

- There are fewer outlets, but the outlets have to be larger
- Larger cross profile of the canals is needed due to smaller inclination

Structures with valves compared with the outlet without structures

Advantages

- No salt intrusion into the channel
- Lower embankment of the drainage channel is sufficient.
- Safer solution against sea induced flooding

Disadvantages

- Larger cross profile or retention is needed to guarantee the same discharge due to restricted outflow

Safety of the hinterland is important and salt intrusion is undesirable, so the choice is made for a structure with valves in the outlet. This structure does hamper the discharge, so that detention and embankments has to be designed for it, but the embankments do not have to withstand the springtide water-levels.

Maintenance of the structure with valves is an important issue; the drainage system depends on a working structure. To minimize the efforts of maintenance a centralized approach is chosen; fewer structures have to be maintained. The additional advantages of this combination are the possibility of using water in the drainage system for other purposes. Also the embankments can be developed in an ecological way and thus form a link between different ecological areas. In figure 9.14 a possible layout of the outlet is given, with a detention area on the landside of the outlet. The chosen solutions induce enlargement of the cross profile of the canals, but this does not balance the advantages; less maintenance and no salt intrusion.

Chapter 10 Drainage system design

When designing the new drainage system of the reclaimed area there are a few aspects to be designed, these can been seen in figure 10.1 and are listed below.

- Management of the detention areas
- Drainage of the reclaimed land
- Safety of the canal dike

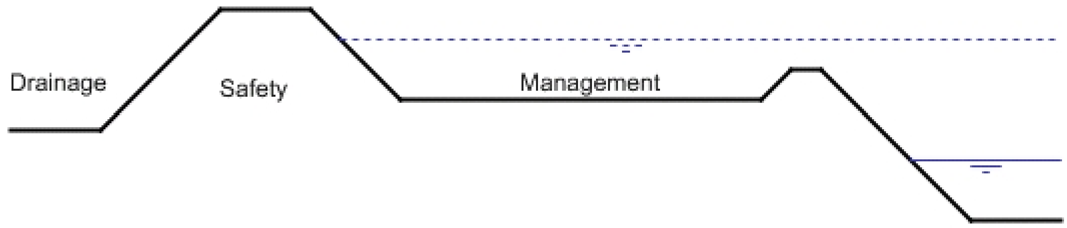


Figure 10.1 Design features of the drainage system

These aspects will be dealt with separately: First the management of the detention areas is dealt with. The detention areas can be used for other than detention purposes, like agricultural use, but the risk of flooding of these areas has to be diminished to an acceptable rate, which has consequences on the embankment and on the drainage of the detention area. This has to be done without endangering the safety of the hinterland. Second the drainage of the reclaimed land is dealt with. The problem with the new reclaimed land is that it is actually laying lower than the water levels in the drainage canals during typhoon situation, so pumping has to be applied; however during normal operation a free flow is possible. Third the protection of the reclaimed land against flooding of the canals will be treated.

10.1 Management of the detention areas

The amount of water that has to be discharged to the sea during the typhoon season is too large to pass the structure with valves. There has to be a head difference at the outlet structure, which implies the water level in the discharge canal has to be higher than the water level of the sea. To have enough discharge capacity, either the outlet structure must be very large or the embankments of the discharge canal have to be very high or both. During high tide the head difference becomes lower and therefore the discharge capacity will not be sufficient anymore.

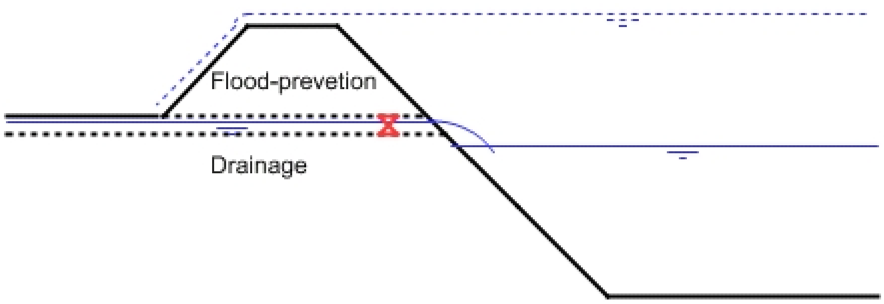


Figure 10.2 Elements to manage the detention areas

A solution to keep the embankments lower, the structure smaller and a sufficient discharge capacity is detention. In chapter 9 Sobek was used to determine the discharge and the water levels for several canal cross-sections and alternatives. The model showed that, in order to keep the water levels in the drainage canals below EL + 2.82 meter a detention area of 2.5 ha. is needed. This detention area can be used for other purposes, such like agricultural, but still there is an increased risk of rain-induced flooding of this area. The detention areas should not flood with every minor typhoon, so extra measures have to be taken to prevent flooding of the area during minor typhoons. If this area is used for other purposes, it also has to be drained. Figure 10.2 shows the different elements of the dike between the detention area and the canal.

10.1.1 Flood-prevention

As stated above the land has to be protected if it is going to be used for other purposes than detention. An embankment is needed to prevent flooding of the detention area during the periods were no heavy typhoons occur. To determine the height of the embankment the same model is used as in the previous chapter, but the rainfall is reduced from once in 50 years to once a year, i.e. reducing the one-day rainfall from 2000 millimeter to 600 millimeter. From the model it follows that an embankment with a height of EL + 2.32 meter is enough to provide safety against a once in a year flooding.

10.1.2 Inlet into detention area

When a precipitation with a larger return rate than one year strikes the area, the water level in the outlet rises above this embankment. When this happens water will rush over the crest of the dike with the critical velocity, i.e. the velocity where the Froude-number equals one, which is in this case 1.8 meter per second, assuming that the maximum water level in the canal is 0.5 meter higher than the crest of the dike and the overflow is not yet drowned. This velocity is calculated in Appendix H. A schematization of the overflow structure is shown in figure 10.3. After passing the crest the speed will reach super-critical velocities, which can cause damage to the land directly behind the embankment. There are two possible alternatives to solve this problem, these are designing the whole embankment on the high flow velocities or designing a special structure and centralize the overflowing water.

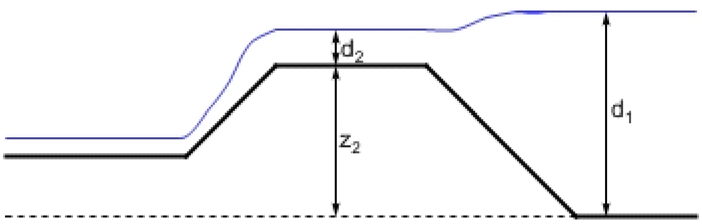


Figure 10.3 An overflow-structure

The first alternative is designing the whole embankment on the maximum flow that can exist on the crest. This means that along the whole stretch of the detention area the embankment measures have to be taken to resist to the forces of the water. Also the area behind the embankment has to be protected from scour due to the high super critical velocities. This can be done by applying a stilling basin behind the embankment with baffle blocks to dissipate the energy of the water. The stilling basin can be used as road during normal operation of the drainage system. The baffle blocks are then formed by concrete elements on the side of the road. An elaboration of this alternative can be seen in figure 10.4.

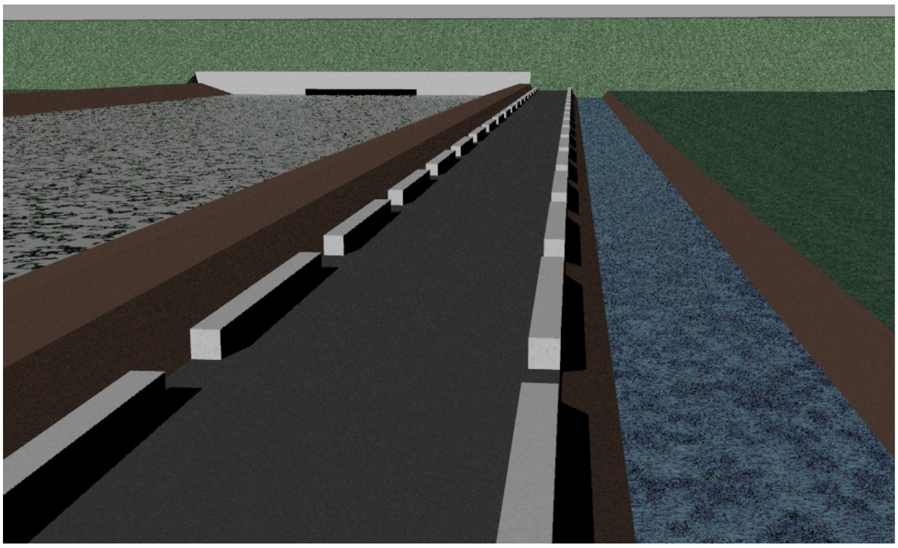


Figure 10.4 Embankment as overflow structure and the road behind it as stilling basin

The second alternative is designing a particular piece of the dike as an overflow structure, a so called lateral spillway. The problems of high currents and the scour due to those currents are limited to predefined places. The capacity of an overflow structure is high enough to provide enough discharge from the outlet canal to the detention areas. There are two overflow structures of twelve meters needed on each site of the canal to ensure sufficient discharge into the detention area during the heavy rainfall. By concentrating the overflow to determined places, also the problems of the overflow structure are concentrated. The same amount of water will have to cross a smaller opening, thus increasing the velocity, but it means lower velocities at the other stretches of the embankment, increasing the ability of ecological development. By discharging water from the canal to the detention areas with an alongside overflow structure the water level in the canal will rise, this due to reducing the flow velocity in the canal. This can be seen in figure 10.5: $d_2 > d_0$.

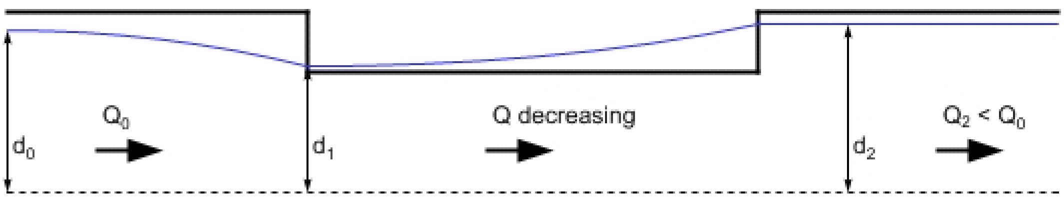


Figure 10.5 Water level near a lateral spillway

Because the flow into the detention area is centralized the currents in the detention area will be also centralized and therefore be stronger. To prevent damage due to these stronger currents the water can be distributed over the area with canals, for instance with the drainage canals which already have to be present to dewater the area. By combining the distribution and drainage of water in the detention area, a reduction in cost can be achieved, due to the reduction in required work and an increase in usable area, i.e. area not used for infrastructure like drainage and distribution canals. In this alternative the remaining part of the dike needs to be high enough to prevent overflow. An impression of this solution is given in figure 10.6.

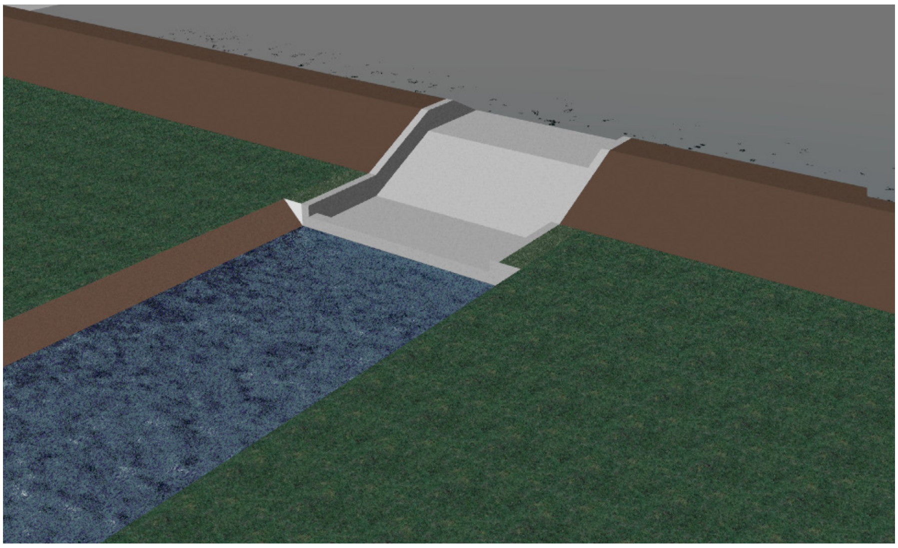


Figure 10.6 Overflow structure with stilling basin and distribution canal

There has to be one lateral spillway on each side of the canal at the beginning of the detention area and one at the end of the detention area. There is one at the beginning of the detention area because this is the most effective place for the inflow; due to the backwater curve the water levels in the supplying canals will be lowered. There is one at the end of the detention area so the complete reclaimed area can be drained if the structures are combined and there is a better distribution of the water in the detention area. Furthermore the outlet structure will be safe in this way because if the water will be too high in front of the outlet structure the water will flow into the detention area.

10.1.3 Drainage

The land has to be drained if the area is not used for detention. To minimize the efforts of draining the area, the drainage should be completely natural. Therefore a construction is needed to allow the water to pass the embankment, but this construction should also provide safety against flooding of the detention area during a less then once in a year rainfall.

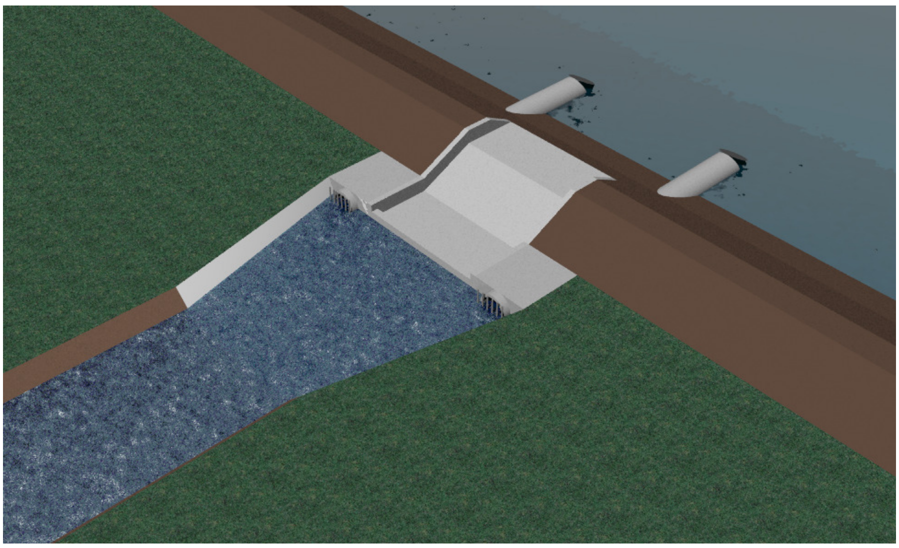


Figure 10.7 Combined overflow structure with outlet to the main discharge canal

As stated above, the drainage canals can be used for distributing the water over the detention area if it is needed. The outlet structure can be combined with the inlet structure; for example by integrating the culverts on the sides of the overflow structure, as can be seen in figure 10.7. Clogging up of the outlets has to be prevented. This can be done by using a fence which has to be cleaned regularly.

To prevent water from flowing into the drainage system while detention is not yet needed a valve will be used. If the valve is too heavy, the water cannot push the valve completely open and thus the flow is restricted. This can be solved by placing a counterweight at the valve or by a mechanical solution, i.e. electrical or hydraulic actuators. By placing electrical or hydraulic actuators, there is an increased need of maintenance, complexity and risk of failure.

10.1.4 Conclusion

Flood prevention

- There has to be an embankment of the canal with a height of 2.32 meter above EL to protect the detention area against a water level in the canal with a return rate of 1 year.

Inlet into detention area

- By centralizing the inlets into the detention area the problems of high currents are limited to predefined places. Therefore only these places have to be protected.
- A centralized inlet for the detention-area will give higher but still acceptable water velocities in the detention area. The drainage system of the detention area can be used for the distribution of the water; the higher velocities are again limited to predefined places.

Drainage

- An outlet structure is needed to drain the area if it is not used for detention. This can be combined with the inlet structure.
- To prevent water from flowing into the drainage system while detention is not yet needed a valve will be used.
- The valve can be a restriction to the outflow of the drainage system. To ensure sufficient discharge a counterweight is needed for the valves or a mechanical solution.

10.2 Drainage of the reclaimed land

As stated in the introduction of this paragraph, the problem of the reclaimed land is that it is actually lower then the water level in the drainage canal during typhoon level, actually on some places the land lies below mean sea level. To solve this problem the typhoon situation and normal operation has to be looked at as is showed in figure 10.8.

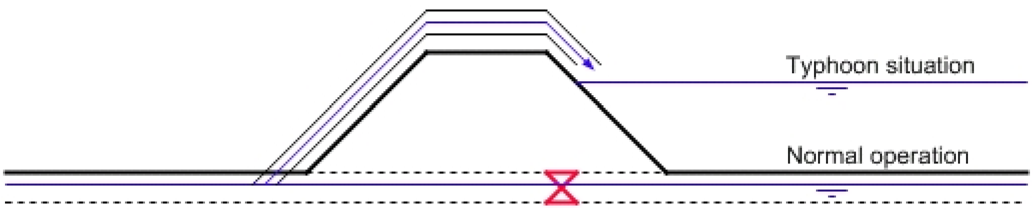


Figure 10.8 Two situations for the drainage system

10.2.1 Typhoon situation

During typhoons the water level in the outlet canal can reach 2.82 meter above EL. The reclaimed area is laying much lower, i.e. EL + 1 meter. This area needs to be drained, also during a rainfall with a return rate of 50 years.

In the **Error! Reference source not found.** and **Error! Reference source not found.** in the previous chapter the discharges due to a rainfall with a return rate of 50 years for a paved and an unpaved area are shown. The reclaimed area is 125 hectares but is divided into two parts by the outlet canal. Therefore two areas of 62.5 hectares need to be drained. These areas can be drained in one or two directions. So the maximum discharges of the drain have to be calculated from a 50-year rainfall for an area of 62.5 respectively 31.25 hectares. This gives a maximum discharge of respectively 12 and 6 m^3/s.

To overcome the head difference over the dike different pumps can be used. Before selecting a pump, there has to be looked at the type of pump that can be used and the number of pumps that is optimal to be installed. There are several types of pumps that can be installed; a screw pump or a centrifugal pump. The selected pump can be driven either by an electrical engine or a combustion engine. To minimize the costs and the effort of maintenance a minimum of pumps needs to be installed, which is in this case one pump station on each side of the channel with a capacity of 12 cubic meters per second.

During a typhoon there is an increased possibility of electrical power failure, this due to the method of energy supply. This is done by wiring above the ground, which can be easily broken by the forces of the typhoon. Therefore the risk of failure for an electrical installation is very high. So there had to be a back-up installation in the form of a combustion engine or a generator. It is better to keep the pumping system as simple as possible, so connecting a combustion engine directly to the pump is preferred.

10.2.2 Normal situation

During the normal situation the water levels in the main drainage canal can be lower than the reclaimed land. In this situation natural drainage is possible. A non-mechanical solution saves operational and maintenance costs. Between the reclaimed area and the main drainage canals are the detention areas. The water has to cross these areas before it can be discharged on the main channel.

Where natural drainage is possible a culvert should be constructed underneath the embankment. This culvert has to be equipped with valves to prevent water flowing back to the reclaimed area. As stated in the paragraphs above there is always the need for artificial drainage, i.e. with pumps. The two systems, i.e. the artificial drainage and the natural drainage system, can be combined in one structure, where they act as a parallel system. This is the technically least advanced option, which decreases the possibility of failure and the maintenance required.

There are solutions possible where valves are combined with pumps in one construction. If the valve is closed, the build-in pump can discharge the water. When natural discharge is possible the valve will be opened. Because the pump is integrated in the valve, the weight of the valve itself will increase. Due to the weight it is not likely the valve can be opened by the force of the water, thus the valve must be moved by means of electric or hydraulic actuators. This implies an increase of maintenance.

10.2.3 Conclusion

- During typhoon situation artificial drainage is needed for the reclaimed area
- During normal operation natural drainage is possible
- To decrease operational costs and maintenance the natural and the artificial drainage systems can be combined. This implies that the construction has more valves.

10.3 Safety

The reclaimed area has to be safe not only against sea-induced flooding, but it also has to be protected from the water in the detention areas. The maximum water level is 2.82 meter above the reference level (EL) if a once in the fifty year typhoon hits the area. Due to the size of the detention area, which has a total width of 250 meter, the significant wave-height becomes 0.65 meter. See also Appendix I paragraph I.1. The waves will cause a wave run-up of 1.39 meter, as is calculated in Appendix I paragraph I.2. Besides the wave run-up there is a wind setup of 0.05 meter calculated with Cress. All these factors contribute to the needed crest level of the dike and are shown in figure 10.9.

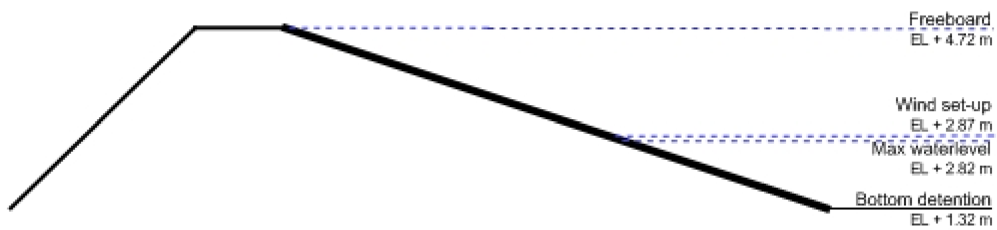


Figure 10.9 Calculation crest level dike

10.3.1 Improvements

When the application of detention areas is chosen for a significant amount of space will be needed for this purpose. To ensure safety of the area, i.e. the hinterland and the reclaimed area, there is a detention area needed of 2.5 hectare. Besides the space that is needed for the detention area, there is another disadvantage of a rather big water surface on the landside of the coastal protection. Due to the high wind velocities during typhoons, the water will be set up by the forces of the wind. Due to the large fetch and high wind velocities the waves become larger which haves a rather big influence of the needed crest level of the dike.

The profile of the detention area can be optimized in several ways, which are

- Deepening the detention area
- Optimizing the shape of the detention area
- Protection of the dike against the wave attack
- Increasing the roughness of the slopes of the dike
- Changing the shape of the embankment

Deepening of the retention area leads to a smaller detention area, while the storing capacity will be the same as one with a bigger surface. Reducing the surface area reduces the effective fetch length, thus reducing the wave height, but increasing the depth of the detention area is cause of higher waves so the net effect will be negative. A positive effect is that by deepening the detention area, soil will become available for other purposes, like the construction of the dikes. This makes it possible to make the construction of the retention area cheaper.

By optimizing the shape of the detention area the fetch length can also be reduced. The first estimation of the shape of the area was a length of 100 meter and a width of 250 meter. This results in a effective fetch length of 250 meter. If the shape is altered into a square with a length of 158 * 158 meters, the surface area remains the same. The effective fetch length is now reduced from 250 meter to 158 meter. However reducing the fetch length does have not a large effect on the occurring significant wave height. The wave height is only reduced with several centimeters, and also the wind set-up is only reduced with a few centimeters.

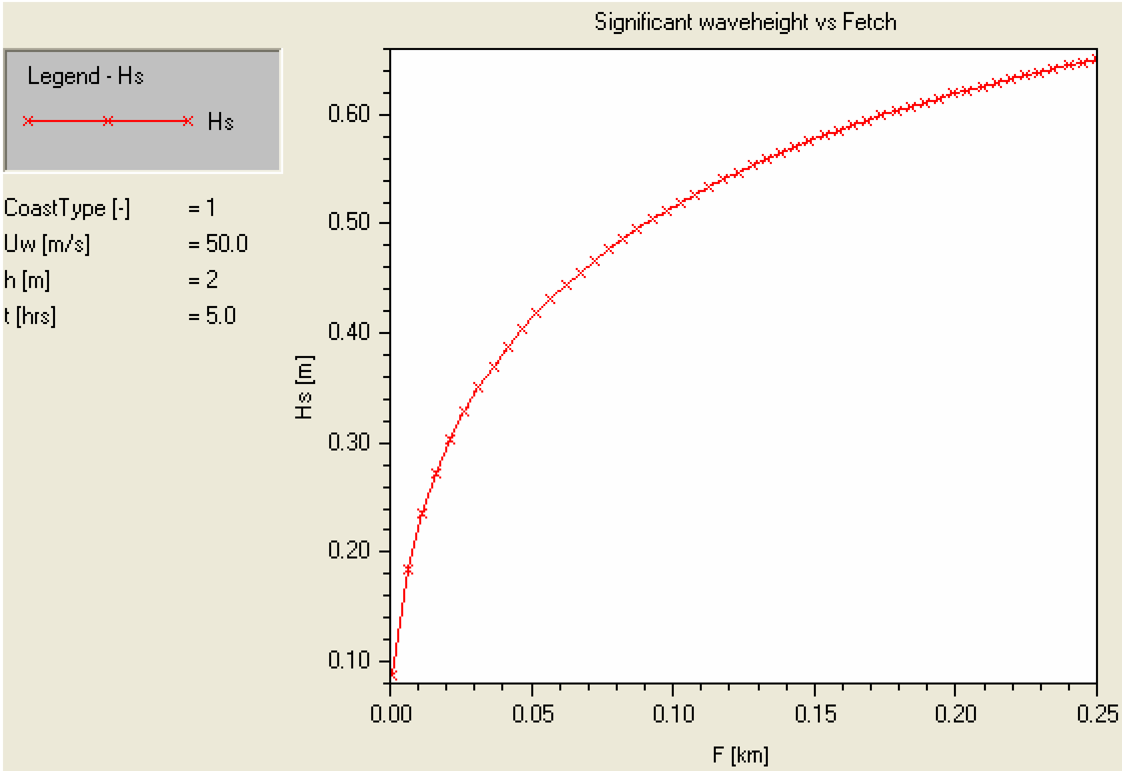


Figure 10.10 Wave height versus the fetch length

If the lower embankment, i.e. the embankment that is next to the canal, is heightened to the same level as the maximum water level in the canal, the fetch length is reduced with fifty percent. In this way a sort of compartment within the detention area is created. So the waves cannot develop on the whole length of the detention area. However reducing the fetch-length with fifty percent reduces the significant wave height only with 12 centimeters to a height of 0.53 meter as can be seen in figure 10.10. To effectively reduce the wave height the fetch length has to be reduced very strong, which is not feasible.

If the embankments are better protected against the wave attack, the wave run-up can be reduced. This results in lower crest-levels of the dikes. By using ecological development in front of the dike, the waves can be broken. By applying environmental friendly embankments the wave run-up can be reduced, for example trees in front of the dike can reduce the forces of the waves. The vegetation can stand temporal flooding and if damage occurs it will be self sustainable to a certain extent. However in the first few years the shore has to be protected against the water because the vegetation is not fully grown yet and damage is likely to occur. This temporal protection can be achieved by applying a construction like an extra revetment which makes this solution more expensive. The wave reduction due to the vegetation is difficult to determine and therefore there is given no quantification.

The wave run-up can be reduced with a factor 0.6 if the dike consists of rubble mount and with a factor 0.9 if smooth slopes or stones are placed. By reducing the run-up again the crest height can be lower. Disadvantage is that the required materials are more expensive

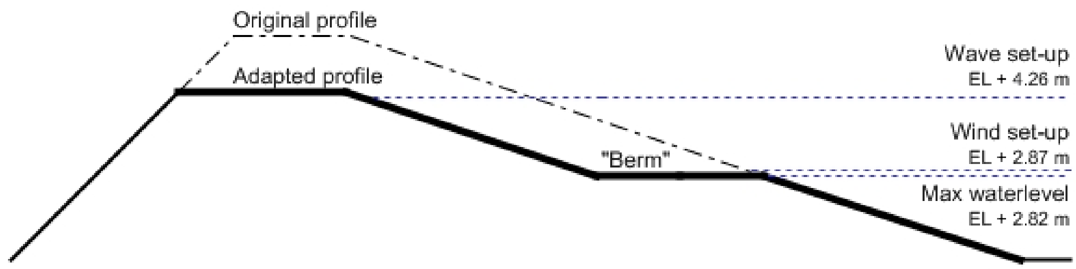


Figure 10.11 Adapted profile with a "berm" to reduce wave run-up

By changing the shape of the dike the wave run-up can be reduced. If a "berm" is used this can reduce the wave run-up, see also figure 10.11. In this way the height of the embankment can be reduced and there is possibility to reduce the amount of the soil that is needed for the embankment. The impact on the surroundings is reduced by this method, i.e. by lowering the embankment the barrier between the reclaimed area and the detention area is reduced.

In table 10.1 the resulting crest height and the surface of the cross section for each improvement are shown.

Table 10.1 Resulting crest heights for different improvements[14]

Improvement	Wind set-up	Wave run-up	Free-board	Crest height	Cross section
Conventional dike	0.05 m	1.35 m	1.39 m	EL + 4.72 m	46 m2
Optimization area shape	0.02 m	1.22 m	1.22 m	EL + 4.59 m	42 m2
Roughness factor = 0.6	0.05 m	0.81 m	0.83 m	EL + 4.20 m	34 m2
Shape change	0.05 m	0.89 m	0.86 m	EL + 4.26 m	38 m2
Area shape / shape change	0.02 m	0.74 m	0.70 m	EL + 4.09 m	34 m2
Roughness factor / shape change	0.05 m	0.52 m	0.53 m	EL + 3.91 m	31 m2
Accumulated	0.02 m	0.45 m	0.42 m	EL + 3.79 m	29 m2

10.3.2 Conclusion

- To protect the reclaimed area against flooding of the detention area a conventional dike with a crest height of EL + 4.72 meter is needed.
- Deepening of the detention area gives only a small decrease of the crest height.
- The following improvements will decrease the crest height and the cross section surface: optimization of shape of detention area, protection of the dike, using revetment with a high roughness and the application of a "berm". The effects of these improvements are shown in .
- Using the dike with the "berm" will decrease the crest height and the cross section surface while there are no extra costs. Because there is

[14] A settlement of 0.05 meter is taken into account for the calculation of the construction crest height

chosen for a centralized outlet into the detention is it is a small effort to reduce the fetch-length by optimizing the shape of the detention area. These improvements bring a new crest height of EL + 4.09 meter.

- Applying revetment with a higher roughness decreases the crest height but will induce extra costs. If all the improvements are applied the resulting crest height is EL + 3.79 meter. If vegetation is used at the foreshore the wave height will decrease even more and the dike will get a higher ecological value.

10.4 Conclusion drainage system design

The choice for detention area is implies a rather big water area within the coastal defense. This area is sensitive for the forces of the wind, i.e. waves will develop with a height of maximum 0.65 meter. In the first, original design, there would be a crest height of 4.78 meter above EL and a cross section surface of 46 m^2. To decrease the wave run-up on the dike a so-called "berm" can be used. Furthermore the fetch and therefore the wave height can be reduced by optimizing the area. This will give a crest height of 4.09 meter above the EL and a surface cross area of 34 m^2 while it does not induce extra costs. To reduce the wave run-up even further, a choice can be made to apply ecological developments in front of the dike or applying a rough armor layer to the dike. Both measures reduce the crest height and the surface cross area as shown in .

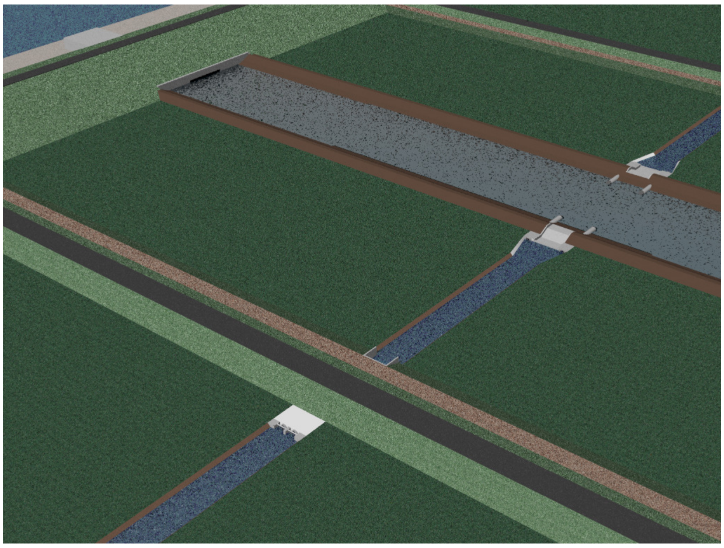


Figure 10.12 Impression of the detention area, the embankments and the drainage canal

The land that is used as detention area can be used for agricultural or ecological purposes, although there is an increased risk of a minor to severe flooding every few years. To prevent these areas from flooding there will be a lower embankment with a height of 2.82 meter above EL and on centralized places an overflow with a height of 2.32 meter above EL. These overflows are centralized to reduce the stretch of the dike which has to be protected. The water from the overflows is transported into the detention area by the same canals which are used for drainage of the reclamation area. The high currents from the overflow are limited to predefined places and no extra canals are needed.

By using valves there is no need for pumps to drain the detention areas, but there are pumps needed for the reclamation area. In figure 10.12 an impression of the detention area is given.

Chapter 11 Outlet structure

The purpose of the outlet structures is twofold. First it has to discharge the water from the land. Second the structure has to protect the same area from flooding of the sea. So serving these purposes the outlet structure has to be equipped with valves. These valves will always hamper the discharge of the drainage system more or less. This restriction to the discharge has to be small enough to be able to discharge the large amounts of water during typhoon. The structure must also be able to deal with debris which comes either from the drainage system or from the sea. This debris may not block the outlet or prevent the gate from closing if necessary.

11.1 Gate-type

At this moment there are some valve-types in use, these are the commonly known flap-gates. Besides the flap-gates other types of gates will be discussed. The types of gates are listed below:

- Flap-gates
- Flap-gates with counterweight
- Balanced gate
- Computer controlled gate

11.1.1 Flap-gates

This design is already being used in the area and consisted out of a plate of metal with a rubber seal which can be pushed open by the water if the pressure inside the culvert is higher then the pressure outside. To push the valve open there is a rather large head difference needed to provide enough torque to lift the gate. However during low discharge there is not enough water pressure to open the flap-gate and therefore the discharge is hampered. The layout of the flap gate and a schematization of the forces working on it can be seen in figure 11.1.

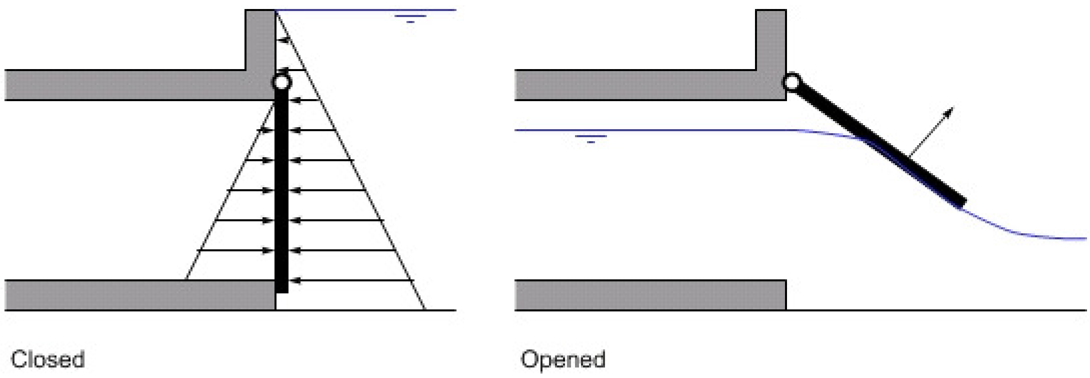


Figure 11.1 A flap-gate in closed and opened position

Due to the force that is needed to push the valve open, the drainage will be hampered during low discharge. In the current situation this causes problems. A site survey showed local people have forced the gates open with stones or wood. This can be seen in figure 11.2. By forcing the gates open there is an increased risk that the area will be flooded from the sea. The gates are not able to close in time and it is doubtful if anyone will close the gates manually. Another problem with flap-gates is that they will not open when there is debris in front of the gate, as can be seen in figure 11.2. If this debris is not cleared on a regular basis, the drainage system will fail and the area will inundate during a typhoon situation.

Figure 11.2 An outlet forced open with a stone (left) and completely clogged up with debris (right)

11.1.2 Flap-gates with counterweight

The flap-gate can be improved by applying a counter-weight, see figure 11.3, so the head difference that is needed to open the gate is reduced. By applying a counterweight the force and therefore the head difference that is needed to open the gate can be reduced to zero. The whole gate is acting like a balance, it is in equilibrium.

The most optimal solution is not the equilibrium but when the gate itself is heavier than the counterweight. First the gate has to be closed when the head difference decreases, even if the gate is completely submerged, because the gate will be subject to uplifting buoyancy forces. Second, during a wave attack the valve is not allowed to open and close all the time because damage is likely to occur then. To prevent the opening and closing from waves the gate must have a certain higher weight than the counterweight.

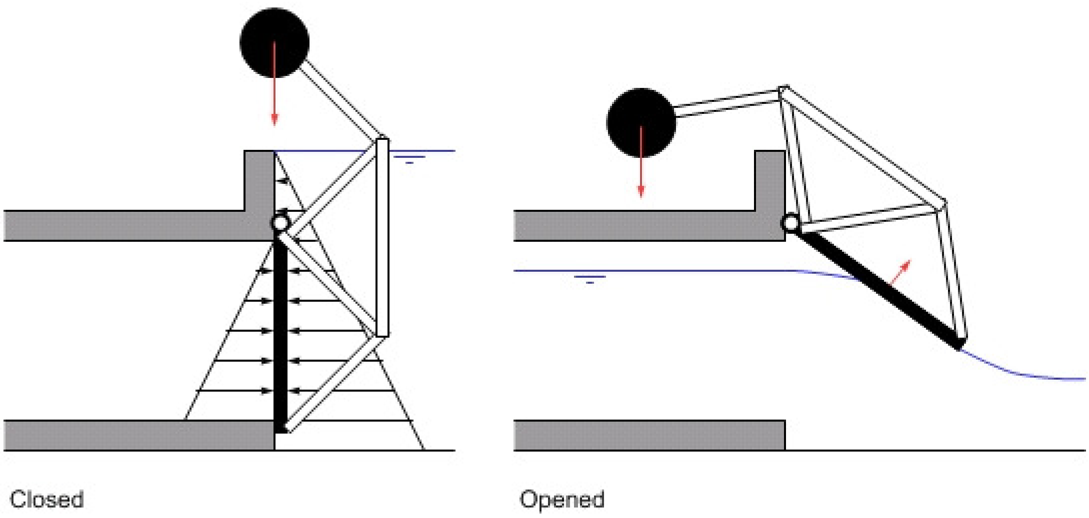


Figure 11.3 Flap gate, improved design, in closed and opened position

This alternative solves some of the disadvantages of the normal flap-gate. Due to the counterweight a smaller force is needed to open the gate. Therefore it is possible to discharge when there is a smaller head difference and the discharge will be less hampered. This removes the need of primitive measures to force the gates open and therefore the risk of flooding from the sea will be reduced.

The problem with debris is not solved when this solution is applied; however since the gate does not restrict the smaller discharges, some of the debris and sediment is flushed away, but the outlet can still clogged up by debris. Regular maintenance is still needed but can be reduced by applying fencing in front of the gate. The construction of the gate, i.e. the frame with the counter-weight has to be designed to withstand the impact of debris during is a high water table of the sea.

11.1.3 Balanced gate

The balanced gate is not a flap-gate like the previous alternatives, but a sector-gate which is operated with a counter-weight and a floating body on one side and the gate itself and another floating body on the other side. This can be seen in figure 11.4. By modifying the angle of the counterweight and the size of the floating bodies, the opening point and the closing point of the gate can be determined. The gate it self has to be protected from debris, because it can distort the balance between the elements. Therefore fences have to be applied on both sides.

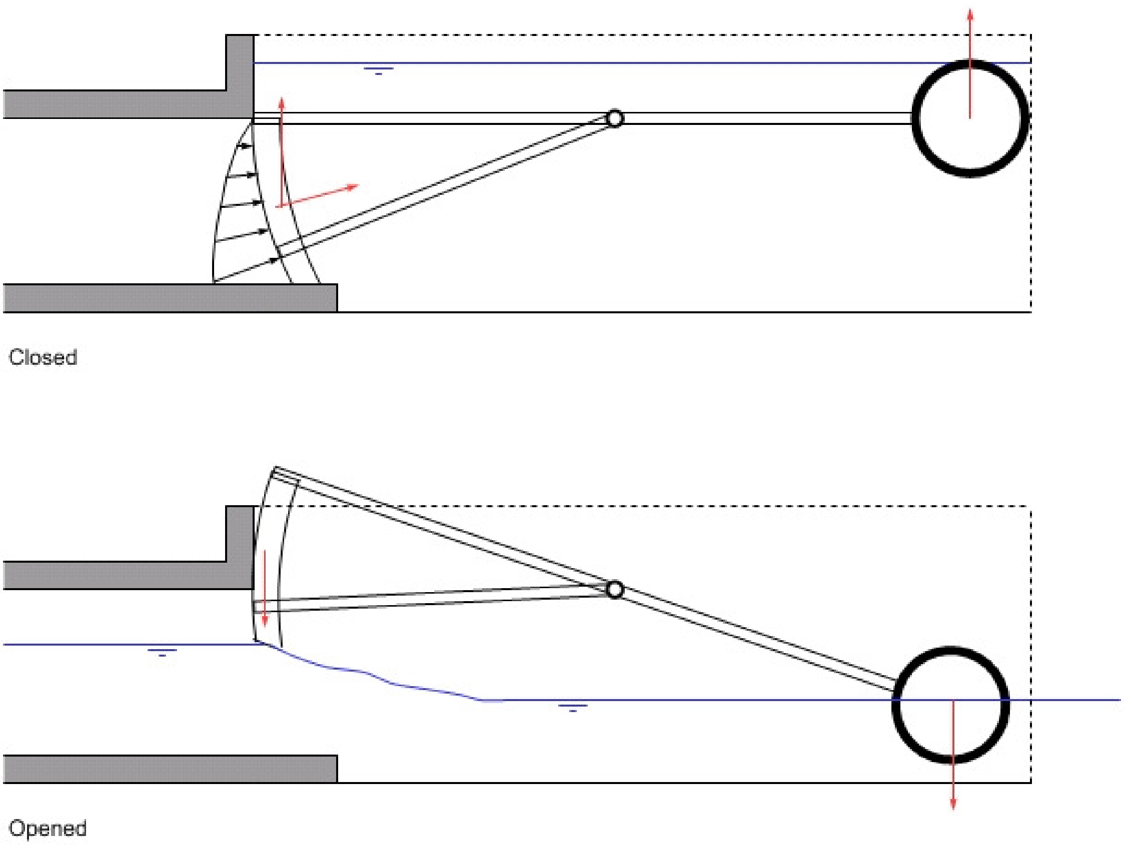


Figure 11.4 Balanced gate, in closed and opened position

This solution solves the problems the flap-gate has. By pivoting around another point, the gate is not sensitive to debris in front of the gate. However the balance itself has to be protected from the debris, because this will distort the equilibrium and thus prevent the gate from opening. The gate won't hamper low discharges if it is low tide because it can be tuned to open when this water level occurs.

This gate has however also some drawbacks. It is relying on equilibrium, if this equilibrium is distorted the gate is most likely not going to function properly, this means that the construction has to be protected from influences of the outside, i.e. debris or people altering the balance. To keep the gate working with the varying water levels on the outside is a complex structure is needed consisting out of floaters, pivots and bypass channels. All these elements are making this design complex and will also increase the risk that it will not work when it is necessary.

11.1.4 Computer controlled gate

A computer controlled gate is a sector-gate or a slide-gate which is opened by either an electric or a hydraulic actuator. This actuator is controlled by a computer. This computer decides depending on the water levels and the forecast of the water-levels whether the gates should be opened and how much they will be opened. The gates itself have to be protected from the debris, but the sector-gate and the slide-gate type are not likely to be jammed by the debris. By using a computer controlled gate, a discharge regime can be created. Water can be stored and used for other purposes, for example to flush the debris and sediment away from the outlet. By applying this type of gate problems with debris are not expected. The gates are controlled, so they can be lifted to the ideal height.

Using a computer controlled gate solves the problems of the debris and the small discharges, but also has certain drawbacks. During typhoons problems concerning the power supply are expected, so this solution needs a back-up facility like a generator. The actuators, the control mechanism and all facilities needed are making this solution very complex and expensive. To keep the gate working, regular maintenance is required, which consist not only on maintaining the moving parts, but also tuning the computer system if necessary. This maintenance is more difficult than regular maintenance on gates and therefore it will be more expensive.

11.1.5 Conclusion

- In the current situation flap-gates do not function properly due to clogging up by debris and hampering the discharge if there is a low head difference. If flap-gates are applied in the new situation these problems will continue to exist and maintenance or cleaning of the outlets is necessary.
- A flap-gate with a counter weight will give no restrictions to the water outflow. But the construction still has to be protected against the debris. This can be done by fences. The debris in front o the fencing can be flushed away by the standard discharge or has to be cleaned. The solution solves some of the problems of the standard flap-gates while the maintenance efforts won’t increase.
- The balanced gate is a very complex solution, which depends for proper function on floating counterweights and a way to determine the head difference over the construction. The complete structure has to be protected from debris, because it can distort the equilibrium, so fencing is needed. One of the advantages is that it does not hamper the flow of the standard discharge, but despite this advantage it has large disadvantages like complexity and increased maintenance efforts.

- The computer controlled gate is the most advanced option, but not the most complex one. It requires a rather large investment on the structure and the system. It also needs specialized maintenance on the controlling system and the hydraulic or electric actuators. This gate offers the opportunity to retain water in the drainage system that can be used for other purposes like irrigation and flushing.

The improved design of the flap-gates is the most suitable solution in this situation. It is a simple solution which can solve some of the problems that exist in the area. The other solution can be seen as either not working or too complex and expensive. The design of the improved flap-gate will be further elaborated in the next section.

11.2 Design

The gate consist out of several elements that have to be designed, these elements are the actual flap-gate, the counterweight and the accompanying structures like a fence for debris. The dimension of the gate have to be determined first, from these dimensions the weight of the gate follows and the needed counterweight can be determined. If all main dimensions of the gate are determined, the accompanying structures can be designed.

11.2.1 Gate

The gate has to be designed in an ultimate limit state, which is in this case when there is springtide and a wave attack on the sea side from the gate while the drainage system is empty. The gate is then loaded with the unfavorable load of the hydrostatic pressure and wave pressure on one side and no supporting loads on the other sides. In this way the needed number and strength of supporting beams can be determined. The gate is placed under an angle of 30 degrees; this makes it easier for the water to push the gate open, but increases the length of the gate from 2.5 meters to 3 meters. The total dimensions of one gate are a height of 3 meter and a width of 5 meter.

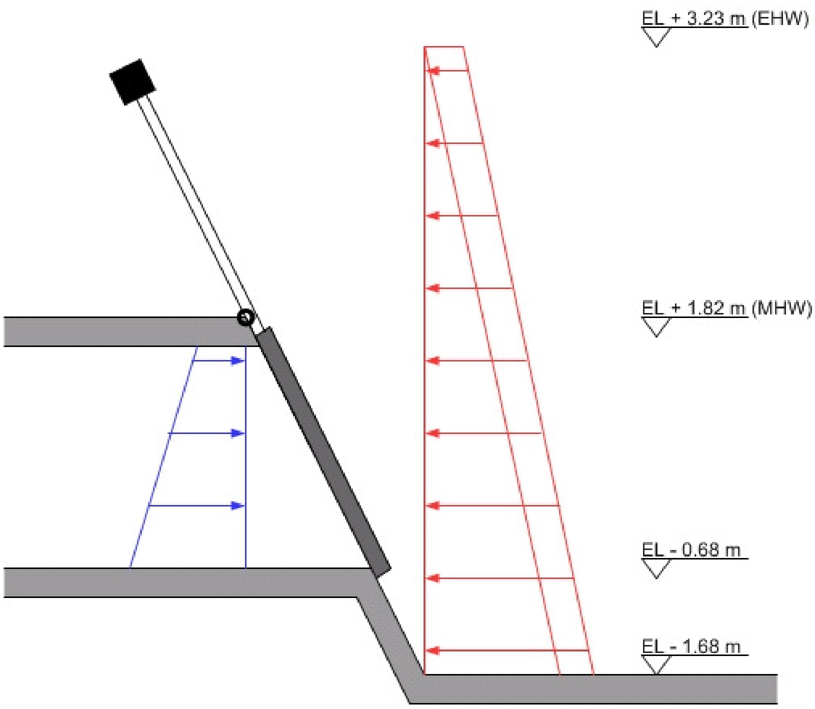


Figure 11.5 Loads on the gate and the depth of the elements

The loads on the gate are the hydrostatic load and the wave load. The hydrostatic pressure increases with the water depth, while the resulting pressure from the waves will diminish with depth. The largest combined pressure on the gate can be found at the lowest point of the gate, in this case 0.68 meter below EL, see also Figure 11.5. The loads on the construction are depending on the several depths of the different parts of the outlet structure.

The loads have to be resisted by the gate. The gate consists out of a 10 mm thick plate with I-beams as stiffeners. The I-beams are of the type IPE200, with a height of 200 mm, the space between the stiffeners has to be optimized. This is done by using a spreadsheet, which is given in Appendix J, the optimization is done by increasing the space between the stiffeners until the maximum allowable stress in the material is reached. The distance between the stiffeners is optimal if it is 300 mm. The gate itself will get a total weight of 2500 kilogram. An impression of the gate can bee seen in figure 11.6.

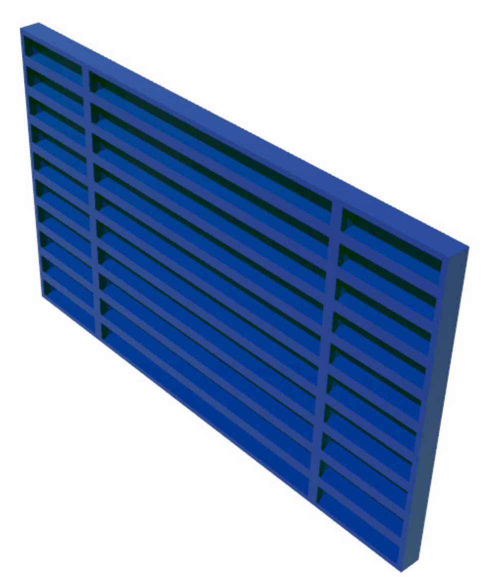


Figure 11.6 The gate with the stiffeners

11.2.2 Counterweight

The counterweight has to ensure that the gate can be pushed open by the water, even if there is only a small head difference. It should not compensate all the weight of the gate, because of the variable wave pressure on the outside. The gate should not go open and slam shut with each wave colliding against the construction. The counterweight has to provide a moment of at least 18 kNm on the hinge, as can be seen from figure 11.7. The construction of the counterweight has to be designed in the ultimate limit state, that is when the gate is opened and the moment above the supporting hinge is the largest.

From figure 11.7 follows that the needed counterweight is 1800 kilograms if the arm of the counter weight is 2 meters. This counterweight can be made from concrete, which offers a high density at a reasonable price. Due to the total weight of the gate, which is around 4300 kilograms, the connection to the culvert has to be made at the sides of the culvert, i.e. the space between the arms of the counterweight is 5 meters. The counterweight can be made of a concrete beam of 5 meters long and with a width of 400 mm and a height of 400 mm.

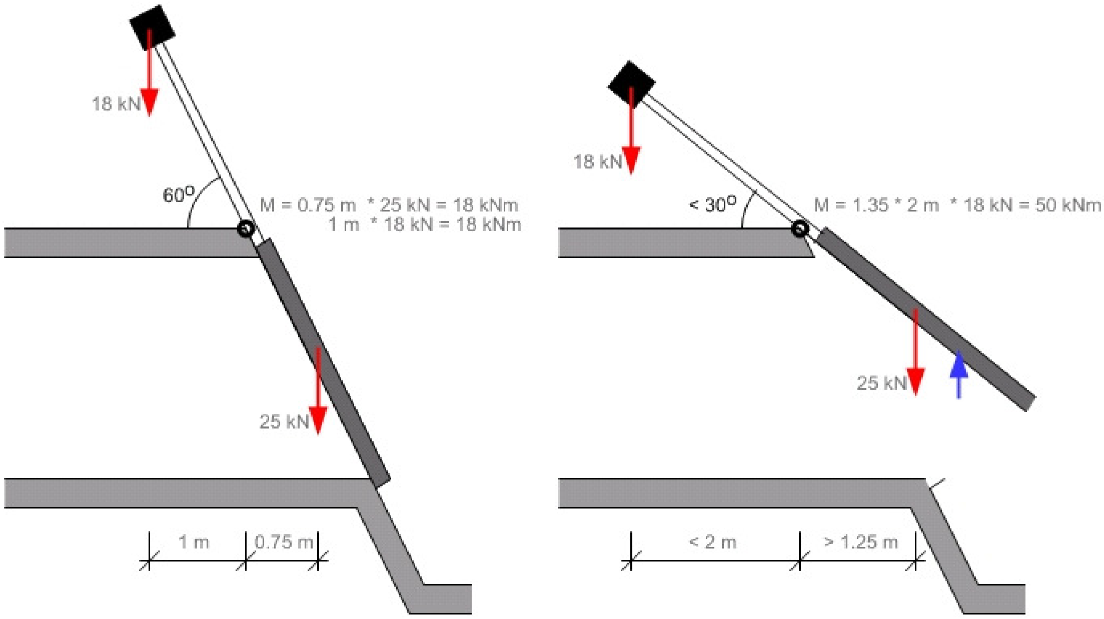


Figure 11.7 Equilibrium of the gate

The arms of the counterweight have to withstand the maximum moment that can exist from the 1800 kilogram counterweight. The maximum moment that can develop in ultimate limit state is 25 kNm per arm; see also figure 11.7. To withstand this moment a girder with dimensions 100x200x5 mm is needed. The total construction of the gate can be seen in figure 11.8.

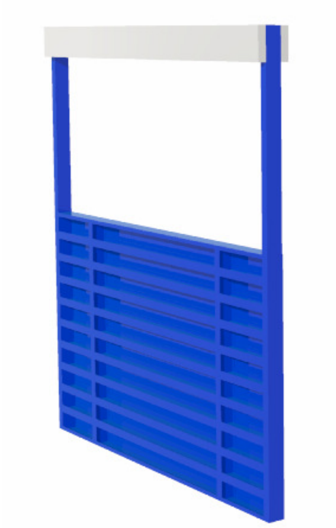


Figure 11.8 The gate with counterweight

11.2.3 Accompanying structures

Besides the gates, there are more structures in the outlet. The outlet relies on the free movement of the gate, so the gate and the counterweight as well have to be protected against debris and other things that can hamper the proper functioning of the gate. The outlet is being constructed in the coastal protection and also has to fit in the coastal protection in order to prevent a weak link in the coastal protection. Drawings of the total construction can be seen in Appendix K.

The gate can be protected from debris by using fences. Debris will be stopped by the fences and will be flushed away when there is a discharge. The discharge structure of the outlet is lower then the highest possible water level, so provisions have to be made to prevent debris from being deposited behind the fencing after an extreme high water. This can be done by applying a grid on top of the outlet structure.

The counterweight has to be protected also from the forces of the waves. The hinges and the counterweight are placed below the springtide water level. During springtide the counterweight structure will suffer from the wave attack. If a wave hits the counterweight itself, it has to be designed for this. The gate relies on equilibrium of forces; slamming waves can distort this equilibrium and possibly open the gate. To prevent this, the counterweight has to be sheltered, which can be done by a wall in front of it with only openings for the arms which support the counterweight. The space that is formed in this way can be covered with a grid, which offers accessibility to the structure for maintenance and adjustments.

The gate is a part of the coastal protection and may not be the weakest link in it. Therefore the outlet structure has to provide enough safety against seepage and other failure modes. Seepage along the culvert can be prevented by screens, while the construction as a whole can be considered as safe if the structure cannot be overturned by the pressure of the water. Due to the weight of the structure a good foundation is obligatory, if the soil is not strong enough, a pile foundation can be applied.

11.2.4 Conclusion

- A drawing of the designed outlet structure can be seen in Appendix K.
- The gate, placed under an angle of 30 degrees will be 5 meter wide and 3 meter high. The weight of the gate will be 2500 kilograms and needs a counterweight of 1800 kilogram to ensure discharge when a head-difference of 10 centimeters or more occurs.
- The gate is protected against debris by fences in front of the outlet and a grid on top of the outlet structure.
- The counterweight is protected against waves by a concrete wall in front of the counterweight.

11.3 Conclusions outlet structure

In the current situation flap-gates do not function properly due to clogging up by debris and hampering the discharge if there is a low head difference. Therefore there is chosen for to fit up the flap-gate with a counterweight. This is a simple construction which solves the problem of hampering the discharge if there is a low head-difference. Other solutions are far more complex and expensive. The problem of debris is not primarily solved with this design. To solve the problem of the debris fences in front of the structure and a grid on top of the outlet structure are needed. To protect the counterweight a concrete wall is placed in front.

Chapter 12 Conclusion and recommendation

In this chapter the main purpose statement is treated and conclusions of the project are drawn.

12.1 Conclusion

The purpose statement of this project is to design a new coastal protection and improve the dewatering of the project area. The project area is the coastal zone between Dajia River and Da'an River in Western Taiwan. These designs have to sound with the ecological, recreational and spatial requirements. The project is divided into three phases. This final report is the result of the third phase.

The main purpose of the second phase was to generate solutions and determine the best suitable solutions for a save coastal protection and a sufficient dewatering system. To achieve this, a literature study has been conducted. Alternatives are generated and compared. The following alternatives are chosen.

First the conclusion is drawn that land reclamation is feasible. For coastal protection two alternatives are selected. First dike improvement which is for example creating a green dike or a boulevard. Second, applying of soft solutions, these are solutions without the use of coastal structures. For the dewatering also two alternatives are selected. First, temporary storage of excess rainwater referred to as detention. Second, is the removal of the bottlenecks, i.e. the outlets in the current dewatering-system.

In the third phase the location and the size of the land reclamation is selected. An area of 500 meters width and 2 km's length is selected at the south of the project area. This location suits best because of the limited down drift erosion and limited impact on ecological important areas.

12.1.1 Coastal protection

- With the presented design in this report the coastal protection is safer than the existing protection and upgraded to satisfy recreational and ecological needs.
- The recreational and ecological needs lead to larger cross sectional surfaces and therefore the new protection will be more expensive than the current protection.
- The needed dimensions of the designed elements are shown in table 12.1.

Table 12.1 Dimensions of coastal protection

	Toe level	Crest level	Outer slope	Inner slope	Berm	Cross section	revetment
	[m] + EL	[m] + EL				[m2]	
Existing dike	3.5	6.2	1:2	1:1.5	No	21	concrete
Land reclamation dike	1	8.32	1:6	1:3	Yes	321	Grass/ loose rock
dike with foreshore vegetation	3.3	6.9	1:9	1:3	Yes	108	Grass
dike Without foreshore vegetation	3.3	6.9	1:9	1:3	Yes	108	Placed blocks/ grass
Sea wall	3.5	7 *	Vertical	-	No	-	Concrete
* including a parapet of 0.5 meter							

12.1.2 Drainage system

- The existing drainage system is sufficient if maintained properly.
- The current flap gates should be fitted up with a counterweight. This is needed to assure discharge with a low head difference. Fences are needed to prevent clogging up by debris.

12.1.3 Land reclamation

- A far larger coastal protection is needed to protect the reclaimed area.
- When land reclamation is applied extra measures have to be applied to prevent flooding.
- For a land reclamation area of 100 hectare a detention area of 2.5 hectare is necessary to prevent flooding. This detention area needs a high dike due to wind set-up.
- When land reclamation is applied centralizing of the outlets is preferred because this requires a lower maintenance effort.

12.1.4 General conclusions

In this project, possibilities for land reclamation, ecological friendly and safe structures with recreational opportunities have been investigated.

When land reclamation is applied the shoreline is moved seaward so the protective structure will be more massive. Also the level of the reclaimed land is lower and therefore drainage efforts will be higher. To obtain an ecological friendly coastal protection milder slopes are needed so this results again in a more massive structure.

A combination of land reclamation and ecological friendliness will result in an accumulated effect and therefore a very large structure compared with the current situation. In the case of this project this means almost 20 % of the reclaimed land will be occupied by the coastal protection. Since the choice is made for detention 1.25 % of the reclaimed land will be used for that purpose. This combined with the fact that additional structures and facilities are needed in the reclaimed area to assure drainage and prevent flooding and salt intrusion means a high effort for land reclamation. It has to be determined if the value of the reclaimed land is high enough to justify these efforts.

12.2 Recommendations

With respect to the whole project a few recommendations should be made here. These recommendations are mainly directed to assumptions made for the designs in this project. The assumptions are made because no adequate data was available. Some of these assumptions have far fetching consequences for the designs and development of the area; these deserve more attention and further investigation.

12.2.1 Sediment transport

Little is known about the current sediment transport at the coast of the project area. A general conclusion drawn from site surveys was that this is an accreting coast. Site surveys are however always but a snapshot. During the time the project team was in Taiwan for example, the rivers at the north and south of the area were completely dry, while it is known these rivers can have an extreme discharge in the wet season, which will have an influence on the coastal processes. Furthermore different processes can play a role on different sections of the coast at the project area, and therefore different parts could be more or less accreting and it could even be possible to have some local erosion. Therefore it is recommended to have either more historical data about the coast and bathymetry or have an investigation on the seabed movement over a longer period.

12.2.2 Soil conditions

During the project, no information was available on the soil conditions. These conditions are however important to know before construction can start. Therefore a geotechnical research should be performed in order to establish the final design.

Also the groundwater table was assumed to be stable. This assumption needs further investigation and possibly adjustment when data shows different trends in the groundwater level.

12.2.3 Safety

While it wasn't exactly clear what method the WRA usually uses to establish a dike design with a certain safety, a frequency analysis for wave heights like it is used in this report was not common. This approach which is in line with Dutch standards is likely to lead to a safer design. However more safety leads to a higher crest height and consequently higher costs for the coastal protection. It is recommended to assess if this higher safety is desired and if the WRA is willing to make these extra costs.

Another subject in this category is the safety against earthquakes. There was no specific earthquake data available for the project area, so more global data is used. Since it is known earthquakes in Taiwan occur less frequently at the west coast, more detailed data for the project area is likely to lead to a lower design earthquake rate which will lead to more economical designs. Therefore it is recommended to gather more detailed earthquake data.

12.2.4 Slope

One of the most important recommendations concerns the assumption made regarding the slope of the foreshore. In this project, by using visual estimation the slope of the foreshore is assumed to be 1:200. It doesn't need further explanation that visual estimation is not particularly an accurate method to establish this information; also the slope is likely to vary over the coastal stretch. However no data was available so an assumption had to be made. This assumption has far reaching consequences for the design, especially for the land reclamation. If for example it turned out the slope is 1:400 the land reclamation area could be twice the size with the same designed coastal protection. The assumed slope also has great consequences for the drainage of the reclaimed area. Therefore it is recommended to thoroughly investigate the actual slope of the foreshore by measurements.

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