Safety Standards project

Risk analysis for new sea dike design guidelines in Vietnam

Marten Hillen
May 2008

Delft University of Technology

Preface

The photo on the cover shows a small incense burner which construction workers used for good luck during the construction of the dike. Good luck to be safe during the construction and good luck to build a safe dike. Since a dike can never guarantee total safety, one would always need some luck. This project deals with safety standards for sea dikes in Vietnam. Although one could never achieve total safety, one can make a logical decision to define a certain safety level.

This report is the result of the Safety Standards project. During a 10 months stay in Hanoi, Vietnam, I executed this project as part of the Vietnam sea dike project at the Water Resources University. It was wonderful to be in Vietnam for almost three months and live in the thriving city of Hanoi. I was lucky to meet many different Vietnamese people, get an impression of the Vietnamese culture and experience the beauty of this country.

This project already started in Delft, the Netherlands, and I would like to thank Marcel Stive for his enthusiasm and ideas during the preparation. Henk Jan Verhagen gave me a good introduction to the Vietnamese situation and helped me to get started in a very short period of time. I respect his knowledge on the situation of coastal Vietnam and his insight in different cultural perspectives. I would also like to thank Miss Nga of the International Office of the WRU for her help to facilitate my stay at the University guesthouse. During the project I also received help from the experts on probabilistic design from Delft University of Technology: Han Vrijling, Pieter van Gelder, Bas Jonkman, Foekje Buijs and Mai Van Cong. It was helpful that I could contact them any time and get their valuable input.

The fact that I had a very good time at the Water Resources University (WRU) is because of my 'colleagues'. Hereby I would like to thank all my colleagues of the Coastal Engineering faculty of the WRU; Mr. Cat, Mr. Roanh, Miss Thuy, Miss Nga, Tuan, Lam, Tung, Huong, Minh Anh, Tuyen, Trung, Thau, Nguyen, Diem, Chien and Hai. It was a pleasure to work with this team of young academics and researchers. With their open attitude and international orientation I think the Coastal Engineering community will hear and see a lot more from this young faculty. I wish everybody the best with their work and projects!

In particular I would like to thank my Water Resources University supervisor Mr. Quy. I admire his mentality to be open for new methods and discuss different views. He helped a lot with overcoming cultural differences, facilitated the fieldtrip and supported my search for data. Next to all this he introduced me to the Vietnamese culture in an informal way and helped me to feel at home in Hanoi. I was lucky to have so much fun working on the project.

Last, but not least, I would to thank Gerrit Jan Schiereck and his wife Hermine. I consider myself lucky to work with Gerrit Jan. In my opinion his work in Hanoi is very valuable and I am amazed by his knowledge on a broad range of subjects. I learned much from his approach towards the many different problems he faces. I enjoyed just walking into his office and discuss different issues and I have learned a lot by doing just that! I would also like to thank his wife Hermine because of her advice and pleasant dinners.

Thank you all!

Marten Hillen
Delft, May 2008

Abstract

Vietnam experienced sustained economic growth over the last decades, making it one of the fastest growing economies of the world. At this moment Vietnam is still fighting its way out of poverty and trying to improve living standards. With a coastline of 3,260 kilometers many activities take place in the densely populated coastal areas. The government of Vietnam wants to use the coastal zone to its fullest potential and therefore a lot of economic development is planned in these regions. It is important to make the coastal zones safe areas for living and investments.

The coastal areas of Vietnam are protected from the sea by dikes. Currently a major sea dike project investigates and upgrades the sea dikes and creates new dike construction guidelines. This project consists of several subprojects which each focus on a specific task. Subproject 4 reviews the sea dikes from Quang Ninh to Quang Nam provinces (Northern coastal provinces). The subproject 4 contents are the collection of data on sea dikes, the creation of a sea dike databank, the determination of the dike route and to set up design criteria for sea dikes.

Within subproject 4 the Safety Standards project was set up focused on a plan of approach to define sea dike safety standards with a risk-based approach. Design criteria and guidelines for the construction of sea dikes are (part of) the output of subproject 4 and safety standards can form part of these design criteria. To determine these safety standards a risk assessment is executed. This is a different approach with respect to the current situation and also is a complicated subject. Introducing this new approach for the Vietnam situation the Safety Standards project is the first step in implementing this strategy for coastal defense projects. The introduction of this method in Vietnam is considered more important than finding the exact safety standards for different situations. Therefore the results of the Safety Standards project should be regarded as indicative, as an example. Translation of safety standards to technical design criteria is therefore outside the project scope.

The Safety Standards project uses the coastal provinces Hai Phong and Nam Dinh as case study areas. Both provinces have approximately the same size and number of inhabitants, but different characteristics. Hai Phong is a more industrial province; Nam Dinh is a rural province. The research is focused on the Vietnamese situation and done from a Vietnamese perspective. With calculations based on economic optimalization an approach of defining safety standards was developed and three different safety standards for the Vietnamese sea dikes were found:

1. High safety level for high developed and fast developing areas; a safety standard of 1/1000 years can be considered for these areas.
2. Medium safety level for moderate populated areas with sustained economic growth; a safety standard of 1/200 years can be appropriate.
3. Low safety level for rural areas with no to little development; this can be a safety standard of 1/100 years.

Table of Contents

1. Introduction

This chapter introduces the Safety Standards project. In the first chapter a general introduction of the project background is given (chapter 1.1). Next, the country of Vietnam is introduced with a focus on several aspects relevant for the project in chapter 1.2. Chapter 1.3 introduces the Vietnam sea dike project which forms the framework for the research in this report. In more detail subproject 4 of the Vietnam sea dike project, concerning safety standards and guidelines, is described.

1.1. Project background

From the second week of February 2008 till the end of April 2008 the Safety Standards project took place at the Water Resources University in Hanoi, Vietnam. The project was formulated to contribute to the development of the Vietnam sea dike project, but is also part of the Civil Engineering Master of Science program of Delft University of Technology. In a 10 weeks fulltime period the project was executed. This report can be read separately but is part of the Vietnam sea dike project and supports the formulation of guidelines for the Vietnam sea dikes as part of subproject 4.

This report is only one part of the Safety Standards project. Next to this report a lot of data collection was done which will be used within subproject 4. Also several presentations were given to illustrate the approach and method of the project. Although this report shows most of the work done, parts of it can not be included since they concern getting people involved and showing a new approach towards defining sea dike design criteria.

1.1.1. Minor thesis

This report is a result of an independent project done as a minor thesis (additional graduation work) of the Master Civil Engineering of Delft University of Technology. Its content is focused on defining sea dike safety standards with a probabilistic approach for the sea dikes of Vietnam. The minor thesis of the Master Civil Engineering of Delft University of Technology can contain a very broad range of projects. The main goal of the minor thesis is that a student shows he (or she) is able to perform research at an academic level. This project, to determine sea dike safety standards for Vietnam, is partly an internship at a subproject of the Vietnam sea dike project at the Water Resources University in Hanoi and partly an independent project with a focus on probabilistic design. Next to its contents it also calls upon the ability to work, mostly alone, in a foreign environment where communication and cooperation takes place in a different way.

The content is discussed by appointed University staff members. For this project these are Mister Henk Jan Verhagen (Delft University of Technology), Mister Gerrit Jan Schiereck (Delft Partners, Water Resources University) and Mister Nguyen Ba Quy (director Subproject 4, Water Resources University). They also function as supervisors on this project.

1.1.2. Water Resources University

The Water Resources University (WRU) in Hanoi is the University of the Ministry of Agriculture and Rural Development (MARD) of Vietnam. It conducts research and educates on various fields of interest concerning Water Resources, Water Management, Hydrology, Hydraulics, Environment and Coastal Engineering. The WRU has 10 faculties of which the faculty of Coastal Engineering is one of the youngest. Closely connected with the University are several departments and centers on Water Research, which work independently, but closely cooperate with the WRU.

About 9,500 students study at the WRU of which over 6,000 fulltime (Information brochure, Hanoi Water Resources University 2005 [i]). At the moment not every student applying for the WRU is admitted, but in the near future a new University building in a Hanoi suburb will house about three times the current number students and staff. The WRU has many cooperative foreign relations in training and scientific research. There are strong ties with foreign Universities in various countries including the Netherlands, Sweden, Germany, USA, Japan, India and China.

Because of the WRU's close connection with MARD many researchers of the WRU are involved in MARD projects on national level. Part of the Vietnam sea dike project is executed by WRU staff. Their knowledge and expertise is used to review the sea dikes of Vietnam and define new guidelines.

1.2. Vietnam

The Socialist Republic of Vietnam is with approximately 86 million inhabitants (CIA World Factbook, July 2008 estimate [ii]) a densely populated country in South East Asia. The country is divided in 64 provinces of which 59 are rural provinces and 5 are city provinces. From North to South Vietnam is 1,650 kilometers in length and only 50 kilometers across in its narrowest point (see Figure 1). With two major river deltas, the Red River Delta in the North and the Mekong Delta in the South, and a coastline of 3,260 kilometers the country is very interesting from a Coastal Engineering point of view.

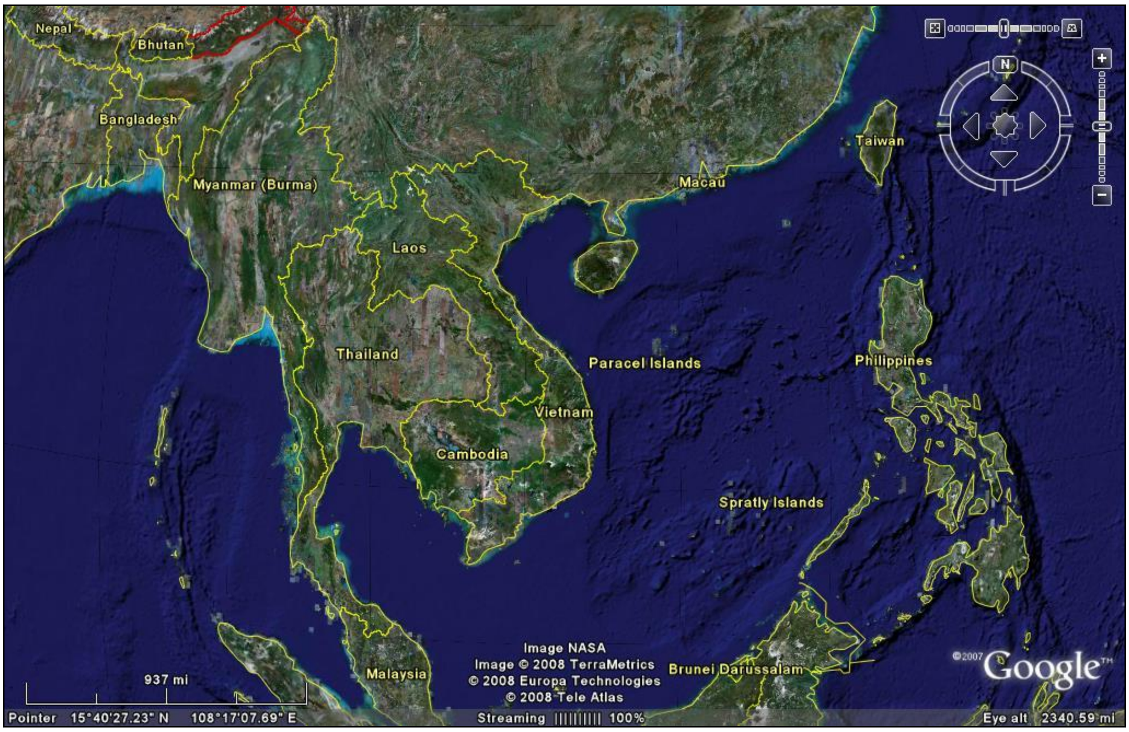

Figure 1: Vietnam and part of the South East Asia region [Google Earth]

Vietnam experienced rapid sustained economic growth over the last decades, making it one of the fastest growing economies of Asia and one of the fasting growing developing countries of the world. The economic growth is utilized to eradicate poverty, but still 14.75% of the population lives below the poverty line (CIA World Factbook, 2007 estimate [ii]). Remarkably, the last two decades the benefits of the economic growth were larger for the poorest 20% of the country than for the top 20% (ADB Economic and Research Department, 2003 [iii]). This is in contrast with most growing economies. The World Bank therefore states that Vietnam has the '*potential to be one of the great success stories in development*' (World Bank, Vietnam fact sheet 2007 [iv]).

1.2.1. Economy

The Communist Party of Vietnam decided to reform the centrally planned economy to a marked oriented economy at the Sixth Party Congress in 1986. The renovation process, *'Doi Moi'*, introduced market mechanisms, but was also focused on keeping social inclusion. From 1986 till now Vietnam has seen successive years of economic growth. In 2001 the economic liberalization process continued with a new five-year social-economic development plan which was again successfully completed at the end of 2005 (Viet Nam Vision 2020, 2007 [v]) (see Figure 2). Vietnam has overcome the period of decline in Asia and in 2007 the economic growth was 8.5% (CIA World Factbook, 2007 [ii]). In 2007 Vietnam joined the World Trade Organization after years of negotiating. The government in Hanoi is now targeting an economic growth rate of 7.5-8% for the next four years (Viet Nam fact sheet, ADB 2007 [vi] and Viet Nam Vision 2020, 2007 [v]).

Economic Indicator	**2002**	**2003**	**2004**	**2005**	**2006**
Per capita Gross National Income ($)	430	470	540	620	700
Gross Domestic Product growth (% change per year)	7.1	7.3	7.8	8.4	8.2
Unemployment rate (%)	6	5.8	5.5	3.8	4.4
Export growth (% change per year)	11.2	20.6	31.4	22.5	23
Import growth (% change per year)	23.3	28	26.6	15.7	33.3

Figure 2: Economic indicators [ADB, Asian Development Outlook 2007 and ADB, Statistical Database System 2007]

With the economic growth the agricultural share of the economy is decreasing and new jobs are created in the industry and service sectors. The contribution of agriculture to the economic output decreased from about 25% in 2000 to less than 20% in 2007 (CIA World Factbook, 2007 [ii]). Although more than half of the labor force works in agriculture, it currently is approximately 19% of the country's GDP. The amount of agricultural output is expected to be the same in the coming years, but its share of the GDP will become smaller over the years. The added value of agricultural products will increase 3 – 3.2% (Viet Nam Vision 2020, 2007 [v]). The economic structure of the GDP in 2010 is expected to be the following; agricultural sector 15-16%, industrial sector 43-44% and service sector 40-41%.

The high economic growth brings along various challenges. The complete transition to an open market economy is expected to be done within the next years and the government puts a lot of effort in it to make this change successfully. The economy began to show signs of overheating during 2007 and inflation accelerated from 6.6 percent in December 2006 to 15.7 percent by February 2008 (Viet Nam economic update, April 2008 [vii]). The country's main challenge is to stabilize Vietnam's economy for the coming decades.

1.2.2. Coastal areas

With two large river deltas and a long coastline many activities take place in the fertile, but also vulnerable coastal areas. The river deltas are the most densely populated areas of Vietnam and are prone to flooding from both the rivers and the sea. Although the river deltas are low-lying areas of land, all coastal land is above mean sea level. In the Northern and Southern part of Vietnam the coastal land is, from shoreline to approximately 20 kilometers inland, between 0.5 and 10 meters above mean sea level. In central Vietnam some higher areas are found.

Currently, most of the coastal areas are used for agricultural purposes. This includes fishery, forestry, aquaculture and of course the growth of rice and a variety of other crops. As shown in paragraph 1.2.1 the share of industry and services of the GDP is increasing and the share of agriculture is decreasing. This development can clearly be seen in the coastal areas where most of the new jobs are created in the industrial and service sector (Vietnam fact sheet, ADB 2007 [vi]). With increasing trade, ports along the coast grow rapidly and this is followed by new industry next to the adjacent transport corridors.

The government of Vietnam wants to use the coastal zone to its fullest potential. This is illustrated by one of the objectives stated in the 'Emergency Rehabilitation of Calamity Damage Project' after the dike breaches in Nam Dinh province in 2005. One of the three major objectives to repair the sea dikes was to '*exploit fully the potential of the coastal area, to transform the production structure, to create jobs, to contribute to the career of poverty reduction and hunger alleviation*' (Emergency Rehabilitation of Calamity Damage Project, ADB 2007 [viii]).

1.2.3. Vulnerability coastal areas

The South China Sea to the East of Vietnam is one of the major typhoon centers of the world. The coast of Vietnam gets hit by 4 to 6 typhoons per year (see Figure 3). These typhoons generate a high storm surge and with the accompanied waves the sea dikes face a serious threat. Because of the torrential rains during and directly after these typhoons another severe danger is flooding from the rivers inland. Millions of households live in typhoon prone areas and are used to cope with these tropical storms. Given the frequency of these natural disasters typhoons cause a relatively low number of casualties, because the households in these areas are adapted to them and people tend to help each other after flooding occurs.

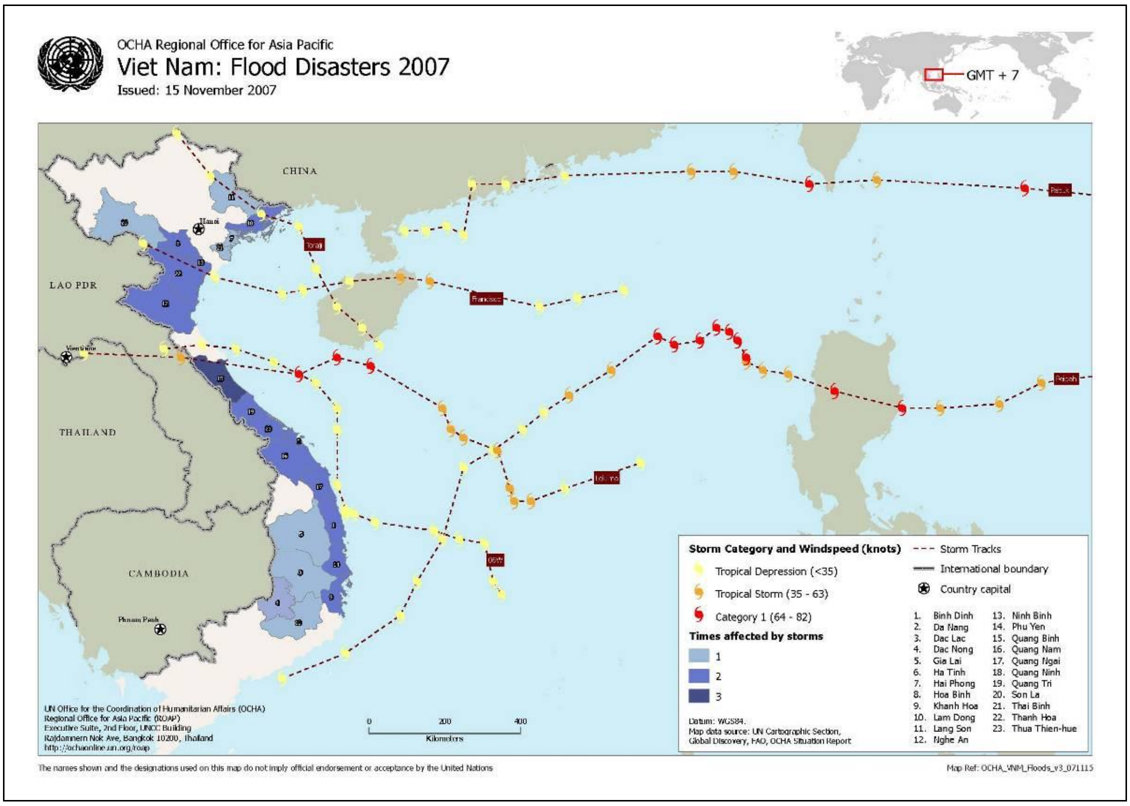

Figure 3: Flood disasters and typhoons 2007 [United Nations OCHA]

In 2007 central Vietnam suffered from major (inland) flooding after a typhoon hit the area. Major storms hit the coast of Northern Vietnam in 2005 causing the sea dikes to breach. Storms #2, #6 and #7 caused severe economic and social damage and also resulted in the loss of lives (see Figure 4). The total direct economic damage is estimated by the central board of flood and storm control to be over 350 million US dollars (USD).

Description	**Quantity**
Number of casualties	397
Number of houses, schools and healthcare stations lost:	
– houses	7,100
– flooded houses	210,500
– flooded classes	5,000
– damaged healthcare stations	250
Agricultural production:	
– area crops destroyed	497,000 ha
– area fish breeding destroyed	54,000 ha
– area of shrimp farming lost	3,500 ha
Number of boats lost	382
Revetment	3,223,000 m^3
Number of impaired bridges	200

Figure 4: Consequences of 2005 storm season [Central board of flood and storm control, Vietnam]

Another issue that can put the coastal regions of Vietnam under extra pressure is climate change. '*Climate change is expected to significantly impact the poor, particularly those in low-lying, vulnerable, coastal areas*,' according to Douglas Graham, environment team leader World Bank Viet Nam in Outlook magazine March 2008. Climate change will cause a rise in sea level, but also an increasing number of typhoons are likely to hit Vietnam, which can cause a rise in floods. MARD says the nation's sea dike system is at grave risk of being breached because of the extra pressure due to climate change (Outlook, 2008 [ix]). If these predictions are correct then even more pressure will be put upon Vietnam's coastal regions.

1.3. Sea dike project

The coastal defence strategies of Vietnam with respect to sea dikes, their construction and maintenance are the responsibility of the Ministry of Agriculture and Rural Development (MARD). Within MARD the sea dikes are operationally run by the Department of Dike Management and Flood Control (DDMFC). On provincial level the provincial Department of Agriculture and Rural Development (DARD) and provincial dike departments govern the sea dikes per province. The DDMFC of MARD maintains over 3,000 kilometers of coastal and estuarine dikes (Pilarczyk and Vinh, 1999 [x]).

MARD initiated a large sea dike project to review and upgrade the sea dikes of Vietnam and also formulate new guidelines for the construction of sea dikes. For that purpose a research program has been started: "Scientific Technology Program to rehabilitate and upgrade sea dikes and hydraulic structures at the estuary and coastal areas" with a decision of the vice minister of MARD in March 2007 (Review ADB Emergency Rehabilitation of Calamity Damage Project, 2007 [xi]). In July 2007 also a new law on sea dikes was accepted and enforced by the national government (Outlook, 2008 [ix]). The current state of many of the sea dikes is far from optimal and many breaches of sea dikes in the Northern coastal provinces of Vietnam showed this vulnerability. This combined with the country's ambitions in the coastal zones underlines the importance of the Vietnam sea dike project.

The Vietnam sea dike project is executed in two steps. First the Northern part of Vietnam is dealt with: the sea dikes from Quang Ninh to Quang Nam provinces. These provinces have a surface area of over 58,000 km^2 and are inhabited by over 17 million people (about 21% of the Vietnamese population). The coastline of these provinces measures 1,658 kilometers in length (Statistical analysis Northern coastal provinces, 2005 [xii]). This first part of the sea dike project is divided into 5 subprojects (Technical Assistance for Sea Dike Research, December 2007 [xiii]):

- Subproject 1 is run by the Institute of Mechanics and focuses on waterlevels. Main goal is to build a complete data set of (predicted) tides and typhoon surges along the shore.
- Subproject 2 is run by Center for Estuarine and Coastal Engineering and focuses on waves. Main purpose is to propose a method for the calculation of the wave parameters with appropriate accuracy.
- Subproject 3 is executed by Water Resources University staff and focuses dike cross sections. The result of this subproject is a proposal of feasible cross-sections for sea dikes with a special focus on different dike types and local conditions.
- Subproject 4 is also run by the Water Resources University and is a sea dike master plan. It researches the basic sciences of sea dikes, focuses on defining a new dike route and tries to come up with design guidelines to ensure the sustainable development of the dikes.
- Subproject 5 is run by Vietnam Institute of Water Resources and is focused on soft soil foundation. It researches technical soil requirements and the classification of soil and foundation and is mainly focused of the use of (building) materials.

1.3.1. Subproject 4

The content of the Vietnam sea dike project as stated above can be divided into two parts: (1) the development of knowledge on sea dikes and the boundary conditions and (2) the generation of guidelines for sea dikes. Within subproject 4, "Masterplan", this is illustrated by a set of different goals.

The goals on knowledge development mainly consist of data collection on different fields of interest. Subproject 4 collects data on the existing sea dike system; sea dike locations, their current state and the dike routing. Also via a literature review data is collected on how sea dike guidelines are formulated in other countries. The creation of design guidelines for sea dikes can be seen in other goals of subproject 4. Goals to come up with safety standards, a master plan, dike alignments and standard dike classification are included to ensure future sustainable development of sea dikes (Subproject 4; Masterplan, 2008 [xiv]).

Within the contents and goals of subproject 4 safety standards are mentioned. The exact definition of safety standards is not completely clear from the subproject 4 project description. Therefore this project will define a definition for safety standards and use a probabilistic approach to determine these safety standards. This will be discussed and illustrated in chapter 3.2.

2. Study area

This chapter describes the characteristics of the project's study area. The coastal provinces of Hai Phong and Nam Dinh were chosen as study area and a first introduction to their characteristics is given in chapter 2.1. In the following chapters 2.2 and 2.3 the local situation of these provinces is explained. To get a more detailed impression the results of a three day fieldtrip are presented in chapter 2.4.

2.1. Introduction

To illustrate the probabilistic method to acquire safety standards, it is not necessarily important to show the method for every specific situation along the coast of Northern Vietnam. To get a clear overview of the method and to show its applicability for different situations two Northern coastal provinces of Vietnam were chosen as study area; the province Hai Phong and the province Nam Dinh (see Figure 5). These provinces are comparable in size and number of inhabitants, but both have their own character. Hai Phong is with the largest port of Northern Vietnam a region where a lot of economic growth is expected to take place and already has an industrial character. Nam Dinh is more of a rural province and is a well-studied area because of its erosion problems. Both provinces have the potential to change very rapidly, since changes in both land-use and economy are expected, as well as changes in the coastline. Therefore it is interesting to show the application of the method for these provinces.

Figure 5: Hai Phong and Nam Dinh provinces, located in the North of Vietnam [Google Earth]

The two coastal provinces are situated in the Red River Delta (Vietnamese: Dong Bang Song Hong). Approximately 165 kilometers of the 3,260 kilometers of the coastline of Vietnam are in this delta. The Red River Delta got inhabited approximately 4,000 years ago and with the Mekong River Delta it belongs to the most densely populated regions of Vietnam. The region experiences dynamic changes both in land-use and economy as in coastal change. It is also subject to the intense impact of both river floods and sea floods caused by typhoons, change in sea waterlevel and erosion.

2.2. Hai Phong

Hai Phong province is best known for its major port city Hai Phong, but also the popular summer resort Do Son and Cat Ba Island, on which a national park is situated, are well-known. Hai Phong province has 14 districts, of which 5 are city districts which all are part of the capital; Hai Phong city. The province is densely populated with on average over 1,000 people per square kilometer. Five districts are adjacent to the South China Sea and are therefore prone to flooding from the sea: Hai An, Do Son, Cat Hai, Kien Thuy and Tien Lang (see Figure 6 and Figure 7). Of these districts Cat Hai and Do Son are not taken into account in the calculations in chapter 4. This is because Cat Ba Island has high rocky coast and no specific information on Cat Hai Island could be found. Do Son also has a (partly) high rocky coast and the newly constructed tourism facilities are constructed outside of the sea dikes.

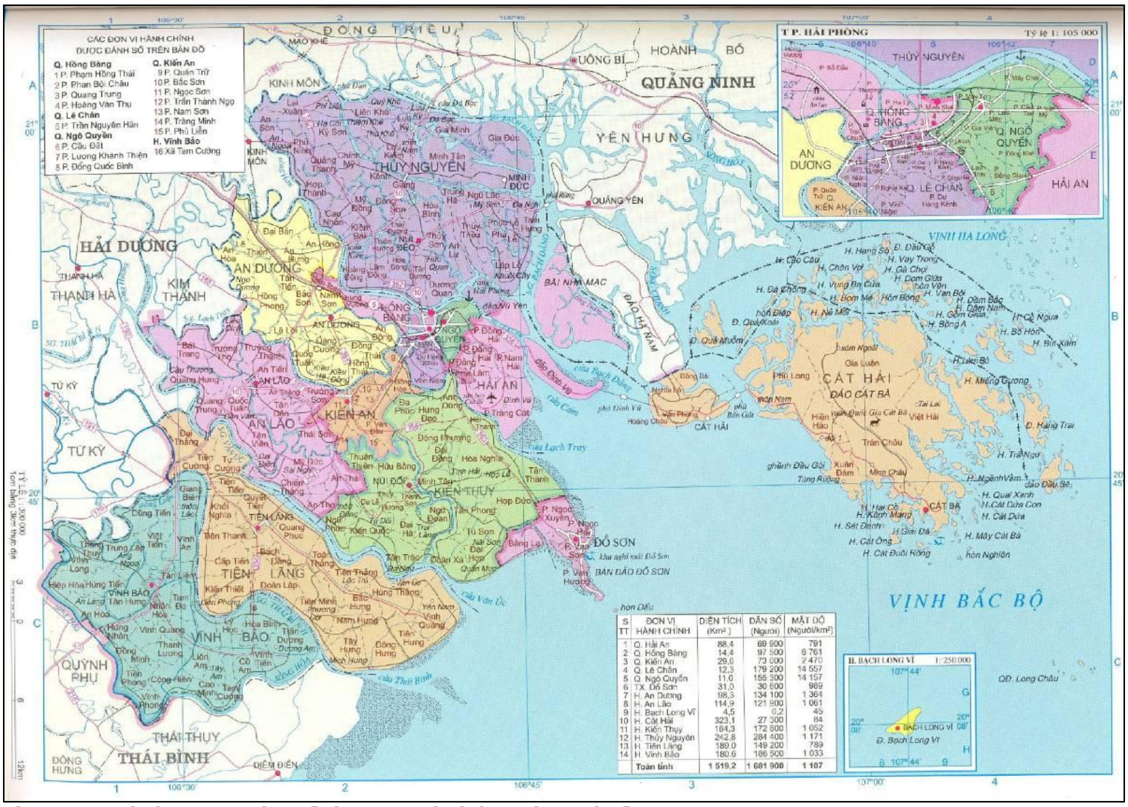

Figure 6: Hai Phong province [Vietnam Administrative Atlas]

Hai Phong	km^2	population	population density
Hai Phong City Districts			
Hai An	88.4	69,900	791
Hong Bang	14.4	97,500	6,761
Kien An	29.6	73,000	2,470
Le Chan	12.3	179,200	14,557
Ngo Quyen	11.0	155,300	14,157
Districts			
Do Son	31.0	30,600	989
An Duong	98.3	134,100	1,364
An Lao	114.9	121,900	1,061
Bach Long Vi (in South China Sea)	4.5	200	45
Cat Hai	323.1	27,300	84
Kien Thuy	164.3	172,800	1,052
Thuy Nguyen	242.8	284,400	1,171
Tien Lang	189.0	149,200	789
Vinh Bao	180.6	186,500	1,033
Hai Phong province	**1,519.2**	**1,681,900**	**1,107**

Figure 7: Hai Phong province districts [Vietnam Administrative Atlas]

2.2.1. Economy and economic growth

Although more than half of the surface area is used for agriculture (see Figure 8) and it is still the main source of income for many people in Hai Phong, the industry and services sector have a far bigger share in the province GDP. The ports and their surrounding industry still become increasingly important and a lot of port development plans are currently executed. 40% of Haiphongs GDP is earned by industry and engineering, compared to 12% by agriculture, fishery and forestry and 48% by service. The percentages of industrial and service share are still growing compared to the agriculture percentage (see Figure 9).

#	District name	District area (km^2)	Main land-use per area (km^2)		
			Agriculture	Non-agriculture	Non-used land
1	Hồng Bàng	14.49	2.87	11.49	0.12
2	Ngô Quyền	11.22	0.19	11.02	0.00
3	Lê Chân	11.81	2.37	9.39	0.04
4	Hải An	104.84	39.91	64.37	0.55
5	Kiến An	29.52	11.93	17.41	0.16
6	Đồ Sơn	31.41	14.03	12.10	5.27
7	Thuỷ Nguyên	242.79	125.27	104.95	12.56
8	An Dương	97.56	59.36	36.26	1.94
9	An Lão	114.90	66.66	46.06	2.17
10	Kiến Thuỵ	164.32	95.27	64.48	4.55
11	Tiên Lãng	189.62	130.63	52.33	6.65
12	Vĩnh Bảo	180.53	128.60	49.48	2.44
13	Cát Hải	323.11	188.60	121.44	13.06
14	Bạch Long Vĩ	3.19	1.06	1.05	1.08
Total of province		1,519.37 (100%)	866.82 (57.0%)	601.90 (39.6%)	50.64 (3.3%)

Figure 8: Land-use Hai Phong districts [Department of Environment and Resources Hai Phong, 2005]

	Effectuate in 2005	Effectuate in 2006	Growth 2006 relative to 2005
Gross Domestic Product (GDP) 1994 Pricing	14,043.10	15,799.30	112.51%
Agriculture, Forestry, Aquatic Branch	1,615.50	1,681.20	104.07%
Industry- Construction Branch	5,670.20	6,453.10	113.81%
Service Group	6,757.40	7,665.00	113.43%

Figure 9: Hai Phong GDP and sectors [http://www.haiphong.gov.vn]

The relatively high percentage of industrial share of the GDP is because of the port of Hai Phong. The Hai Phong city port is located in the Cam estuary, about 15 kilometers inland from the coast of Hai An district. The port's area is still expanding to peninsular Dinh Vu and also island Cat Hai is marked for port expansion. The port mainly handles general cargo, dry bulk and some containers (see Figure 10). Twelve privately owned berths and a number of terminals are available at the moment and the maximum accepted vessel size currently is 40,000 DWT (Vietnam port association, 2008 [xv]).

The Hai Phong port and its corridor to Hanoi are both seen as economic growth areas. Dinh Vu island and Cat Hai island are appointed economic growth zones and new (port) industry is expected in these areas. Also deepening the ports main waterways is considered as is a plan to protect the developing industry at Dinh Vu and Cat Hai by a new sea dike.

	2001	2002	2003	2004	2005	2006
Total	8,575,000 MT	10,350,000MT	10,518,000 MT	10,500,000 MT	10,511,000 MT	11,151,000 MT MT
Import	4,358,000MT	5,370,000 MT	5,401,000MT	5,370,000 MT	5,370,000 MT	5,199,000 MT
Export	1,336,000 MT	1,400,000 MT	1,758,000 MT	1,800,000 MT	1,911,000 MT	2,825,000 MT
Domestic	2,881,000MT	3,580,000 MT	3,359,000 MT	3,300,000 MT	3,230,000 MT	3,127,000 MT
Container	219,000 Teus	228,000 Teus	377,000 Teus	398,300 TEUs	424,128 TEUs	464,000 TEUs
Ship calls	1,710	2,316	2,650	2,430	2,430	2,056

Figure 10: Hai Phong port cargo throughput statistics 2001 - 2006 [Vietnam Port Association]

2.2.2. Climate and hydraulic conditions

Haiphong has a tropical climate with high humidity and high temperatures. Located within the belt of tropical monsoons of East Asia and adjacent to the South China Sea, Hai Phong is under monsoon influence. The cold and dry monsoons from the Nord-east in winter time occur from November to April. The cool and fresh South-eastern monsoons, during summer time, cause a lot of rain from May to October. The average annual rainfall varies from 1,600mm to 1,800mm.

There are often tropical storms between June to September. The frequency of storms and typhoons appears to have increased in recent years. Typhoons are normally accompanied by storm surges, wind set ups and wind waves. The damage due to a typhoon in the Hai Phong area is mostly less than that experienced in other parts of the country, since the area is relatively well sheltered.

The winds and waves are mainly influenced by the monsoon winds of East Asia. On the basis of statistical figures on wind and waves at Hon Dau gauging station (located on a small island in front of Do Son peninsular), the level of rising water caused by storms at the studied area can be determined. This data is presented in chapter 4.3 where it will be used to determine maximum water level return periods. In the coastal zone near Haiphong the tides are diurnal with a spring tide/neap tide cycle of 14 days. In this area of the South China Sea the diurnal tide current plays the main role in determining the currents.

2.3. Nam Dinh

Nam Dinh province is located to the South of where the Red River enters the South China Sea. This region was formed by deposition of sediment from the Red River. Nam Dinh province has 10 districts, of which 3 districts are adjacent to the sea (see Figure 11). From North to South these are: Giao Thuy, Hai Hau and Nghia Hung. Because of the fertility of the alluvial soil Nam Dinh province is attractive for agriculture and is also a densely populated area of Vietnam. Like most provinces in the Red River Delta, the population density is on average over 1,000 people per square kilometer (see Figure 12).

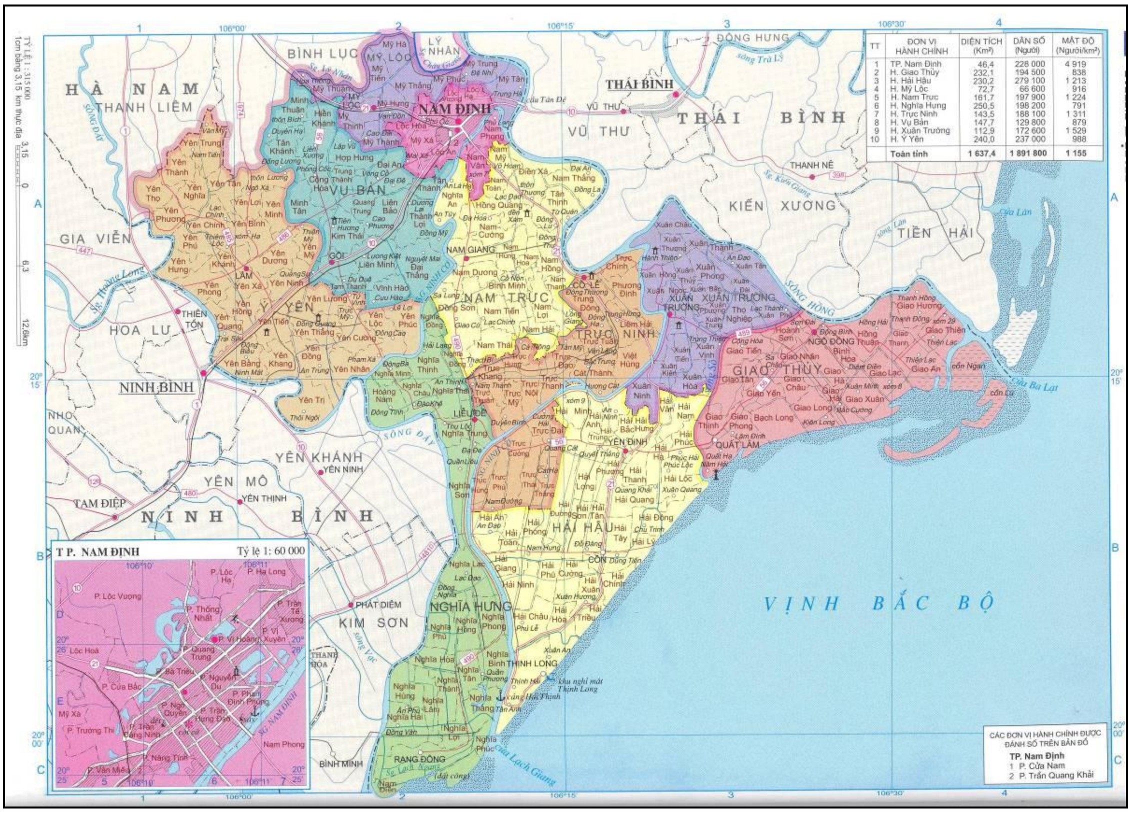

Figure 11: Nam Dinh province [Vietnam Administrative Atlas]

Nam Dinh	surface area (km$^{2)}$	population	population density (per km^2)
Nam Dinh	46.4	228,000	4,919
Giao Thuy	232.1	194,500	838
Hai Hau	230.2	279,100	1,213
My Loc	72.7	66,600	916
Nam Truc	161.7	197,900	1,224
Nghia Hung	250.5	198,200	791
Truc Ninh	143.5	188,100	1,311
Vu Ban	147.7	129,800	879
Xuan Truong	112.9	172,600	1,529
Y Yen	240.0	237,000	988
Nam Dinh province	**1,637.4**	**1,891,800**	**1,155**

Figure 12: Nam Dinh districts [Vietnam Administrative Atlas]

Nam Dinh has a coastline of 70 kilometers divided over three districts (Coastal Morphology – A Case Study in Province of Nam Dinh, Vu 2003 [xvi]):

- Giao Thuy district; from the Ba Lat estuary to the So estuary - 27 km.
- Hai Hau district; from the So estuary to the Ninh Co estuary - 27 km.
- Nghia Hung district; from the Ninh Co estuary to the Day estuary - 16 km.

2.3.1. Economy and economic growth

Current main source of income in Nam Dinh province is derived from agriculture and aquaculture. Together the land-use by these sectors combined is 70% of the total surface area of Nam Dinh (see Figure 13). The next years growth in agricultural and aquacultural output is expected, but less than the growth in the other sectors. Predictions are that percentage of the land-use of agriculture and aquaculture will decrease over the years.

Classification	Total area (km^2)	Percentage (%)
Total area	1,637.40	100.00
Agriculture (of which:)	1,066.62	65.14
Annual crops	910.67	55.62
Fruit bearing trees	73.88	4.51
Perennial crops	0.65	0.04
Grassland for raising cattle	0.22	0.01
Aquaculture	81.20	4.96
Forestry	47.23	2.88
Forests	47.21	2.88
Experimental area for good species	0.02	0.00
Specialized area	253.12	15.46
Residential area	93.99	5.74
Un-used area, rivers, mountains etc.	176.44	10.78

Figure 13: Land-use Nam Định in the year 2000 [Institute of Statistics and Economics, 2000]

Some growth is expected in the service sector. Especially the tourism branch is expecting growth, with the beaches and popular tourist cities Quat Lam and Thinh Long as main attractions. In both of these tourist towns new hotels and bars are constructed. For the development of the industry current plans are not available, but this development can be seen at a few locations in the coastal districts, for example the Ninh Co River mouth. As long as the province still copes with the erosion problem (see chapter 2.3.3) no high investments in the coastal area are expected.

2.3.2. Climate and hydraulic conditions

Nam Dinh province has a tropical climate with maritime influence. Average rainfall is comparable with Hai Phong province and between 1,600 and 1,800 mm. per year, 85% of this falls during the rainy season (April to October). During August and September, when the rainfall is at its yearly maximum, the heavy rainfall can cause (inland) flooding. The winter is cool and dry with temperatures between 16 to 21 degrees Celsius, but during summer the average temperature is about 28 degrees Celsius with high humidity.

Typhoons and tropical storms frequent the area between July and October. With the typhoons come torrential rain causing severe flooding and erosion to the sea dikes. Storms in the Nam Dinh district with winds over Beaufort strength 9 (or higher) caused in the period from 1976 till 1995 the loss of more than 4,000 houses, 6 fishing ships and the lives of 25 people. The most damage occurred at shrimp hatching ponds and salt mining fields. Due to storm and wave actions, water set-up combined with high tide the sea dike system in Nam Dinh gets damaged almost every year (Coastal Morphology – A Case Study in Province of Nam Dinh, Vu 2003 [xvi]).

As Hai Phong also Nam Dinh experiences two wave climates, dictated by the winds of the East Asia monsoons. The summer monsoon, from May to September, gives waves mainly coming from the South. The winter monsoon, from October to April, gives waves coming from the North-east. This influences the sediment transport and erosion processes as briefly discussed in paragraph 2.3.3.

Nam Dinh has a diurnal tide with a tidal range of around 3 meters. Observations at Hon Dau gauging station are also seen as representative for Nam Dinh and show that the tide in this area is purely diurnal. One high tide and one low tide each day, one spring tide and one neap tide each month.

2.3.3. Erosion

Severe erosion problems occur South of the Red River mouth in Nam Dinh province, in Hai Hau district. 30 Kilometers of the coastline of Nam Dinh face erosion at a rate of 10 to 20 meters per year. This started in the beginning of last century. On the contrary, the districts Giao Thuy and Nghia Hung districts experience accretion from sediment from respectively the Red River and the Day River.

According to studies by Vu and Wijdeven the erosion can be explained by the sediment transport processes. During summer the Red River has a large sediment output with mostly suspended sediment transport. Due to the South-Western monsoon this sediment gets transported to deep water. During the winter there is low sediment output and the North-East monsoon does not return the sediment eroded during summer (Coastal Morphology – A Case Study in Province of Nam Dinh, Vu 2003 [xvi] and Coastal Erosion on a Densely Populated Delta Coast - a case study of Nam Dinh province, Red River delta, Vietnam, Wijdeven 2002 [xvii]). Erosion in Hai Hau district causes the undermining and the resulting settlement of the toe of the sea dikes, thereby endangering the sea dikes.

2.3.4. Land reclamation and tandem dike system

Over the years the inhabitants of Nam Dinh have increased the province surface area by land reclamation. Newly formed tidal flats were reclaimed by building dikes to protect the lands. The land reclamation in Nam Dinh characterizes the expanding of the Red River Delta. During the French colonial period urban areas like Hanoi, Hai Phong and Nam Dinh experienced growth and also the plantations that the French set up increased the need for new land (Coastal Erosion on a Densely Populated Delta Coast - a case study of Nam Dinh province, Red River delta, Vietnam, Wijdeven 2002 [xvii]). In the Nghia Hung district this reclamation process still continues, but in Hai Hau however severe coastal erosion has caused this process to reverse.

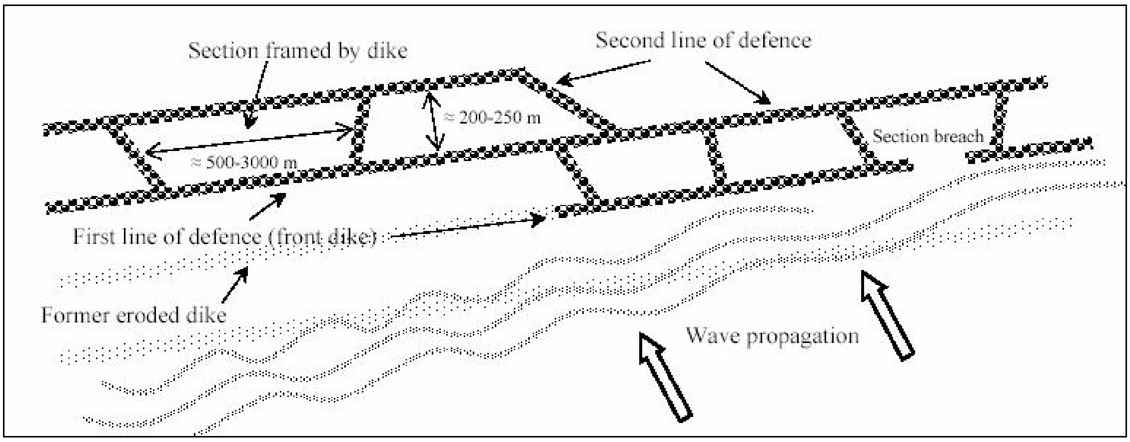

Figure 14: Nam Dinh tandem dike system [Mai]

Most of Nam Dinh's coastal areas are protected by a tandem (two) dike system (see Figure 14). This is built based on the character of typhoons in the area. Typhoon and storm attacks seldom last longer than six hours. The first dike is supposed to withstand wave-attack, but the area between both dikes can flood and the second dike stops the flooding before it can get more inland. The sections between the two dikes vary in width between 100 meters and 3 kilometers, but the general distance between them is 200 to 250 meters. Based on previous flooding events the system proved to be successful. During (most of) the storms of the last decades only the areas between the two dikes were flooded.

2.4. Fieldtrip

Next to the statistical data presented in the next chapters, data was gathered by a fieldtrip in the beginning of the project period. This site-visit is important to get a feel for the spatial and temporal scales of the problem. It helps in acquiring background information for the set up of the project as the present local situation can be visited. It is also a good opportunity to gather extra formal, but also informal, information and thereby gives a clear overview of the situation. This can be a supplement to the statistical data. This chapter has the intention to give this overview and is illustrated with various photos taken during the fieldtrip.

In the period from Thursday February 28 till Saturday March 1 the fieldtrip was held to see the study area. With a group of four persons of the WRU and a driver this fieldtrip was done. The four participants were Mister Nguyen Ba Quy (director subproject 4, WRU), Miss Pham Thu Huong (Coastal Engineering faculty WRU), Mister Nguyen Quang Chien (Coastal Engineering faculty WRU) and Marten Hillen. The fieldtrip mainly consists of a visit of the coastal districts of the two provinces to see the environment of both provinces, the current coastal defence system, to get an impression of the economic functions and values in the area and to see planned economic development.

In the three day period most of the coast of both provinces was visited and Mr. Dang Ngoc Thang (Nam Dinh provincial dike department) and Mr. Ca (Hai Phong provincial dike department) showed the current coastal defence system. During the fieldtrip a few local workers were interviewed to get an impression of their life in the coastal districts. This chapter will describe the fieldtrip and the impressions. Paragraph 2.4.1 is about the Hai Phong province and paragraph 2.4.2 about the Nam Dinh province. This is not according to the schedule of the fieldtrip itself. The first day of the fieldtrip Nam Dinh province was visited and on the second and third day Hai Phong province, but to keep the report consistent the provinces are discussed in a different order.

2.4.1. Hai Phong province

The province of Hai Phong is situated in the North of the Red River Delta. It contains several river mouths and estuaries and is bordered by the Bach Dang River in the North and the Thai Binh River in the South. The city of Hai Phong is the capital city and one of the largest ports of Vietnam. Another city in the Hai Phong province is Do Son, popular among Vietnamese tourists for its beaches, luxury resorts and nightlife. The islands of Cat Hai and Cat Ba, South of the UNESCO World Heritage site Ha Long bay, are also part of the province.

The site-visit of the province of Hai Phong started in Do Son. Here a local office of the provincial dike department is situated. Mr. Ca of the Hai Phong dike department gave a tour along the dikes North of Do Son and the ports of Hai Phong and Dinh Vu were visited. The coastline in the Hai Phong province has been stable for the last decades and due to its climate and the port activities a lot of new tourist- and industry facilities are planned.

Current state of sea dikes

The coastal areas of Hai Phong provinces are protected by one sea dike (in contrast to the tandem dike system of Nam Dinh province). The coastline of Hai Phong province has a muddy foreshore and at most places along the coasts sandbanks are found in front of the dike. At the sea side of most of the dikes South of Dinh Vu mangroves are planted (see Figure 15). Twenty years ago a program started which started the planting of young mangrove trees in front of the dikes to prevent wave run-up and wave overtopping. This was considered a success and this resulted in the decision to plant mangrove trees in front of every dike North of Do Son. The exact effect of these mangrove trees is still under discussion. The current state of most of the mangroves that have been planted is good, but not all trees look healthy, maybe this is because of the fact that these trees need a very specific environment in which they can grow. The Hai Phong provincial dike department emphasizes that it has been a success so far and therefore the program continues.

Figure 15: Mangrove trees in Hai Phong province [photo: Hillen]

The dikes in Hai Phong are relatively high earthen dikes and most of them also have revetment. Between Do Son and the Lach Tray estuary new revetments have been applied to the dikes. Such a dike can be seen in Figure 16. This dike was upgraded after typhoon damage (typhoon Damrey in 2005) and reinforced in 2006 and is part of a three kilometers stretch of upgraded dike in Hai Phong. The dike department takes care of the sea dikes on the land-districts of Hai Phong. Only Cat Ba island does not have traditional sea dikes since this is a mountainous island.

Figure 16: Restorated sea dike Hai Phong province, left is sea-side [photo: Huong]

Important to state is that most of the tourist facilities and resorts, especially the resorts still under construction, in the Do Son area are not situated behind sea dikes. Also the port facilities of the Dinh Vu port do not have the protection from dikes (yet). More inland the port of Hai Phong city is protected by sea and river dikes.

Port

The port of Hai Phong is a combination of several privately owned enterprises. From the center of Hai Phong it expands to the newly constructed facilities on Dinh Vu island. The port has expanded quickly over the last years, which can be clearly seen if one enters Dinh Vu island. Here a lot of new industry is present and in the end of 2005 new bulk and container terminals started to operate. Currently most of the terrain is still undeveloped, but big signs show the facilities to be built in the near future (see Figure 17). It can be seen that the port of Hai Phong prepares for a higher container throughput. The ships that call the Hai Phong port at the moment are not large intercontinental container vessels, but larger river carriers. Most of the port facilities at the moment are focused on bulk. The Bach Dang and Cam estuaries are used to transfer goods into the inner parts of the port of Hai Phong.

Figure 17: Dinh Vu port facilities (left) and planned facilities (right) [photo: Hillen]

The port facilities which are inside the Bach Dang estuary are not subject to flooding from the sea (Gulf of Tonkin) since this estuary is relatively well sheltered by several islands in front of the estuary. The facilities at Dinh Vu however are not protected by dikes or other coastal structures. Even without any protection to flooding a lot of investment is made and planned in this area.

Do Son

Do Son is a peninsular which high rocky coasts stretch into the sea. From these high parts you have a nice view over the city of Do Son. The stretch of beaches and hotels on the rocky coasts attracts a lot of tourists (mostly Vietnamese) because of the nice climate in the summer time. The last king of Vietnam, king Bao Dai, had a summer resort in this place and the French colonists constructed a casino on one of the rocky hills. This illustrates the popularity of this region.

The hotels and resorts are fully booked during summer times (May till August) and the city is relatively quiet in the periods outside high season. From the end of July till September it is less attractive due to the tropical storms that rush through the area. The beaches are only accessible by low tide. Next to the beaches walls are constructed on which a boulevard is built. During typhoon Damrey in 2005 part of this boulevard was destroyed and it was rebuilt in the next winter period.

With rising incomes in Vietnam and increased accessibility Do Son is attracting more tourists each year. Along the low-lying beaches a lot of artificial islands are constructed to host luxury resorts in the future. Some of these islands are a little comparable with the palm islands in Dubai, although these resorts are constructed on a smaller scale. The conditions of some these construction look relatively poor (see Figure 18) and although still under construction they already show signs of deterioration.

Figure 18: Construction of artificial islands in Do Son (left) and state of the sea wall (right) [photo: Hillen]

Employment and investment

Along the coast of Hai Phong a lot of aquaculture can be found. Next to the traditional fishery, with boats going to the sea at high tide and the farming of shell-fish along the muddy coast, there is a significant amount of shrimp farming behind the dikes. The area used for shrimp farming North of Do Son is bought by investors who are planning an industrial area here. Currently these ponds look deserted. A lot of new industry is also planned in the surrounding area. A new convention center (see Figure 19) has already been built and around this area more investment is expected. The infrastructure in this area is in good condition and relatively new. Traditional crops and rice farming are still the major sources of income in Hai Phong and in the coastal areas an increasing amount of people work in the port- and tourist industry.

Figure 19: Deserted shrimp farms (left) and a new convention center in Do Son area (right) [photo: Hillen]

2.4.2. Nam Dinh province

In Nam Dinh province the coastal districts Giao Thuy and Hai Hau were visited. This is approximately 75% of the coastline of Nam Dinh province. The fieldtrip started in the North-eastern part of Giao Thuy at the Ba Lat estuary (Vietnamese Cua Ba Lat) at the Red River mouth close to the newly acclaimed Ramsar site. From this site the route went via touristy Quat Lam to the eroding coast of Hai Hau district. The fieldtrip ended at the Ninh Co river mouth where the among Vietnamese tourists popular Thinh Long area was visited and the ship yard in the Ninh Co river mouth was seen.

The severe erosion of Nam Dinh province (especially Hai Hau district) makes it an interesting study area for Coastal Engineers. In the past decade a lot of studies have been conducted on the morphology of this province, but also on the dikes and the dike system.

Currently Nam Dinh province still has a quite rural character, with a lot of agriculture along the coast. The beaches and hotels in Quat Lam and Thinh Long are, on the other hand, an increasingly popular tourist attraction. Although there is a small port in the Ninh Co river mouth and some industry can be found along the coast, most of the companies seen in Nam Dinh are small scale salt-, duck-, shrimp- en fishfarming. Even with the erosion-problem in Hai Hau district, Nam Dinh province has potential to develop itself into an attractive place for investments.

Current state of sea dikes

The dike system in Nam Dinh province was subject to a lot of damage caused by the storms of the 2005 storm season. This gave the upgrading of the sea dikes priority. In most of Nam Dinh a tandem dike system is used. A first dike to reduce wave-action (this dike can be overtopped) and a second dike (more inland) is constructed to withstand only a water level difference. This second dike is not able to cope with large forces, only to withstand a certain water level.

Historically more and more land was reclaimed from the sea by constructing a new dike more towards the sea. This land-reclamation continued till a decade ago. This process however still continues in the Southern coastal district Nghia Hung where a lot accretion goes on at the South of Nam Dinh province.

The sea dikes of the three coastal districts of Nam Dinh province have a different character. The coast of Giao Thuy (Northern district) is relatively stable and near the Red river mouth accretion occurs which forms the current Ramsar site. The dikes of Giao Thuy have recently been upgraded with loans from the Asian Development Bank. In Giao Thuy the first sea dike is a high earthen dike with inner and outer slope protection. The toes of these dikes are the instable parts of the dike. Toe protection is often offered by concrete cylinders with sand, but these do not look very stable.

The first dikes have recently been upgraded and are provided with a new concrete revetment. The second dike is a relatively low earthen dike without revetment. Sometimes it is hard to recognize the second dikes because of the activities in front of this dike (like rice-farming or salt mining) which also use small dams themselves. At parts of Giao Thuy extra measures were constructed such as toe protection mentioned above, or T-groins although they were build insufficiently long to stop long-shore sediment transport due to lack of funding. One section of the first dike in Giao Thuy district is strengthened by tetrapods to minimize wave-impact (see Figure 20). In tourist town Quat Lam a lot of hotels are in a section which is not protected by dikes. These hotels are used to small flooding (0.5 meters) during storm season (August-September).

Figure 20: Giao Thuy sea dike (left) and tetrapods (right) [photo: Hillen]

In Hai Hau district the dikes are under a lot of pressure. This area suffers from erosion at a very high rate. Where in the past dikes were constructed towards the sea (for land reclamation), these dike-sections had to be given up and the second dike became the new sea-dike (and a new second dike had to be constructed). The erosion of Hai Hau district gives some dramatic pictures of churches in the muddy foreshore of the district (see Figure 21). During typhoon Damrey flooding occurred in the Southern part of Hai Hau district. In the Norhern part only the area between the two-dike system was flooded, which is no problem since it is constructed for this purpose. Salt-farmers could tell that this area never experienced flooding, the water only came to the second dike.

Figure 21: Second dike has become first dike (left) and erosion in Hai Hau district [photo: Hillen (left), photo: Huong (right)]

Tourism and industry

In Nam Dinh tourism is concentrated in Quat Lam (Southern part of Giao Thuy district) and Thinh Long (Southern part of Hai Hau district). Both towns feature boulevards with numerous restaurants, hotels, bars and karaoke places. Quat Lam is (like Do Son in Hai Phong province) also an infamous red light district. Both are popular among Vietnamese tourists and are crowded during summer time. Tourism is on the rise in Vietnam and at the borders of both Quat Lam and Thinh Long new hotels are constructed, but on smaller scale than the development in Do Son.

Not a lot of industry can be seen (directly) behind the dikes of Nam Dinh province. Development is going on at the Ninh Co river mouth at the South of Hai Hau district. Here a modern shipyard is constructed and there are plans for more investment in this shipyard and its surroundings. The shipyard company would like a groin to be constructed at the Ninh Co river mouth. In the North of Giao Thuy, more inland in the Red river also ship yards are present, but this industry is relatively well protected by the coastal lands and the accretion at the Red river mouth.

Employment in Nam Dinh

Nam Dinh province is less industrialized compared to Hai Phong province. In the coastal districts a lot of traditional rice-, duck-, shrimp- and salt-farming is still present. These areas have relatively little investments and the workers have to work hard to earn some profit. It is not legal to live between the two dikes, but here small temporary houses are constructed by workers who sleep at the site during periods of harvest. Also some small storage houses are constructed between the two dikes, but most of the farmers do live further inland. Observed from the interviews some of the employment in Nam Dinh province is around the poverty line of 1USD/day income (see Figure 22 and Figure 23). It is important to note that these people are directly hit when flooding occurs in this area.

Salt-worker

"The price of salt is not very high. During a year I got several tons of salt from one hectare. Usually I have an income of about 500,000 VND per month (32USD). I feel safe behind the second dike, this land never flooded. When a typhoon hits this area I go to my home which is located approximately 500 meters more inland."

Figure 22: Salt worker [photo: Hillen]

Fisherman

"I go fishing when it is high tide. Last night we went out fishing at 3 a.m.. My income depends on the catch and is between 1,000,000 VND to 4,000,000 VND per month. It is hard work to be a fisherman, but it gives me a good income."

Figure 23: Fisherman [photo: Hillen]

3. Risk-based approach

In this chapter a new approach and method for defining Vietnam sea dike safety standards is given. In chapter 4 an economic optimalization method will be used to find safety levels of different dike sections and later in chapter 4.6 to find safety standards. The introduction (chapter 3.1) motivates the use of a new approach to determine sea dike safety standards. Chapter 3.2 introduces the project's definition of safety standards. The next chapter (chapter 3.3) illustrates the current Vietnamese approach to determine dike design guidelines. This chapter also illustrates how current Vietnam safety standards are determined. Chapter 3.4 illustrates the use of probabilistic design. Next, in chapter 3.5 the method to determine economic optimal safety levels of dike sections is explained. This is the method that will be applied on the study area.

3.1. Introduction

Where the Vietnam sea dike subproject 4 is an initiative to set up new sea dike design guidelines, this report helps to find safety standards which can be needed to determine these guidelines. Sea dike guidelines can be determined in different ways. To create safety in coastal areas with residential and agricultural functions sea dikes were built to prevent the sea from flooding the land. Historically, the first dikes constructed by humans were made just a little higher than the highest water level they knew. With this approach the dikes were consequently increased in height and strength after a higher water level (and flooding) had occurred. Over time the knowledge on dike construction, but also on hydraulic conditions, increased. This resulted in using better construction methods for dikes and in better guidelines for dike design. Today, dike heights are still determined in many different ways, mostly combining different formulas to find out what height, or actually what strength is needed for a dike.

Safety standards for dikes give a safety level with an exceedance frequency which a dike should be able to withstand. This safety standard with corresponding exceedance frequency can be determined in various ways. The concept of finding safety standards with economic optimalization appears to be good applicable for the Vietnamese situation. With the future of Vietnam in mind, this new approach takes into account future scenarios and is a step forward for decision-making in coastal zone management of Vietnam.

The approach illustrated in this chapter is considered to correspond with Vietnam's ambitions. To find an approach and a method that would really work for the Vietnamese situation, this chapter is focused on that situation and the calculation in the next chapter are made according to the Vietnamese perspective. The method shown here is rather basic and it could be done in more detail, but to set up a very detailed approach and use of such a method is not the main goal of this project. The focus is on introducing it, rather on executing it in great detail and finding the exact numbers.

3.2. Safety standards and risk

Sea dikes try to increase the safety against flooding from the sea. Safety against flooding is always a subjective topic and is in the end an important (and difficult) political decision. The level of safety depends on the perspective from which it is approached and is therefore psychological. Total safety can never be guaranteed or achieved. Therefore the task to determine a certain safety standard is a difficult one.

The concept of safety standards is rather abstract. A safety standard in this project gives the safety level one thinks should be applied for a certain situation; a certain coastal area to be protected. To derive such a standard various steps are executed in this project. First, several safety levels are determined for various locations; they are calculated per coastal district of the study area - per coastal district of the provinces Hai Phong and Nam Dinh. Since safety is a psychological concept it cannot be used to calculate safety levels. But, although safety is a psychological concept, it is closely connected risk. Within this project safety is therefore based on risk. Risk is within the Safety Standards project defined as a product of probability and consequence. In this way a safety standard gives the risk acceptability and then the question what risk level is acceptable should be answered. This helps to assess the safety of technological problems and make decisions based on a risk assessment.

In this report safety standards determine the design conditions on which the construction of sea dikes should be based. A safety standard defines the safety level which (in this case) a dike should be able to withstand. These safety standards are expressed in an exceedance frequency (frequency of x/year(s)), which indicates the probability of flooding of the coastal area.

Safety, risk and safety standards are abstract conceptions. The above description only gives a short explanation. More detailed definitions and descriptions can be found in literature. More information is given in the Delft University of Technology lecture notes on 'Probability in Civil Engineering' (Vrijling, 2000 [xviii]), several publications on risk and safety by Vrouwenvelder and Vrijling and specifically for the Vietnam situation in 'Risk analysis of coastal flood defences: a Vietnam case' (Mai, 2008 [xix]).

3.3. Current Vietnamese approach

Several approaches towards acquiring construction guidelines can be seen over the world. Most common are deterministic approaches which are widely applied, including in Vietnam. Although this project focuses on another approach towards defining dike design guidelines in Vietnam, it is interesting to investigate the current approach.

Like stated in the introduction (chapter 3.1) dike height is traditionally based on a certain water level, which for example can be the highest known storm surge level. This approach towards dike design is still the standard approach in most countries in the world. Dike design in Vietnam has a similar approach. In the dike design guidelines given by the Ministry of Agriculture and Rural Development (MARD, 14 TCN 130–2002 [xx]) the design dike height is determined by summing several factors, see Figure 24.

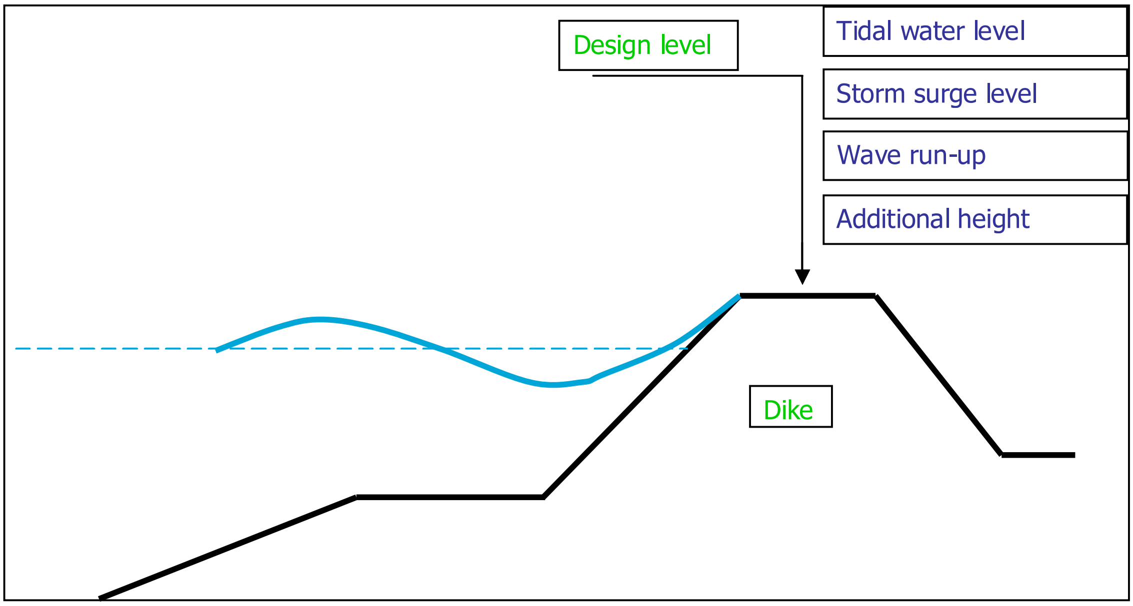

Figure 24: Design dike height according the Vietnamese approach [Hillen, based on Vrijling]

This approach still dates from 2002 and part of the Vietnam sea dike project is to update these guidelines. In 2007 an addendum was added to the 2002 guidelines and although these guidelines are still the governing guidelines already new approaches are used. Next to a formula to determine dike height, the design guidelines describe in detail the construction of dikes, their revetments and solutions to prevent toe erosion. In chapter 4.2 this guideline is used to determine the dike costs. The calculation to find the design level (dike height) according to the current Vietnamese design standards is for example made with formula (3.1).

$$Z_d = Z_{tp} + H_{nd} + H_{sl} + a \quad (3.1)$$

in which:

in which:	Z_d	crest level of the dike [m]
	Z_{tp}	design tidal water level [m] *(a)*
	H_{nd}	surge height during construction [m] *(b)*
	H_{sl}	wave run-up [m] *(c)*
	a	free board, calculated based on standards [m] *(d)*

(a) Design tidal water level Z_{tp}
This water level is based the tidal water level corresponding to an exceedance frequency P = 5%. This means that 5% of the tidal water levels is higher than the design level. This governing tidal water level for the Vietnamese sea dikes is around 2 to 2.5 meters (Emergency closing dike breaches, 2007 [xxi]).

(b) Storm surge height H_{nd}
The storm surge set up is based on a storm with wind speeds between 9 and 11 on the Beaufort scale. This usually gives a storm surge set up of around 2 meters.

(c) Wave run-up h_{sl}
The wave run-up is calculated with a run-up formula ($h_{sl} = K_\Delta \cdot K_w \cdot K_\rho \cdot K_\beta \cdot R_0 \cdot \overline{H_s}$). This formula takes into account the roughness and permeability of the slope, the angle of the incident wave and the significant wave height near the dike.

(d) Free board
An extra safety height, which is usually between 0.1 and 1.0 meter.

The guideline is outdated and research already pointed out that formulas used are out of date or not applied correctly (Safety Assessment of Sea Dikes in Vietnam, Mai 2004 [xxii]). The needed formula and numbers can be determined more precisely now a days. The Vietnamese approach does not take uncertainties, the costs of dike construction and the (economic) value of the hinterland into account. Compared with the situation in Vietnam this approach does not satisfy the goals of the Vietnam sea dike project.

3.3.1. Vietnam safety standards

In the 2002 Vietnam sea dike guideline several different classes of sea dikes are described. For river dikes in Vietnam already a system with different classes (corresponding with different safety levels) exists, but there is no general approach for the coast of Vietnam. Every provincial dike department also has a major influence on determining different sea dike classes. The way the dike system is currently classified was mostly done in the past and is based on old set of indicators. The existing different classes are based on the following criteria (Department of Dike Management and Flood Control, 2008 [xxiii] [xxiv]):

- Area and administrative borders
- The importance relating to defence, security and social-economics
- Population in the protected area
- Characteristics of floods and storms
- Average inundation depth of populated areas compared to design water level

Unfortunately the sea dike design guidelines do not describe how and how much these characteristics contribute to defining several classes of dikes and thereby several safety standards. No clear guidelines on this subject are available. This makes the classification of dikes into different safety standards unclear. With the current Vietnam sea dike project MARD also aims for more detail in this classification.

3.4. Probabilistic design

With a deterministic approach one assumes that a dike is safe when the value of the load does not exceed the design value of the dike. Therefore the safety level of the protected area as a whole is not explicitly known. With this approach the failure probability of the system, which is the sea dike system in this case, is also not known. The dike is regarded as a single element, not in relation to the protected area. Next to this, the length of the sea dike is not taken into account, which also influences the probability of flooding.

With the deterministic approach, as described in the previous chapter, sea dikes will in the end be constructed based on an exceedance probability which is the same along a stretch of coast with the same hydraulic conditions. This means that these coastal areas face the same chance of failure and the amount of damage due to flooding is left out of the dike design. Especially with respect to the future of Vietnam, the value of the hinterland can be a very important factor. While Vietnam is undergoing a dynamic period with a lot of change, many changes can be expected to take place along the coast (see paragraph 1.2.2). The economic growth and major changes in the coastal areas of Vietnam are not taken into account with this deterministic approach.

The probabilistic approach aims to determine the true probability of flooding of a polder and judge the acceptability of flooding with respect to the consequences. Probabilistic design methods are, contrary to the deterministic approach, based on acceptable probability of flooding. The accepted probability of flooding is not the same for every (coastal) area. Sea dikes do not have to have the same strength since it different dike sections have different values for their hinterland. The risk acceptability depends on the topography and hydraulic conditions of the protected area, the expected flooding damage and the safety standards of the country. For this reason accepted risk is a better measure than an accepted failure probability because risk is a function of the probability and the consequences of flooding. The most general definition of risk is the product of the exceedance probability and consequences (see chapter 3.2). Within decision-making total safety cannot be guaranteed, but based on accepted risk good choices can be made. This also helps to find more cost-efficient solutions for coastal safety.

The acceptable level of risk can be determined in different ways. One of these ways is to formulate acceptable level of risk by an economical cost benefit analysis. With this approach the economically optimal design level is calculated to determine safety standards for sea dikes in Vietnam. This approach takes into account the importance of the hinterland of the sea dikes (see Figure 25). The dike designs will be based on a risk analysis as proposed in the report "Probabilistic design and risk analysis of water defenses in relation to the Vietnamese water defense system" (Vrijling and Hauer, October 2000 [xxv]). Due to the lack of time and purpose of the Safety Standards project a simplified approach is used, will be illustrated in more detail in chapter 3.5.

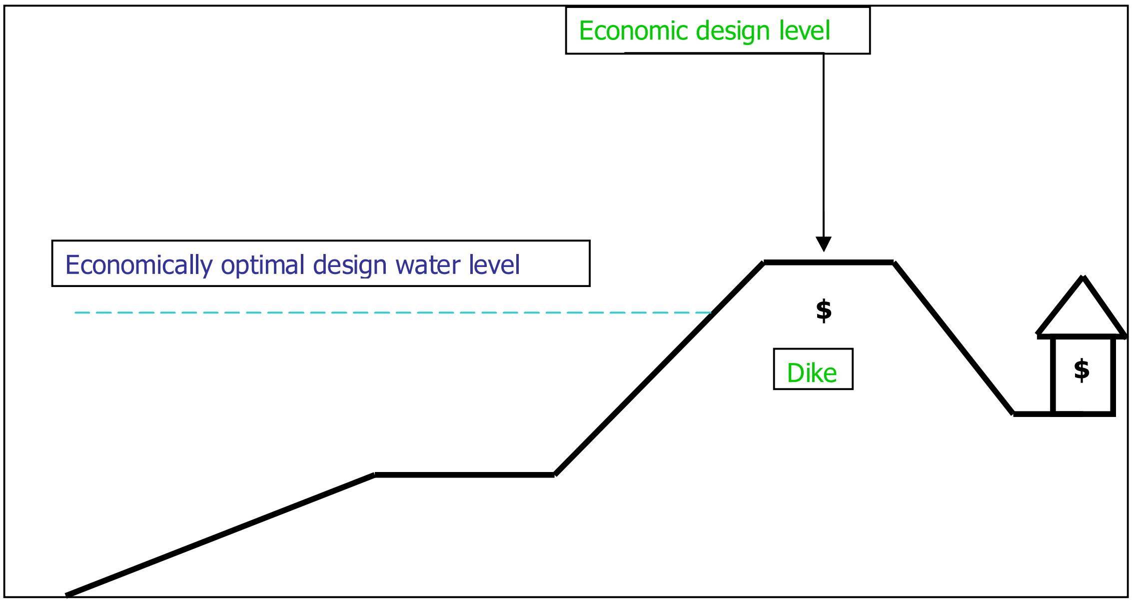

Figure 25: Economic design dike height [Hillen, based on Vrijling]

3.5. Economic optimalization method

The method of economic optimalization considers a coastal area prone to flooding. For this area the optimal safety level will be determined by balancing the investments in safety with the reduction in risk. The area considered depends on the topography of the coastal region and possible internal boundaries. This area is protected against flooding from the sea by dikes. These sea dikes give the area a certain safety level. The economically optimal sea dike design level can be found at the level with minimal total costs (Economic decision problems for flood prevention, 1956 [xxvi]). The costs for such an area are the costs of the investments for constructing (safer) sea dikes (I) and the costs of the expected economic flooding damage (D) (see formula (3.2)). Summation of these costs gives the total costs and the optimal safety level corresponds with the point of minimal costs (see Figure 26).

$$C_{tot} = I + PV(P_f \cdot D) \quad (3.2)$$

in which:

in which:	C_{tot}	total costs coastal area (billion VND)
	I	dike construction costs (billion VND)
	$PV(P_f \cdot D)$	present value of economic flooding damage (billion VND)

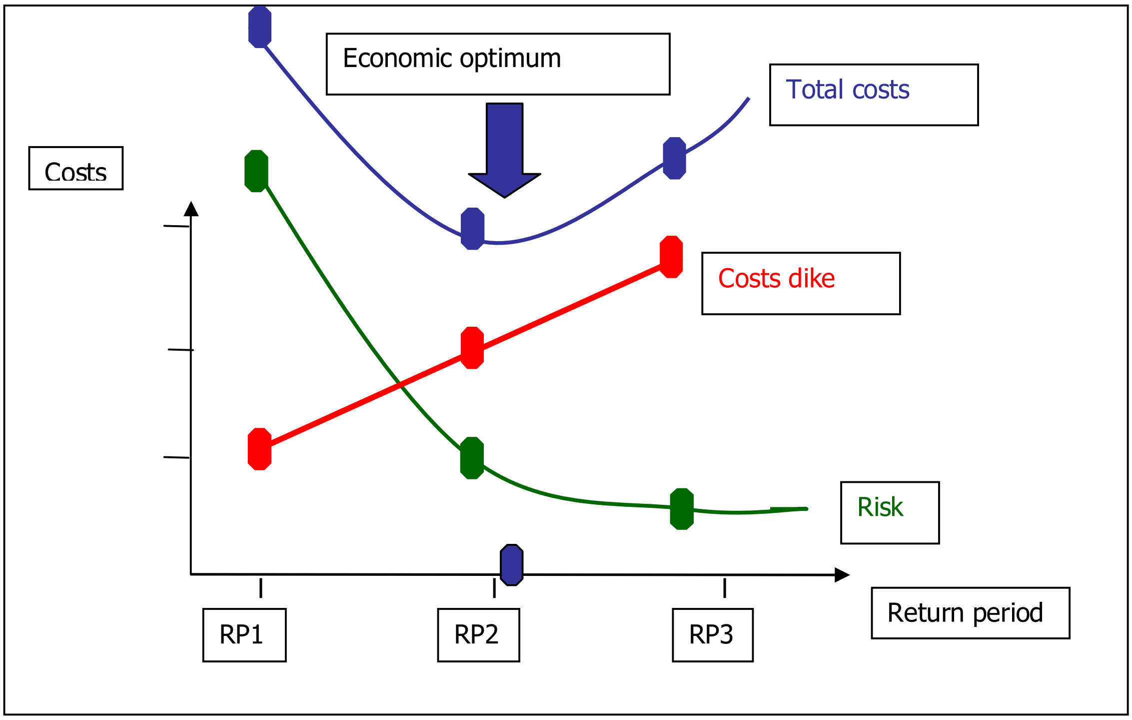

Figure 26: Economic optimum [Vrijling]

This approach is simplified by assuming only one failure mechanism for the sea dike. Overflowing is the only failure mechanism considered, so flooding can only occur when the water level at sea is higher than the sea dike. This is not the case in reality, because with all failure mechanisms taken into account, another failure mechanism than overflowing can occur before the design water level is reached. However, overflowing is a main failure mechanism of a sea dike and this simplification has already proven to be accurate for a first approximation of an economic optimum. Therefore overflowing is considered to be the governing failure mechanism. This assumption links dike heights to certain return periods (which are considered safety levels).

Higher safety is in this situation provided by a higher dike which gives a smaller flooding probability; the dike can withstand storms with a higher return period. This is shown with the graphs in Figure 26. Constructing a higher dike increases the costs (red line in Figure 26). The dike costs consist of the costs made for property rights, constructing the dike body (sand, clay and vertiver grass), applying revetment (on all slopes and toe protection), the construction of a berm, labor and maintenance (formula (3.3)). Of these costs the costs for maintenance are yearly costs, while the other costs are made at the moment of construction. The maintenance costs should therefore be capitalized with respect to the required time horizon (formula (3.4)). In the Safety Standards project an infinite time horizon is used. The present value (PV) of the yearly expected maintenance costs is found by capitalizing the yearly maintenance costs. The costs of dike construction and maintenance are elaborated for the case study area in chapter 4.2.

$$I = I(H) + PV(M) \quad (3.3)$$

in which:	*I*	total investments of safety, total dike costs (billion VND)
	I(H)	dike construction costs per height (billion VND)
	PV(M)	present value of yearly maintenance costs (billion VND)

$$PV(M) = \sum_{n=1}^{T} \frac{M}{(1+r')^n} \quad (3.4)$$

in which:	*PV(M)*	present value of yearly maintenance costs (billion VND)
	T	project planning period or time horizon (years)
	M	yearly maintenance costs (billion VND/year)
	r′	real interest rate (nominal interest rate minus inflation) (%)

The economic flooding damage of the area is considered a constant in the Safety Standards project. This assumption is because of the low-lying coastal areas of Vietnam, which are in the coastal areas of the case study areas between 0.5 and 2 meters above mean sea level. Since the water levels during a storm will probably exceed 3 meters, the complete coastal zone will flood and the total area is considered to be equally damaged regardless the occuring water level.

As the flooding damage is considered a constant, the expected economic flooding damage becomes smaller with higher dikes, dikes which are able to withstand a water level with a higher return period. A lower flooding probability will therefore reduce the risk of flooding (see green line in Figure 26). The costs of the flooding damage are the present value of the expected damage when flooding occurs (formula (3.5)).

$$PV(P_f \cdot D) = \sum_{n=1}^{T} \frac{P_f \cdot D}{(1+r'-g)^n} \quad (3.5)$$

in which:	P_f	probability of failure in a year (corresponding return period) (1/years)
	D	damage in case of flooding (billion VND)
	T	project planning period or time horizon (years)
	r′	real interest rate (%)
	g	economic growth (%)

Economic growth is also taken into account with this method. However, the fast growing economy of Vietnam and its unstable rate of interest and inflation create an uncertain calculation. For the Vietnamese situation the expected economic flooding damage is determined in a different way; with possible growth scenarios. These growth scenarios are described in chapter 4.4. Vietnam's economy is subject to various changes and this causes a highly changing real rate of interest. The influence of the rate of interest is not considered to be high and to have clear comparable calculations one stable rate is assumed. For the calculations a stable real rate of interest (nominal interest adjusted by the inflation) of 2% is assumed.

When the time horizon is considered infinite and economic growth is taken into account as described above, a simplification of formula (3.6) can be used.

$$PV(P_f \cdot D) = \sum_{n=1}^{T} \frac{P_f \cdot D}{(1+r'-g)^n} = \frac{P_f \cdot D}{r} \quad (3.6)$$

in which:

P_f	probability of failure in a year (corresponding return period) (1/years)
D	damage in case of flooding (billion VND)
T	project planning period or time horizon (years)
r'	real interest rate (%)
g	economic growth (%)
r	interest rate (%)

Also for the dike maintenance costs a similar simplification is used (formula (3.7)).

$$PV(M) = \sum_{n=1}^{T} \frac{M}{(1+r')^n} = \frac{M}{r} \quad (3.7)$$

in which:

$PV(M)$	present value of yearly maintenance costs (billion VND)
T	project planning period or time horizon (years)
M	yearly maintenance costs (billion VND/year)
r'	real interest rate (%)
r	interest rate (%)

The aim for the Safety Standards project is to find the right numbers and input to do the economic optimalization calculation properly. Several simplifications are made, but all are considered reasonable estimates for the Vietnamese situation.

3.5.1. Examples

To illustrate the benefits of the method and to show how the method responds to changes in the parameters a few examples are given. These show that (costs-) changes in the area result in different safety levels. In chapter 4 this will be shown for the case study areas, but for extra insight a few examples are given below.

- Decreasing dike costs, for example when cheaper construction techniques are available, result in lower total costs and a higher safety level. Because of the low(er) dike costs it is worth to build a system with a higher safety level (see Figure 27).

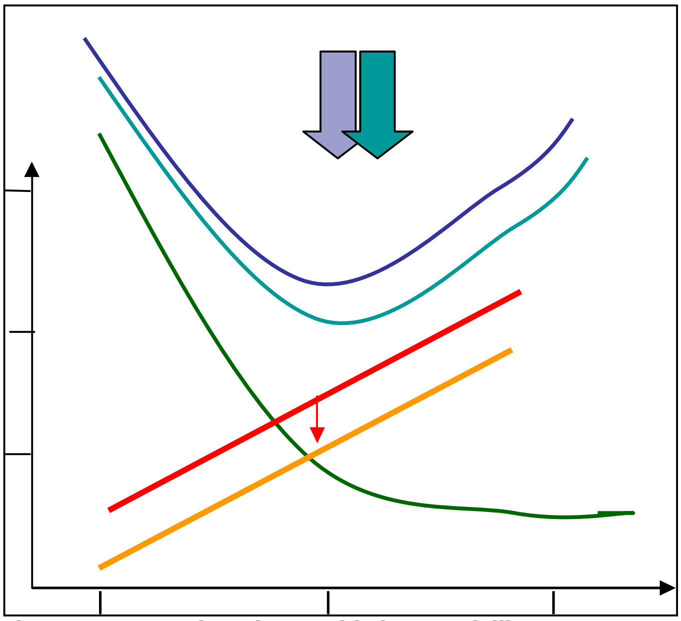

Figure 27: Economic optimum with decreased dike costs

- When the economic flooding damage in the area is expected to be higher, the risk of the area increases. This is also the case with a lower real interest rate, or with higher economic growth. In these situations the total costs will increase because of an increase in risk and this increase will demand a higher safety level. This is visualized in Figure 28.

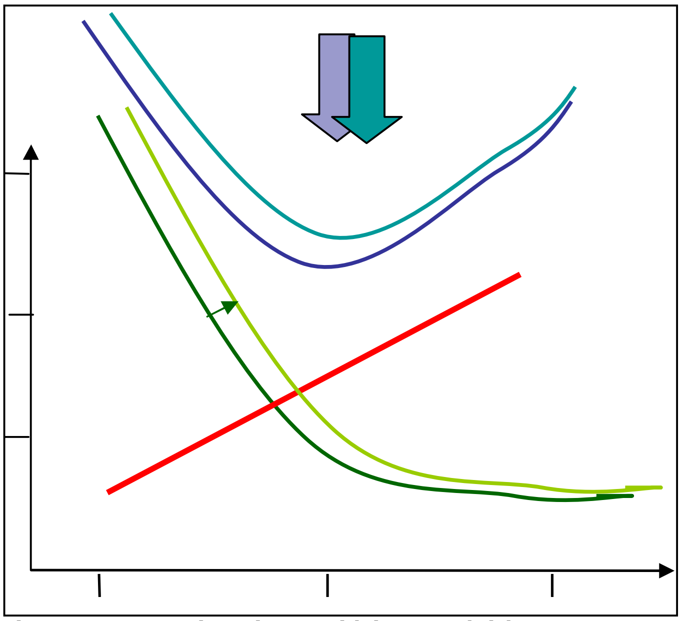

Figure 28: Economic optimum with increased risk

4. Case studies

In this chapter economic optimalization calculations are made for the coastal districts of Hai Phong province and Nam Dinh province. Chapter 4.1 introduces the case studies and explains the focus of the calculations. The next chapters are all steps of the economic optimalization method as illustrated in chapter 3.5. Chapter 4.2 determines the dike costs, chapter 4.3 links exceedance probabilities with these dike costs and in chapter 4.4 flooding damage estimates are given. The results, the economic optimal safety levels, are shown per district in the last chapter (chapter 4.5). In chapter 4.6 three classes of safety standards for Vietnam are derived. Finally, background on how to translate safety standards to dike construction guidelines is given in chapter 4.7.

4.1. Introduction

To illustrate the economic optimalization method to determine safety levels, the coastal districts of two different provinces are used as case studies. This chapter shows that different situations give different economic optimal safety levels. These safety levels are not calculated in detail, but are a reasonable approximation of the Vietnamese situation. The results are indicative estimates, not the exact safety levels. Introducing the new method is considered more important than getting the exact safety levels per district. It also illustrates the importance of good data, because better data gives more accurate results.

For each district two different calculations are made; one based on the current situation and one based on an (potential) economic growth scenario. The economic growth scenario assumes a steady economic growth for coastal Vietnam with extra investments. These scenarios can be compared and give insight in determining safety standards. In the end of this chapter (chapter 4.6) different safety standards for Vietnam are determined based on these calculations.

4.2. Dike costs

To determine the investment needed to create a certain safety level in coastal areas, the costs for dike construction are considered. The area is considered to be without dikes, so the dike costs are the total construction costs of a new dike. This is done because the construction of the current dike structure should be included in the calculation as an investment. The costs are given per 0.5 meter (extra) dike height and the results therefore automatically show the extra costs needed for heightening a dike. Given the poor condition of many of the Vietnamese sea dikes, the costs as determined in this chapter could sometimes be seen as upgrading costs. But in some cases the costs would be lower because of the existence of the current sea dikes.

The costs to construct a dike are based on the dike design standard in Vietnam given by MARD (MARD, 14 TCN 130–2002 [xx]). A standard sea dike cross-section is shown below (see Figure 29). For specific situations the dike costs can be adjusted to the conditions. These specific dike sections are mentioned later in this report.

The costs of dike construction are given in billion Vietnam Dong (VND) per kilometer stretch of sea dike. The amounts as estimated in this chapter are based on one standard cross-section and the costs are based on information provided by the provincial dike departments of Hai Phong and Nam Dinh. The total dike costs are a summation of the following costs to construct a dike: labor + dike body (consisting of sand body + clay layer + vertiver grass) + property rights + revetment + berm + maintenance.

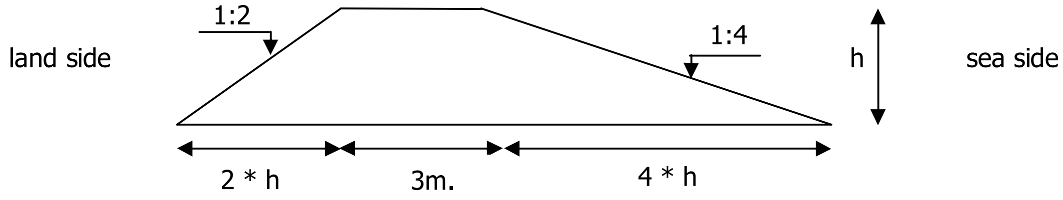

Figure 29: Standard Vietnam sea dike cross-section

Labor

Labor costs are hard to determine in Vietnam. Some of the labor is executed for free by students as part of their social service and for most of the construction work no standards are available. Compared with the costs for the dike body and the revetment labor costs are relatively low. Good estimates could not be given by MARD and the provincial dike departments since most of the labor costs are not clearly communicated by the construction companies. With data from budgets from sea dike upgrading projects of the Asian Development Bank the labor costs are included in the costs of the dike body and the revetment.

Dike body

The costs of the dike body are a summation of the following costs:

- Sand body. The costs of sand depend on the dikes location. One cubic meter of sand costs approximately between 30,000 VND and 120,000 VND. With transport and labor costs the costs are between 80,000 VND/m^3 and 200,000 VND/m^3. In the calculation the costs for the sand body are based on the standard cross-section with the total costs of sand (including transport and labor) of 150,000 VND/m^3.
- Clay layer. A clay layer is applied on both the inner- and outer slope of the sea dike as well as on the crest. For the calculations the thickness of the clay layer is assumed to be 0.50 meter. The costs of clay (including transport and labor) are 250,000 VND/m^3.
- Vertiver grass. Part of the inner slope (and in case of no revetment also the outer slope) of a sea dike is covered with vertiver grass. These costs are considered that small that they are not included in the total dike costs.

Property rights/Land-use

It is hard to give a good estimate of the value of property rights in Vietnam. Some of the soil on which a sea dike is constructed is already government property. Along stretches of sea dike one sometimes finds stretches of land that are already government property in preparation for future dike upgrading. For the calculation the costs of land-use are considered equal to the costs of the corresponding sand body.

Revetment costs

The inner- and outer slope revetment, the crest protection and the toe protection are taken into account in determining the revetment costs. The costs are based on the Asian Development Bank project to upgrade sea dikes in Northern Vietnam in 2006 (Emergency Rehabilitation of Calamity Damage Project, ADB 2007 [viii]). These costs are translated to different heights. For a situation with severe erosion extra toe protection is needed, this is taken into account for Hai Hau district, Nam Dinh province (see below).

Berm

Currently constructed sea dikes in Northern Vietnam have a berm for extra stability on the land-side. Although not mentioned in the dike design manual it is the new (unofficial) standard and is applied for 'high' dikes, this can roughly be translated as for dikes with a height of over 5 meters. Costs are the extra costs of sand- and clay layer for constructing this dike enlargement and are included in the dike costs for dikes higher than 5 meters.

Maintenance

The maintenance costs of Vietnam sea dikes vary per year. This is mostly due to the varying budget the provincial dike departments receive from MARD. MARD itself has a changing budget which it distributes over the provincial dike departments. The provincial dike departments which sea dikes suffered considerable damage over the last year receive a higher budget than others. With the budgets of the dike departments in Hai Phong and Nam Dinh for the years 2007 and 2008 the yearly maintenance costs per kilometer are estimated to be 260,000,000 VND/km. The present value of the yearly maintenance costs is used in the economic optimum calculation.

An overview of sea dike construction costs is given in Figure 30 and Figure 31. Costs are given in billion Vietnam Dong per kilometer sea dike.

Dike height	Dike body	Land-use	Berm	Revetment	**Total costs**
0.5	0.67	0.34		2.50	3.50
1.0	1.78	0.90		5.00	7.68
1.5	3.25	1.69		7.50	12.44
2.0	5.07	2.70		10.00	17.77
2.5	7.21	3.94		12.50	23.65
3.0	9.67	5.40		15.00	30.07
3.5	12.44	7.09		17.50	37.02
4.0	15.50	9.00		20.00	44.50
4.5	18.86	11.14		22.50	52.50
5.0	22.51	13.50	5.13	25.00	66.14
5.5	26.45	16.09	5.44	27.50	75.47
6.0	30.67	18.90	5.75	30.00	85.32
6.5	35.18	21.94	6.06	32.50	95.68
7.0	39.97	25.20	6.38	35.00	106.54
7.5	45.03	28.69	6.69	37.50	117.90
8.0	50.37	32.40	7.00	40.00	129.77
8.5	55.99	36.34	7.31	42.50	142.14
9.0	61.88	40.50	7.63	45.00	155.00
9.5	68.04	44.89	7.94	47.50	168.36
10.0	74.47	49.50	8.25	50.00	182.22

Figure 30: Dike costs standard cross-section (billion VND/km)

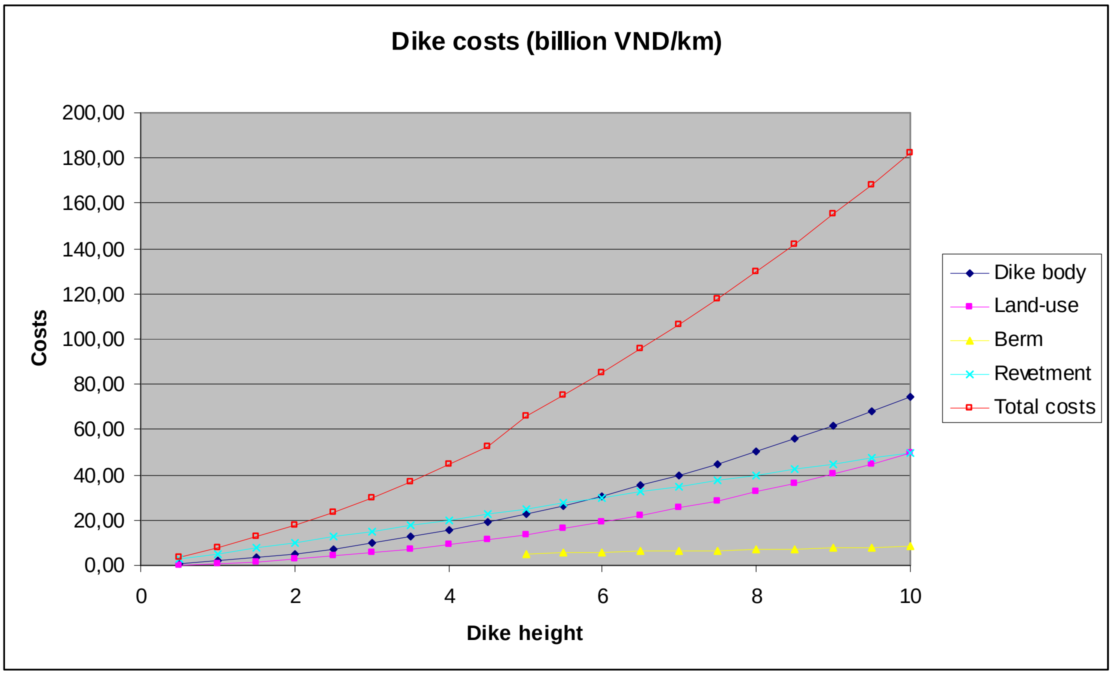

Figure 31: Dike costs per dike height

4.2.1. Special conditions

Specific local conditions may cause an increase in dike construction costs. Most of these conditions cause a relatively small difference in total costs, or are balanced with lower costs for other parts. For the calculations of the case study areas, the situation of severe erosion of Hai Hau district, Nam Dinh, has different dike costs. The Hai Hau district has to cope with severe erosion problems (see paragraph 2.3.3). This requires higher investments to defend the sea dike against erosion. These higher investments are mostly due to an increase in the revetment costs. Therefore the revetment costs for Hai Hau district are significantly higher (approximately 2 times higher than mentioned above).

4.3. Translation of dike height to return period

The costs in the previous chapter were calculated per dike height. Since only the overflowing failure mechanism is assumed (see chapter 3.5), the dike only fails when the sea water level is higher than the dike height. The dike in this situation is assumed to be 'perfect', assuming that the other failure mechanisms never occur. This simplifies the translation of dike heights to return periods by finding the corresponding waterlevels.

To find maximum water level return periods approximations of Vu Thi Thu Thuy (Storm surge modelling for Vietnam's coast, 2003 [xxvii]) were used. Vu used measurements of the 50 highest storms at several locations of the Vietnam coast for a 50 years period. For Hai Phong the measurements of Hon Dau gauging station were used, for Nam Dinh measurements in the Ba Lat estuary (cua Ba Lat) were used. The results were extrapolated to find return periods for dikes with a height of over 8 meters (see Figure 32 and Figure 33).

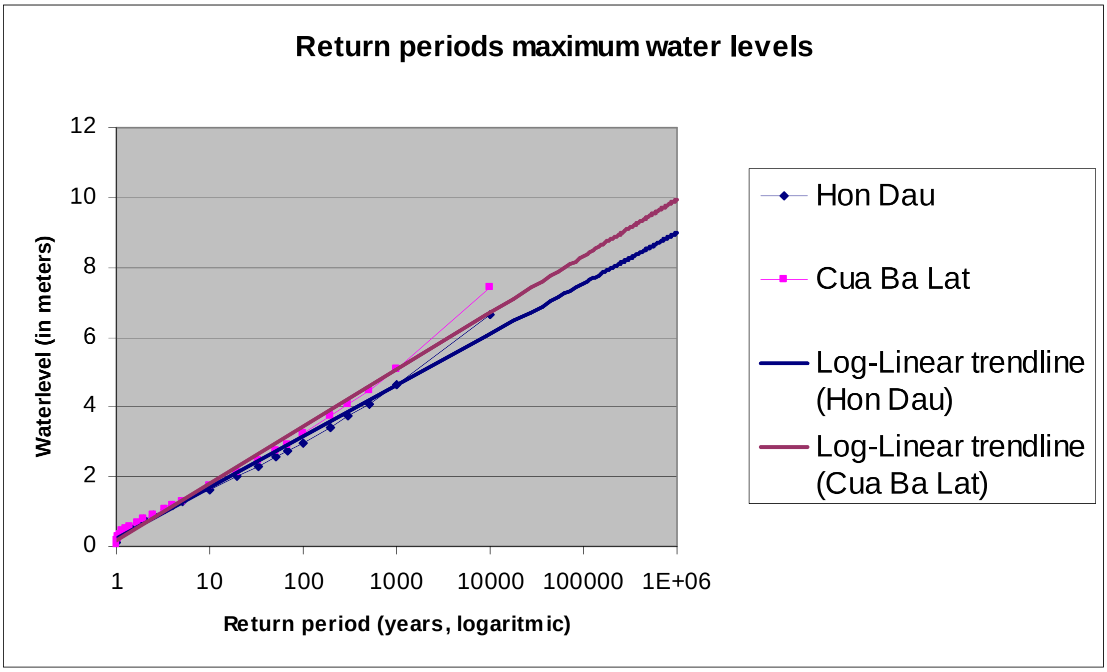

Figure 32: Return periods maximum water levels in log-scale [Vu, 2003]

Storm height (m)	Return period Hon Dau (years)	Return period cua Ba Lat (years)
0.5	2	2
1.0	3	3
1.5	7	6
2.0	16	13
2.5	36	26
3.0	79	54
3.5	173	109
4.0	381	220
4.5	837	447
5.0	1841	907
5.5	4049	1840
6.0	8905	3733
6.5	19584	7575
7.0	43070	15369
7.5	94722	31183
8.0	208319	63269
8.5	458150	128371
9.0	1007595	260462
9.5	2215971	528471
10.0	4873515	1072253

Figure 33: Maximum water levels (storm height) and their return periods

4.4. *Estimated flooding damage*

The flooding damage estimates are based on land-use and properties in the coastal areas. With statistical data of the districts, economic planning scenarios of the government and flooding damage as calculated from previous flooding events these estimates were made. An increased safety level encourages investments (industry, tourism and housing) in the coastal areas behind the dikes. This is actually the intention of Vietnamese government with the sea dike project in general. This is taken into account with the economic growth scenarios.

In this project only the direct economic damage is taken into account. Indirect damage is not considered, but can play an important role; especially with respect to the future scenarios. Cultural and environmental damage are also not taken into account as is the loss of human lives. Inhabitants of the typhoon prone areas receive warnings of typhoons days before they make landfall and evacuation systems work well. Most human lives during typhoons are not lost due to flooding but because of the damage due to the wind force. The risk determination is thus considered to be dominated by the economic risk. When determining safety levels more accurately these have to be taken into account.

In the case study areas considered in this project, the coastal areas are all above mean sea level and gently sloping inland. The coastal zones have an elevation between 0.5 meters and 2 meters above mean sea level. Internal boundaries, such as ridges, heightened roads, or other flood defence structures are not considered, since no detailed elevation maps of the provinces Hai Phong and Nam Dinh could be found. With detailed maps of the coastal districts (Vietnam cartographic publishing house maps (scale 1:25,000)) the flooded areas were determined. Manually it was tried to indicate height differences in the coastal zone with the help of some elevation points, but due to the lack of detail it was not possible to construct flooding scenarios. Therefore the economic opimalization was executed per district of the case study provinces. Due to the relatively low elevation of the coastal areas the flooding depth was also not taken into account. Assumed is that constant damage occurred after flooding. No relation between water level or storm surge height and economic damage was considered.

4.4.1. Damage assessment

Current income in the coastal regions is expected to rise to 10 million Vietnam Dong (USD600) per head this year. This matches the contribution of the agricultural production given by the Asian Development Bank Emergency calamity damage report which is between 3 and 4.5 billion VND for one square kilometer (km^2) agricultural and aquacultural area per year. This amount is used as flooding damage for agricultural and aquacultural area. The damage to industial property is estimated with the investments given in the Vietnam Socio-economic statistical data (per district), which is up to 50% of the yearly production output of the industry. For damage to houses a lower amount is taken into account, since the inundation of houses accounts for relatively low damage within historical floods data (see below). These estimates are compared with the total income in the region and checked with historical flooding damage.

If compared to the income of the coastal areas, the damages based on the production costs, the number of houses and the amount of investments in industry are around three-quarters of the total yearly income of the coastal district. This approximately matches the damage observed for the typhoons of 2005. For the future scenarios the flooding damage is estimated to be higher than the total districts income.

Historical floods were investigated to compare them with the estimated flooding damages. Damages caused by storms #2, #6 and #7 (Damrey) of 2005 which were collected by MARD were investigated for this project. It is clear that flooding damage is hard to determine. Within the flooding damage documents, even if the damage was recorded, most of the time the economic value could not be estimated in VND. The damage caused by the inundation to houses, agricultural area and aquacultural area is significantly lower than the production value of the area. More detailed information is available for typhoon Damrey. The damage of typhoon Damrey in 2005 was estimated to be around 3500 billion VND (220 milion USD) (ADRC-Asian Disaster Reduction Centre, Damrey September 2005 [xxviii] and Disaster Management Working Group (DMWG), October 2005 [xxix]). However it is hard to find a clear overview what every kind damage contributed to the total damage.

4.4.2. Economic growth scenarios

For the economic growth scenarios an increase in land-use value is assumed. Also other damages increases are based on an economic growth situation of 8%. The population increase is determined based on a 1% yearly population growth. Large future investments were estimated based on Vietnam government development plans as found for several port development projects (see Figure 34) and based on projects shown in Vietnam Vision 2020 (see Figure 35).

Project	Total investment	Implementation
Project of Dinh Vu Multi-purpose Port	VND 600 billion	2006-2010
Project of Lao Cai inland waterway port	VND 78 billion	2005-2007
Project of Ben Got-Lach Huyen lighterage area, consisting of 5 buoy berths to accommodate vessels up to 50,000 DWT	VND 600 billion	2 buoy berths put into operations at the end of 2006, the remained 3 buoy berths planned to be completed in the period of 2007-2010

Figure 34: Port development plans [Vietnam Port Association]

Top end investments	USD (Million)	VND (Billion)
High class factory complex	300	4,800
Factory	150	2,400
Raw factory	100	1,600
Industrial area + infrastructure	100	1,600
Tourism area	100	1,600

Figure 35: Top end investments [Viet Nam Vision 2020]

4.4.3. Flooding damage estimates

The flooding damage is the most uncertain part of the safety standards calculation, because the estimates are almost completely based on assumptions and little data. Most of the data does not correspond with each other, which makes determining reasonable estimates hard. The above mentioned method results in the following estimates for the coastal districts of the case study area. The low boundaries are based on the current situation in the coastal district and the growth situations function as upper boundaries (Figure 36). Especially in the Hai Phong districts Hai An and Kien Thuy a lot of industrial development and investments are expected due to the extension of the port of Hai Phong and surrounding industry.

Nam Dinh	*current situation*	*growth situation*
Giao Thuy	1,100	1,750
Hai Hau	1,000	1,600
Nghia Hung	700	1,200

Hai Phong		
Hai An	1,000	5,000
Kien Thuy	1,150	4,500
Tien Lang	800	1,400

Figure 36: Flooding damage estimates (in billion VND)

4.5. Economic optimum

With the dike costs determined in chapter 4.2 and the estimated economic flooding damage in chapter 4.4 the economic optimum can be determined. In Appendix I the economic optimalization graphs are shown per district. In this chapter the graphs of Hai Hau district in Nam Dinh and the graphs of Kien Thuy district in Hai Phong are shown and a short explanation on them is written.

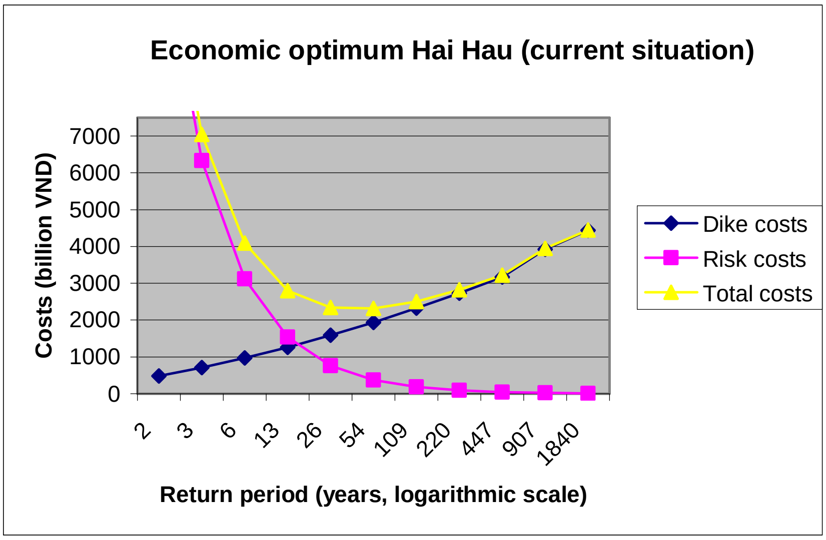

Figure 37: Hai Hau economic optimum (current situation)

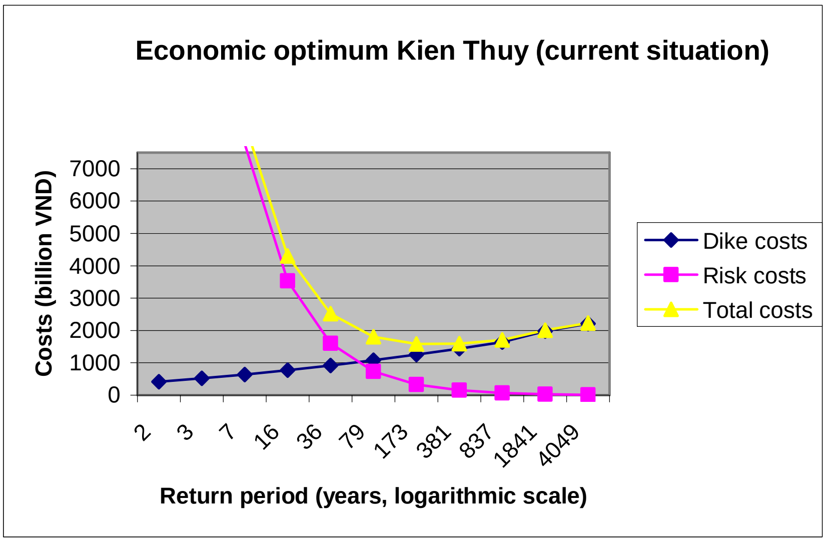

Figure 38: Kien Thuy economic optimum (current situation)

In paragraph 4.4.3 was shown that the current flooding damage for Hai Hau district and Kien Thuy district are approximately the same. However a higher return period is found for Kien Thuy (see Figure 37 and Figure 38). This is due to several differences. First, the dike costs of Hai Hau district are significantly higher because of the erosion problem at the coast. Secondly there is a difference in flooding damage due to the larger amount of industry in Kien Thuy. And, finally, there is a difference between the hydraulic conditions which give the same design water levels a higher return period in Hai Phong provinc (see chapter 4.3). This gives a safety level of approximately 1/30 years for Hai Hau and a safety level of 1/200 years for Kien Thuy. Within the project these are both the lowest and highest safety level of the different coastal districts (based on the current situation).

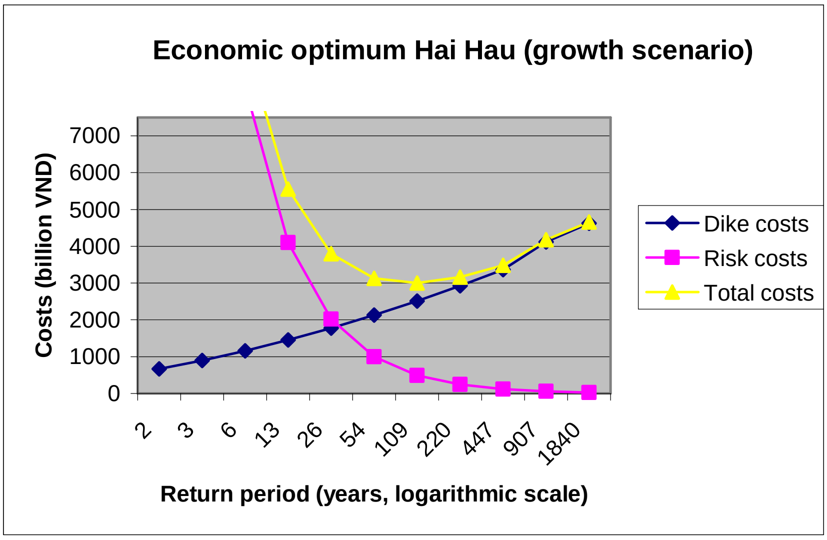

Figure 39: Hai Hau economic optimum (growth scenario)

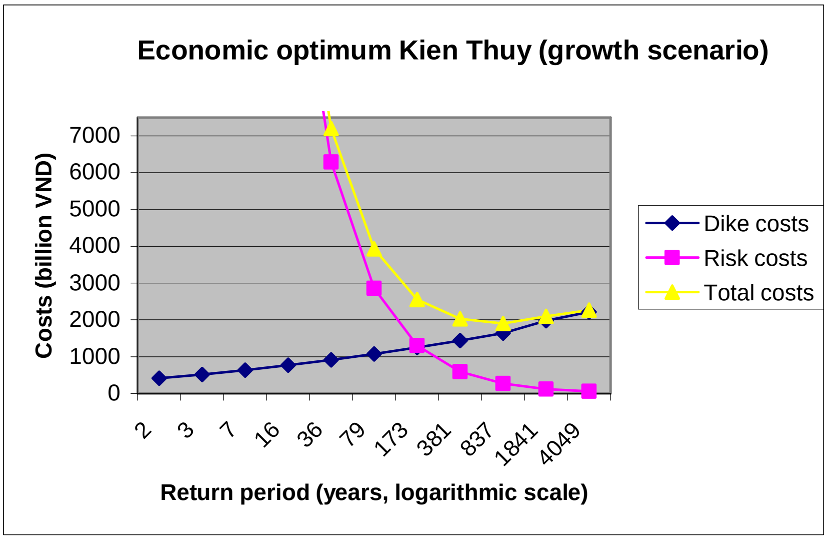

Figure 40: Kien Thuy economic optimum (growth scenario)

For the economic growth scenarios the differences between Hai Hau district and Kien Thuy district can be seen even more clearly. There is a lot of investment and development planned in Kien Thuy district and the Hai Phong government wants to attract a lot more investment in this region. This will result in a higher possible flooding damage, which is a lot larger compared to the expected growth in Hai Hau district. Where the growth in Hai Hau is mostly due to increase of the production, the growth in Kien Thuy is pushed by large industrial investments. This results in a safety level around 1/100 years for Hai Hau and a safety level around 1/850 years for Kien Thuy. The big investments in Kien Thuy have to have a larger safety from the economic optimalization point of view. Figure 41 shows the different safety levels calculated per district.

Nam Dinh	*current situation*	*growth situation*
Giao Thuy	1/100	1/200
Hai Hau	1/30	1/100
Nghia Hung	1/50	1/150
Hai Phong		
Hai An	1/150	1/850
Kien Thuy	1/200	1/850
Tien Lang	1/200	1/200

Figure 41: Safety levels case study area (1/ years)

With the several calculations made for different areas different safety standards are found, but also the importance of several parameters could be seen. The real rate of interest assumed in chapter to capatalize has a lot of impact on the calculations, as have the costs of dike construction. Large differences in estimated flooding damage are of course of influence, but they have less influence than expected.

4.6. Safety standards

If the safety levels determined for Hai Phong and Nam Dinh could be regarded as representative for the Vietnam coast, the safety levels can stand for the safety standards. The calculations in chapter 4.5 could roughly be divided into three groups. These are mostly based on the expected future scenarios.

For two districts, Hai Hau and Nghia Hung, relatively low safety levels are found. In these districts the land is used for agricultural purposes are salt production which have a relatively low value. For these districts also little growth is expected. If the government of Vietnam would apply a policy where investments would be accepted only in better protected areas, these districts could be sufficiently protected with a safety standard of around 1/100 years.

For the majority of the areas a safety level around 1/200 years was determined. Within areas where average development is expected this also holds for several future scenarios.

Several future scenarios for the Hai Phong coastal districts Kien Thuy and Hai An all have a high safety level with return periods around 1/800 years. This is actually hard to determine since the return periods for this safety level are hard to see in the graphs. With an infinite time horizon in mind and the ambitions of the Vietnam the safety standard for densely populated areas where a lot of development takes place is considered to be around 1/1000 years. Higher dikes will also attract more investments, this is included in the 1/1000 years safety level.

For the Vietnamese situation the following safety standards could be applied:

1. High safety level for high developed and fast developing areas; a safety standard of 1/1000 years can be considered for these areas (e.g. Hai An).
2. Medium safety level for moderate populated areas with sustained economic growth; a safety standard of 1/200 years can be appropriate (e.g. Giao Thuy).
3. Low safety level for rural areas with no to little development; this can be a safety standard of 1/100 years (e.g. Hai Hau).

4.7. *Translation of safety standards to sea dike design guidelines*

The safety standards determined in this report (with corresponding inundation frequency) have to be translated to sea dike design guidelines (with corresponding design frequencies). The failure probability of a sea dike is the design frequency a sea dike has to be able to withstand. This is not the same as the safety against flooding of the area, given by the safety standard. When the corresponding water level of the sea dike design frequency occurs a sea dike mostly has some residual strength. This means that no immediate inundation has to take place when this state occurs.

As a first approximation a factor can be applied to take this into account. This factor is determined by expert judgment on multiple Dutch cases and is around 10. This means that if the safety standard is 1/1000 years, the sea dike design frequency would be 1/100 years. It is possible to determine this number more accurately but this would require a complete probabilistic calculation based on detailed field data of the local situation. Assumed when using this factor is that the sea dikes in Vietnam have a certain residual strength.

The translation of safety standards to design frequencies is shown with the following formula (4.1):

$$P(inundation) = P(inundation \mid failure) \cdot P(failure) \quad (4.1)$$

in which:	*P(inundation)*	inundation-chance of the area [1/year]
	P(inundation|failure)	conditional inundation- chance if failure occurs (± 1/10)
	P(failure)	failure-chance of the sea dike [1/year]

A basic calculation is given in the example below to illustrate that the factor mentioned above is indeed around 10 for the Vietnamese situation. This calculation and corresponding illustration is made by Gerrit Jan Schiereck. Minor adjustments were made in the text.

A dike is designed for 0.01/year conditions. The corresponding water level is MSL +3m. With a wave height of 2m and a permissible overtopping discharge of 100 l//s this leads to a crest height of MSL + 5.2m (overtopping formula TAW 2002). According to the water level exceedance line (not shown in this report), the corresponding frequency of that level is ~ 0.00035. This is the probability of inundation due to overflow.

The fault tree (shown in Figure 42) is limited to two failure mechanisms: overflow and failure due to erosion/sliding of the inner slope.

*The probability of exceedance of the design overtopping discharge is, by definition, 0.01. The probability of exceeding the strength of the revetment in that case is e.g. 0.1 (should come from probability analysis, based on experimental evidence of strength revetment). The probability of (severe) damage to the revetment is then (parallel system) 0.1 * 0.01 = 0.001.*

*The probability of erosion of the inner slope, such that the overall stability of the dike is no longer there, given the damage of the revetment is taken here 0.5, leading to a probability of 0.5 * 0.001 = 0.0005 of overall instability.*

Together with the probability of overflow this leads to a probability of inundation (series system) of 0.00085 ~ 0.001 (also given other possible failure mechanisms).

Hence a factor 10 between design frequency and inundation frequency is realistic.

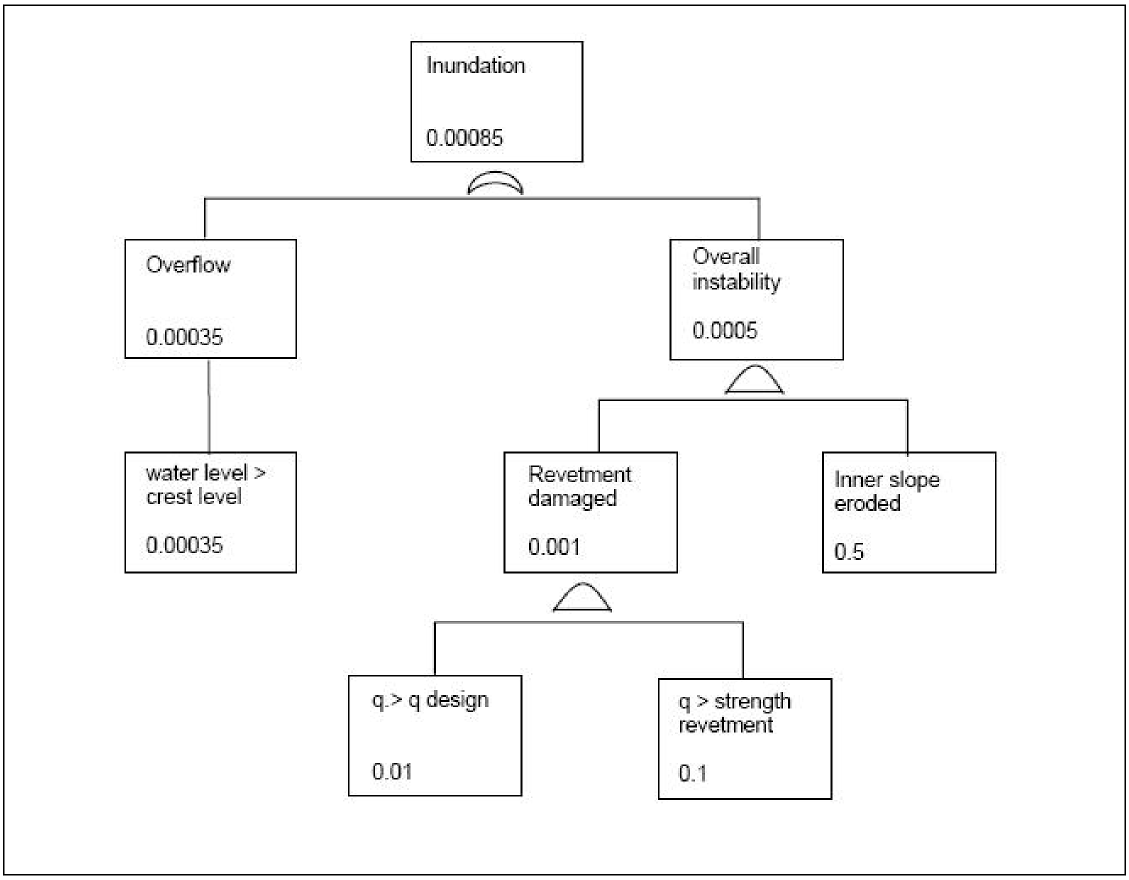

Figure 42: Sea dike failure mechanism fault tree [Schiereck]

5. Vietnamese method

As stated in the previous chapters of this report, the Safety Standards project functions as a starting point for a probabilistic approach towards defining sea dike design guidelines in Vietnam. Where chapter 4 is an illustration of the economic optimalization method, this chapter shows how to continue to work with, and determine, safety levels. Chapter 5.1 introduces the idea behind this chapter and chapter 5.2 gives the steps to continue the project and improve the method as used in the previous chapter.

5.1. Introduction

The calculations of chapter 4 give a clear indication of different safety levels and how they can be determined. These may not be the exact safety levels, because they are based on multiple assumptions. More accurate safety levels per district are hard to assess, because of the current lack of data needed for these calculations. However, it does clearly show that for the Vietnam situation economic optimum safety levels can be determined with a relatively simple method. For different areas than the case study areas the method can also be applied.

Professor Han Vrijling of Delft University of Technology already outlined an approach for an economic optimalization method in "Probabilistic design and risk analysis of water defenses in relation to the Vietnamese water defense system" (Vrijling and Hauer, October 2000 [xxv]). Especially the appendix of this document provides a clear approach to derive safety levels for coastal regions.

In this chapter steps are given to execute economic optimum calculations for the Vietnamese coastal areas. These steps are based on the method used in this report, which was explained in chapter 3. In this method several simplifications were made. These were made to illustrate the very basics of the approach, but also because of the lack of time and manpower, and due to the lack of data. To acquire safety levels in more detail and to use the method to the fullest extend more steps can be added. But, as this report illustrates, a proper basic calculation delivers clear and usable results, therefore the calculations should not be made unneccessary complex. This should be kept in mind when executing the steps mentioned below in chapter 5.2.

5.2. Safety standards method for Vietnam

The method as applied in chapter 4 can be executed more accurate when new data or more manpower is available. To determine safety standards for Vietnam the steps given below could be followed. These steps can be executed according to the economic optimalization method as explained in chapter 3.5. However, the safety standards can in that case be determined in more detail. Safety levels for coastal areas other than the districts of Hai Phong province and Nam Dinh province can also be assessed to check or improve the safety standards given in this report.

The safety standards method as described in the steps below is based on experience within the Safety Standards project and is also a recommendation for further research within Vietnam sea dike subproject 4. The complexicity of the method increases per step, the steps 6 to 9 do require in depth knowledge and require complicated calculations.

1. **Select representative coastal areas**

First, pick an area or a series of representative areas along the Vietnamese coast, for which an economic optimalization calculation can be made. Select areas along the Vietnamese coast which have different characteristics and are likely to have different safety levels. When safety levels are determined for these areas, compare them and determine the safety standards based on a combination of the safety levels and the different characteristics. The following steps below can be executed with one coastal area in mind.

2. **Collect data on current safety standards for Vietnam**

Currently several classes of safety standards are in use in Vietnam for both sea dikes and river dikes. These safety standards have been determined based on both the hydraulic conditions and the importance of the hinterland (see chapter 3.3.1). As a first good estimate it is good to determine the safety level of the area considered, based on these current sea dike design guidelines. These guidelines could be found in reports of the provincial DDMFC, or of MARD. The safety levels found with these guidelines are a useful reference and can be checked with the economic optimalization method later. The method or principles behind the current safety standards can also function as input for the probabilistic approach.

3. **Execute a basic economic optimalization calculation**

Execute an economic optimalization calculation as presented in this report; follow the method as outlined in chapter 3. Apply several simplifications: use only overflowing as a failure mechanism, use approximate dike costs and make a rough estimate of the expected flooding damage. This first estimate gives insight in the importance of the area. Although the method can be done in a greater detail, this first approximation is important for acquiring insight in the problem.

4. **New calculation based on data on area's characteristics**

The calculation made in step 3 could be done more accurate when better specified on the local conditions. This can be done by collecting specific data on the area's characteristics, to determine dike costs and flooding damage in greater detail. The needed data can be found in several reference projects or at the responsible institutes. For subproject 4 of the Vietnam sea dike project a database with data of the Vietnamese sea dikes is constructed. This database could provide data on dike construction. But for the economic optimalization method also a lot of economic data is needed, as are (economic) planning scenarios of the area. For the latter information contact with the Ministry of Planning and Investment (MPI), the provincial Peoples Committees and other provincial planning agencies is needed.

With the information on future investments and planned changes in land-use several planning scenarios can be elaborated. Especially with the large economic growth and changing economy of Vietnam the future of the coastal regions is quite uncertain. Therefore several scenarios with different economic growth and different corresponding investments in the area should be determined and assessed.

With the topography of the area the flooding damage can be determined in more detail. Since the occuring flooding damage depends on the inundated area, the extend of the flooding can be linked to the storm surge level. With a higher storm surge level a larger area will be inundated. As a first assumption the inundated area can be determined by the soil level up to extreme water levels. Also a relation between the depth of flooding and the amount of flooding damage can be established. The higher the flood in the inundated area, the more damage occurs.

After this step it is interesting to compare the results with the safety standards of step 2 and the results of this Safety Standards project.

5. **Determine design water levels in detail**

For more reliable results a better determination of design water levels is desirable. This could take into account the effects of mangrove forests and foreshore conditions of the coast of Vietnam. Changes (like the restoration of mangrove forest) can be taken into account within the calculations. This is also valid for changes due to climate change. Especially when a long time horizon is chosen (like an infinite time horizon in this project), long term changes have to be taken into account.

6. Add casualties, cultural and environmental damage to flooding damage

In the previous calculations the estimated flooding damage is limited to economic damage. A lot of other damage is not taken into account, but plays in important role in determining safety levels. The loss of human life (casualties), cultural damage and environmental damage are of great importance and can be taken into account with the economical optimalization method when capatalized. It is very difficult to determine the costs of a human life, a cultural artifact or an important ecological habitat and therefore it has to be done with care.

7. Assess different failure mechanisms

Until now the safety levels that were found are based only on the overflowing condition. Although overflowing is one of the main failure mechanisms of sea dikes and therefore gives good first estimates, many other failure mechanisms also have to be taken into account. First, assess the importance of the possible failure mechanisms. The calculation can be extended with the most influencial failure mechanisms. If not a good assessment can be made, add wave-overtopping and wave run-up to the calculation.

8. Include the area's topography and create flooding scenarios

Inland barriers such as ridges and (river) dikes may stop the flood and create a specific flooding scenario. In step 4 a simplification of the area's topography was used to determine the inundated area, but with the help of GIS this could be done in more detail. GIS can help to determine the flooding damage in more detail by using several layers in a GIS program indicating land-use, infrastructure, population density.

Also the way the area can be flooded influences the amount of damage. With GIS-maps the amount of flooding damage with a certain flooding scenario can be determined. By creating a few general flooding scenarios the damage in the area is determined more accurately and a more detailed economic optimum is found.

9. Find overall flood risk level

The coastal areas are mostly not only prone to flooding from the sea, but also from rivers and excessive rainfall. To determine the overall flood risk these risks most also be taken into account. This does not play a role in determining the sea dike safety level, but does affect the safety of the coastal area as a whole. For a decision based on risk (assessment) these risks should be investigated and taken into account.

6. Conclusions and recommendations

This chapter gives the Safety Standards project's conclusions (chapter 6.1). Part of the conclusions follow directly from the work presented in this report, part of them are based on experience gathered in the project's period. This is also valid for chapter 6.2, which presents the recommendations.

6.1. Conclusions

The three classes of safety standards that were found for the case study areas are indicative, but look like reasonable standards if compared with other reference projects. This illustrates that this relatively basic approach gives good estimates and that it is possible for the Vietnamese situation to determine (economic) optimal safety levels for coastal (protected) areas. This also means that this approach gives a lot of opportunities for defining new sea dike design guidelines for Vietnam.

The project also found support among the people involved in the Vietnam sea dike project and within the Vietnamese engineering community. The Safety Standards project can be continued within subproject 4 of the Vietnam sea dike project, but the method could also easily be applied at different insitutions or organizations.

More conclusions on specific subjects are given below.

Probabilistic method is applicable on Vietnam situation

This project was started to introduce a new approach to determine safety standards in Vietnam. The situation in Vietnam with respect to coastal engineering is significantly different compared to Western standards. The economic optimalization method used in this project was developed in the Netherlands, but can be applied anywhere. However for the calculation specific data is needed and sometimes assumptions need to be made to execute the method properly. Overall this project shows that the results do match Vietnam's ambitions and give new insights into subjects regarding coastal defence.

Clear difference is found for different districts and scenarios in Hai Phong and Nam Dinh

As expected when selecting the case study area, the provinces of Hai Phong and Nam Dinh and also their coastal districts differ sufficiently to give representable results for the Northern Vietnam coast. The differences in characterisitcs, illustrated by the difference in land-use and economic growth scenarios, help to cover the widely varying scenarios needed to determine safety levels.

Three different classes give a good indication for different safety standards

The results from the different coastal districts clearly show a difference, especially concerning the economic growth scenarios. Although every district has its own safety level, safety levels for comparable situations are quite similar. Three different safety standards cover most of the different coastal areas. On the other hand this also helps to mark certain areas as potential economic growth zones and to control investments and planning along the Vietnam coast.

Data collection in Vietnam is rather difficult

Most uncertainty within the project was created by the lack of data. Due to the new approach and because of the focus on information on the country's economy, economic growth and future investments the collection of data was rather complex. It was also hard to receive needed data as data-owners are very protective on there data and a lot of data is simply not available. This greatly influenced the results of the calculations and because the results are first estimates there are opportunities for improvement.

Adjustments for the sea dikes are needed in areas where new investments are planned

Economic optimalization calculations found a high optimum safety level for areas where a lot of investments are planned. Currently the sea dikes offer a far lower safety level for these regions. With the economic growth and increase in investements in these regions the current sea dikes have to be strengthened to create a sufficiently safe environment for investments.

6.2. Recommendations

The Vietnam sea dike project is a project with large impact on the society and economy of Vietnam. The main recommendation is to continue to work with ambition and enthusiasm on the Vietnam sea dike project, but to keep in mind that changes in the sea dike system have their impact on the social issues. Below more detailed recommendations are given.

Reliable data collection for sea dike projects is needed for proper results and calculations

The importance of good data (collection) could be seen in the Safety Standards project. Due to the lack of reliable data a lot of assumptions had to be made to derive a first approximation of safety standards for Vietnam. Some of the data used in this project was outdated, but was still the best data available. To determine safety standards accurately data on the current situation is of great importance. Good output cannot be expected without good input.

Keep data accessible and organized

Next to the availability of data, also the accessibility of data is important. A lot of data is already collected by several institutes and organizations, but not accessible. Even within the Vietnam sea dike project data between subprojects is sometimes not exchanged. This slows down the project, but also results in poorer results. By organizing and sharing data better overall results can be achieved.

Close cooperation between different institutes and organizations desired

The sea dike project was set up under the responsibility of MARD, but a lot of different institutes and organizations are involved. It is important for the sea dike project that these institutes cooperate to achieve the wanted results together. Especially since all the subprojects are linked to each other close cooperation is needed. This would also strengthen the overall knowledge on coastal engineering.

Economics needed for coastal zone planning

Since the coastal areas are important economic areas, also cooperation with Ministries and Universities involved with economics and planning is required. Currently the institutes and organizations involved in the project all have a technical or engineering background. The goal of sea dike review and improvement is not only technical, but also of great economic importance. The Safety Standards project has a large economic component and especially the economic parts of this project were hard to execute. Therefore specific knowledge on economics is needed and has to be taken into account within the sea dike project.

Focus on key issues

Although highly advanced methods are available and calculations can be made in very great detail, this is not necessary most of the time. Especially in large projects such as the Vietnam sea dike project it is important to focus on the key issues. With a basic approach good insights in the situation can be achieved and important issues can be extracted. A general economic optimalization with good assumptions is more important than the same calculation based on very detailed flooding scenarios but with only little data on the amount of economic damage. Due to the current availability of data a lot of detailed calculations would be unnessary time-consuming and expensive.

Determine translation from inundation frequency (safety standards) to design frequency in detail

Chapter 4.7 already illustrated that there is a difference between the safety standard found in this project and the final sea dike design guideline. This is one of the relatively weak spots of this report and therefore this aspect has to be looked on in more detail. Now the factor is based on expert judgement from non-Vietnamese examplesm not on the local situation. To find design guidelines for the Vietnamese sea dikes a good translation is necessary based on Vietnamese conditions.

Coastal zone policy by national government is required

The safety standards as determined in this project would be only helpful if applied in the right way. This means that these safety standards also influence coastal planning. The government can stimulate investments in areas which are appointed a higher safety standard and discourage investments in low safety standard coastal areas. This would also make the coastal defence of Vietnam more cost-efficient. Note that stimulating investments would mean a change in flooding damage, this means that it has to be taken into account in the economic optimalization calculation.

Continue work on safety standards with probabilistics

The current Vietnamese situation provides the right conditions to introduce the use of probabilistics within determining sea dike design guidelines. At this moment the ambitions, the spectacular economic growth and the changing coastal areas create good conditions to continue working with a probabilistic method. Also as a large project, the Vietnam sea dike project is a good starting point to start to use clear safety standards. This project showed that it could be done with a very basic approach and that this approach gives clear and reasonable results.

Appendix I

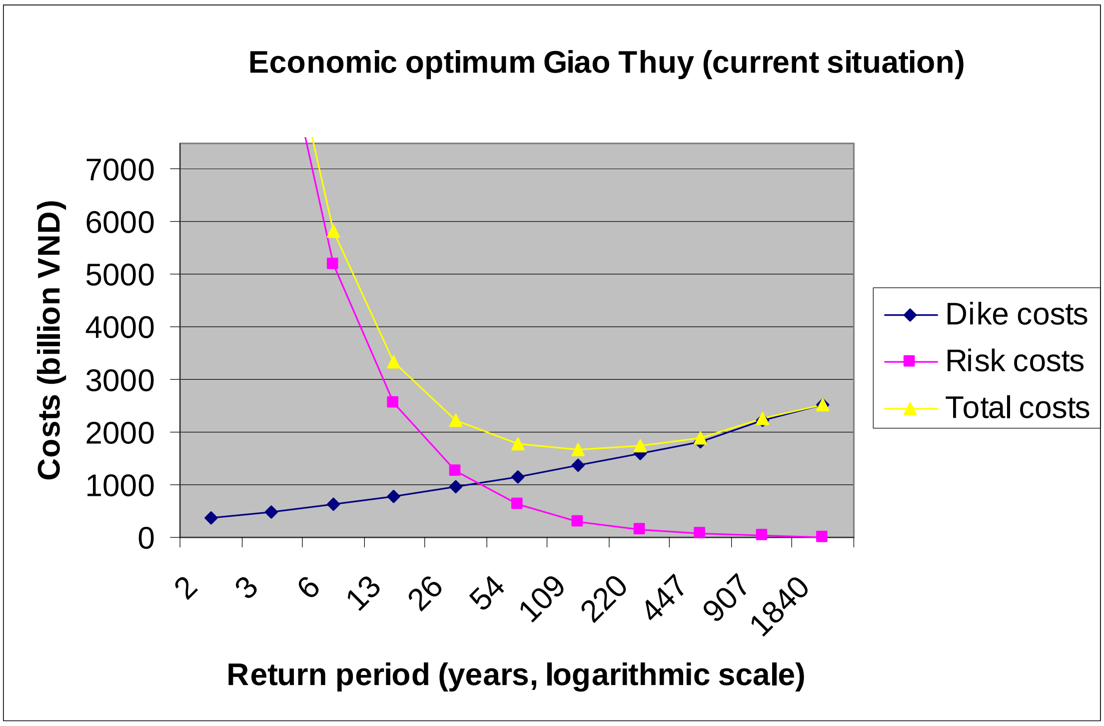

Figure 43: Giao Thuy economic optimum (current situation)

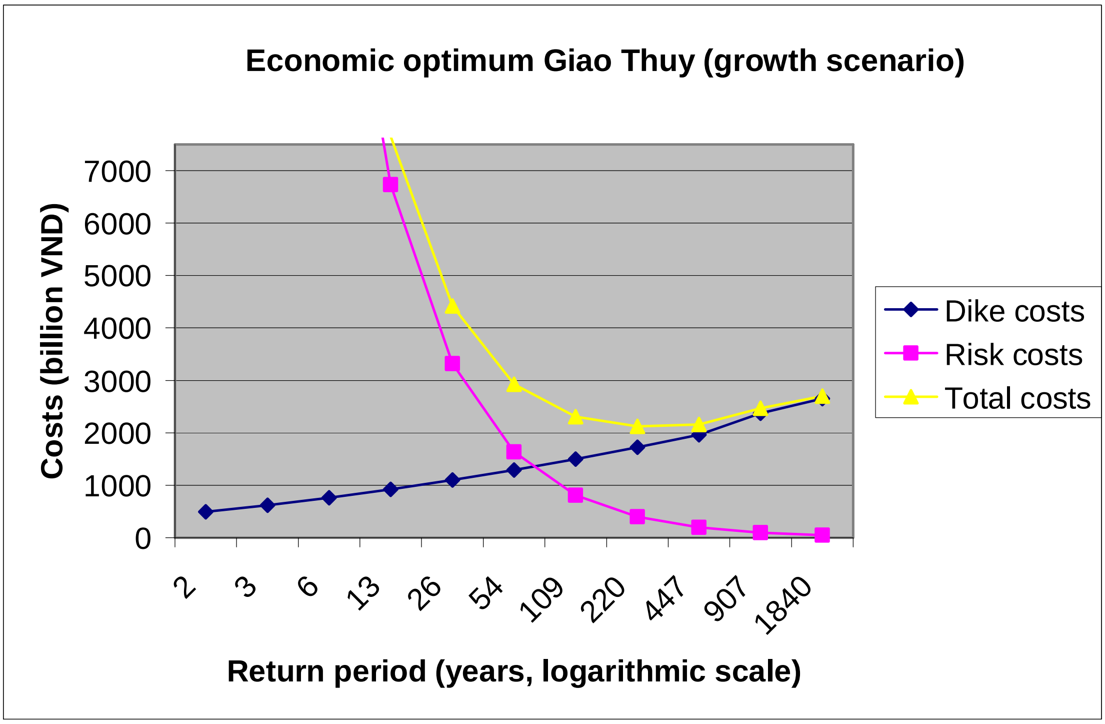

Figure 44: Giao Thuy economic optimum (growth scenario)

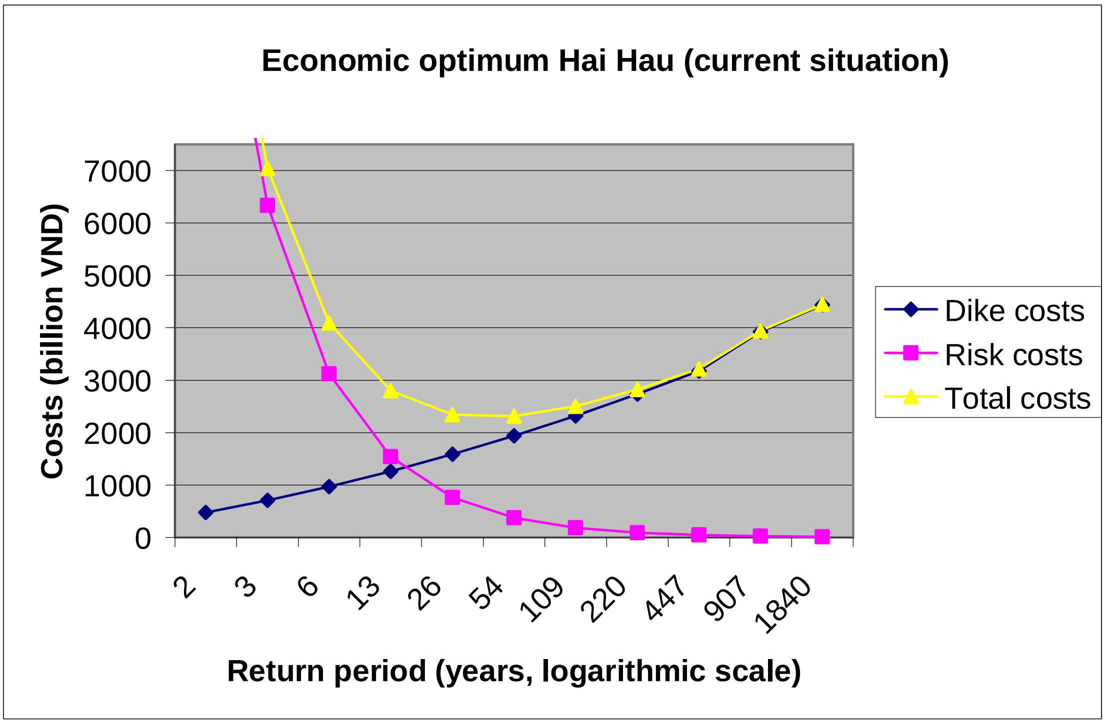

Figure 45: Hai Hau economic optimum (current situation)

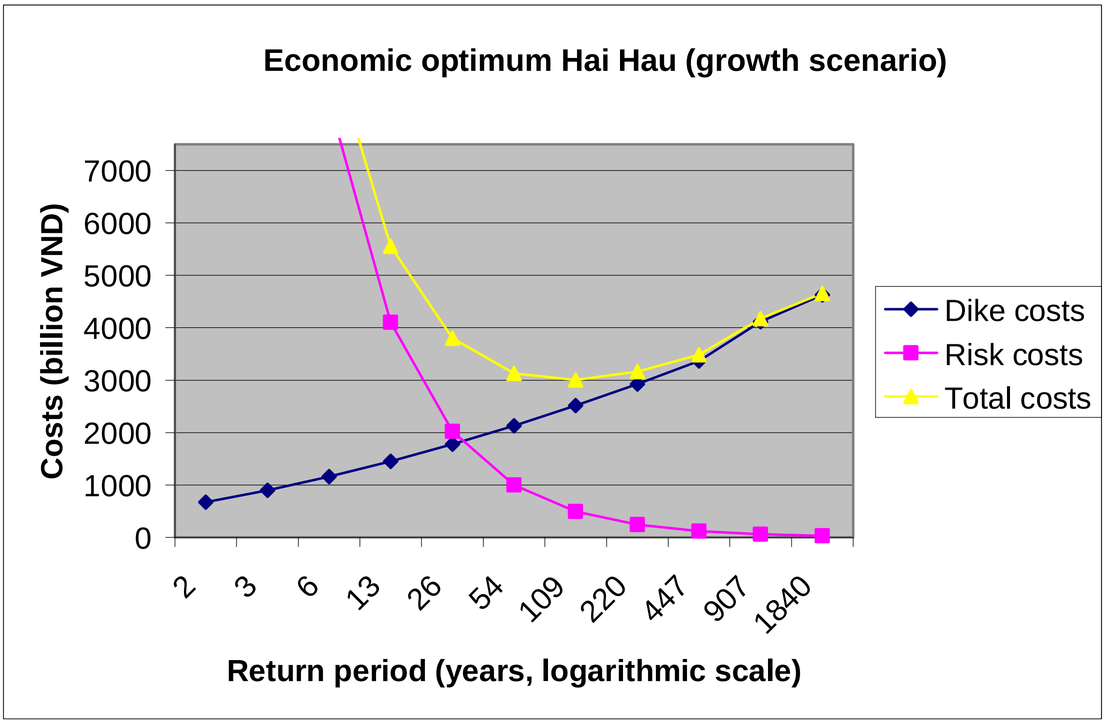

Figure 46: Hai Hau economic optimum (growth scenario)

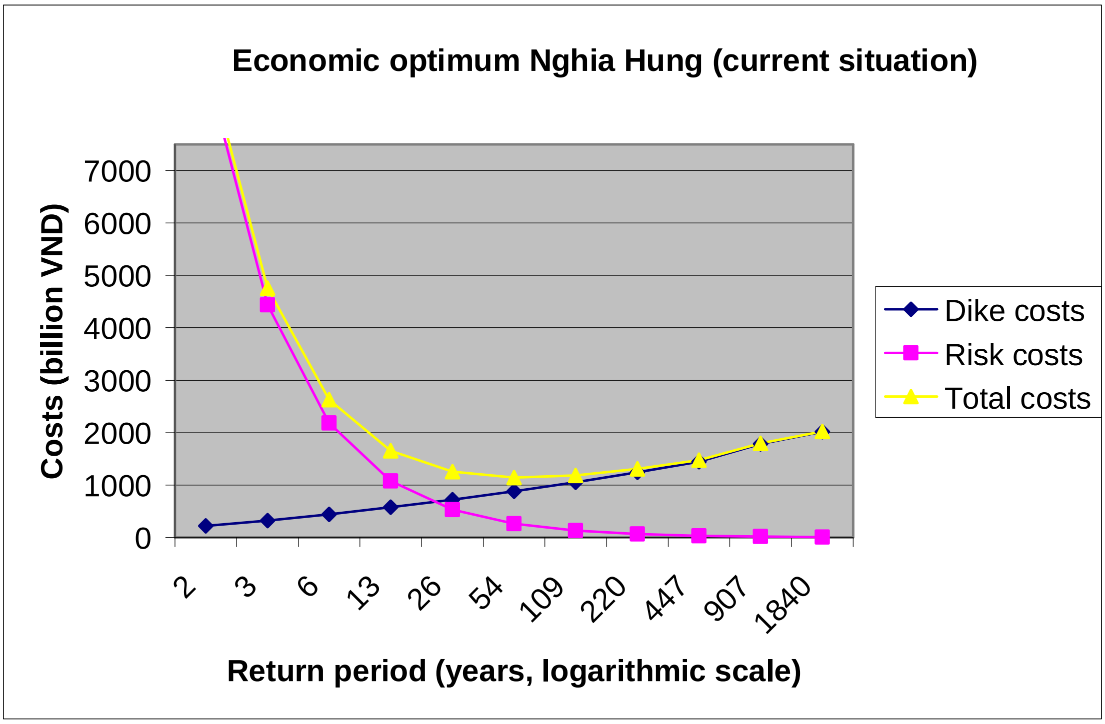

Figure 47: Nghia Hung economic optimum (current situation)

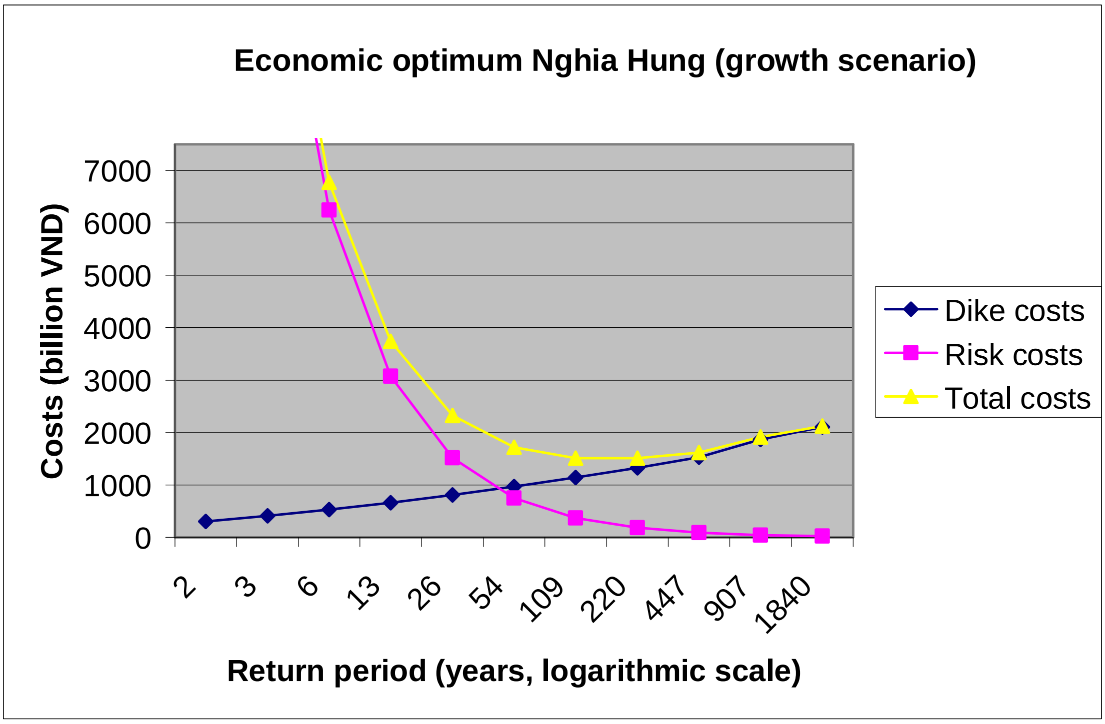

Figure 48: Nghia Hung economic optimum (growth scenario)

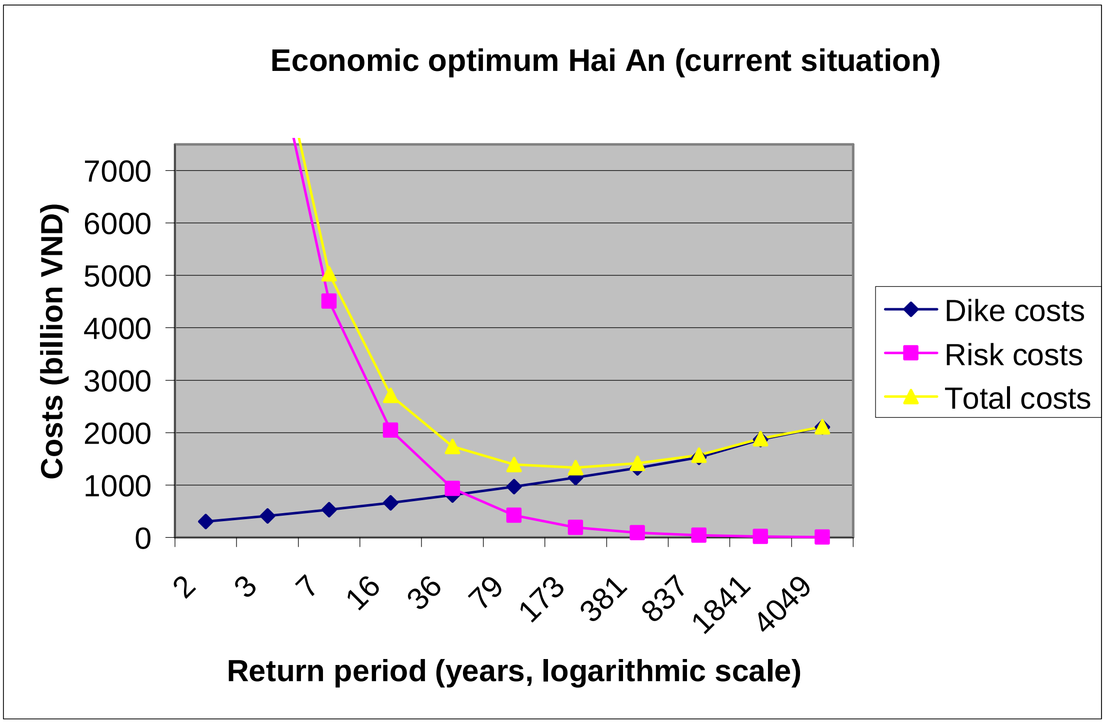

Figure 49: Hai An economic optimum (current situation)

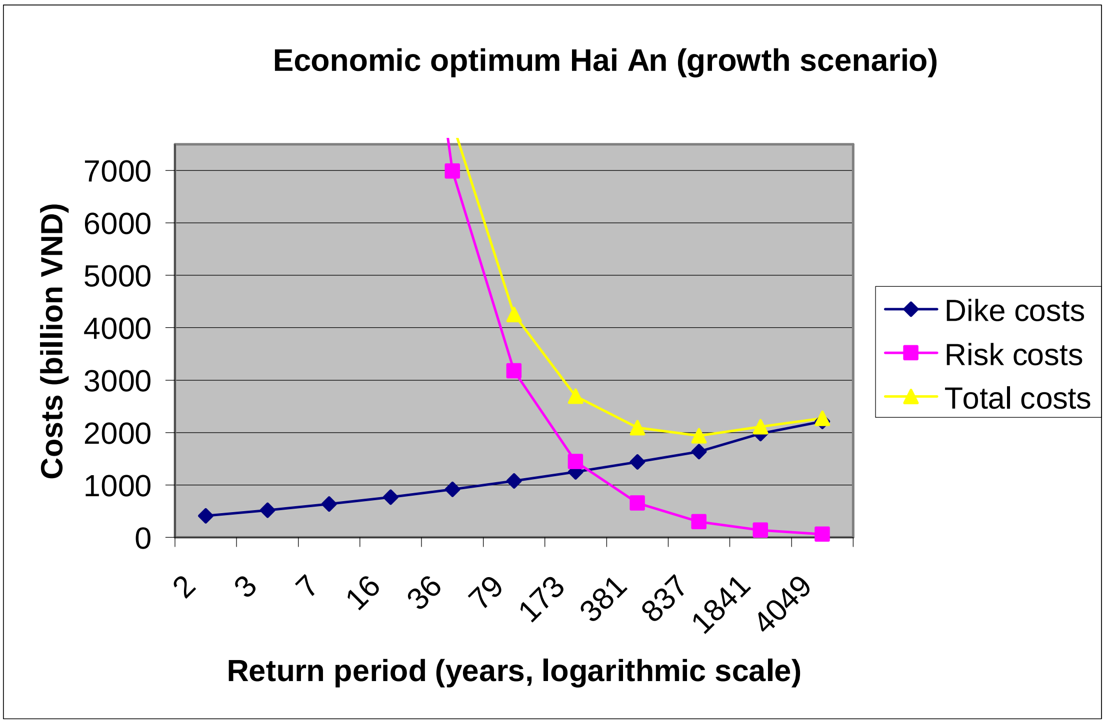

Figure 50: Hai An economic optimum (growth scenario)

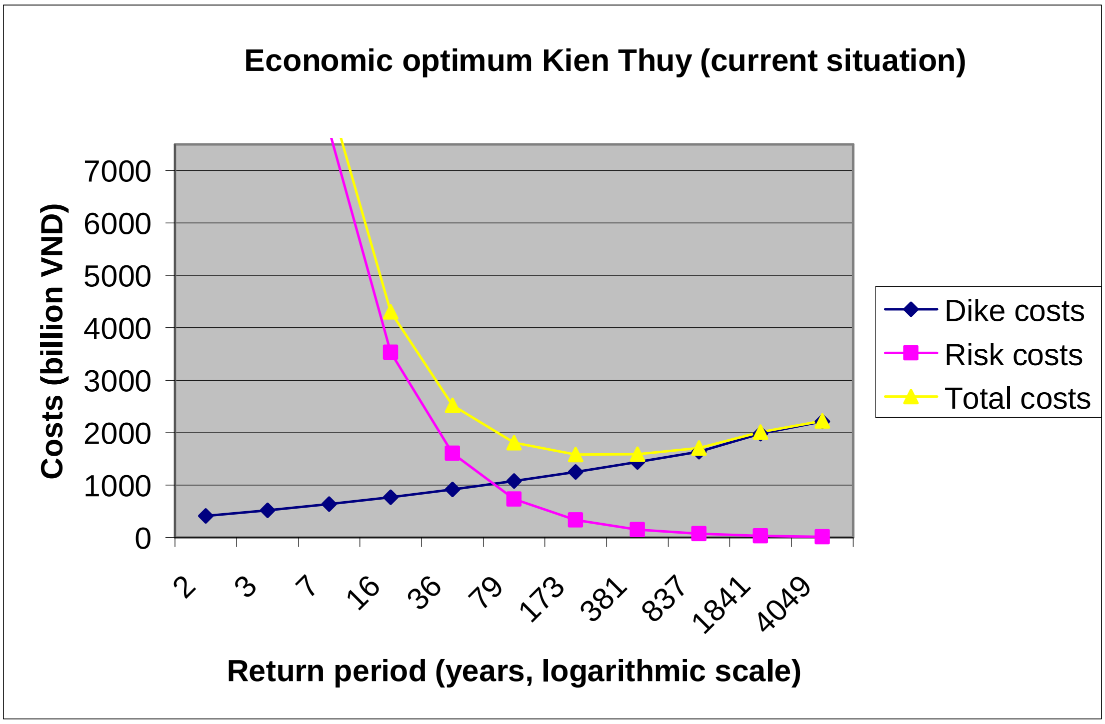

Figure 51: Kien Thuy economic optimum (current situation)

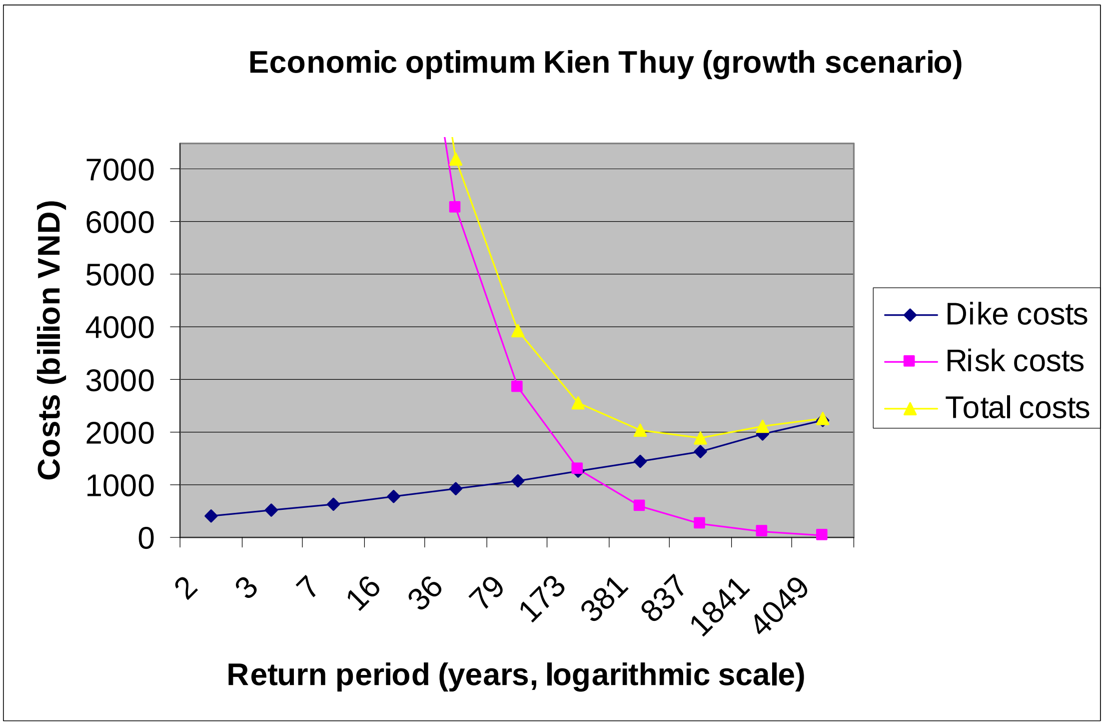

Figure 52: Kien Thuy economic optimum (growth scenario)

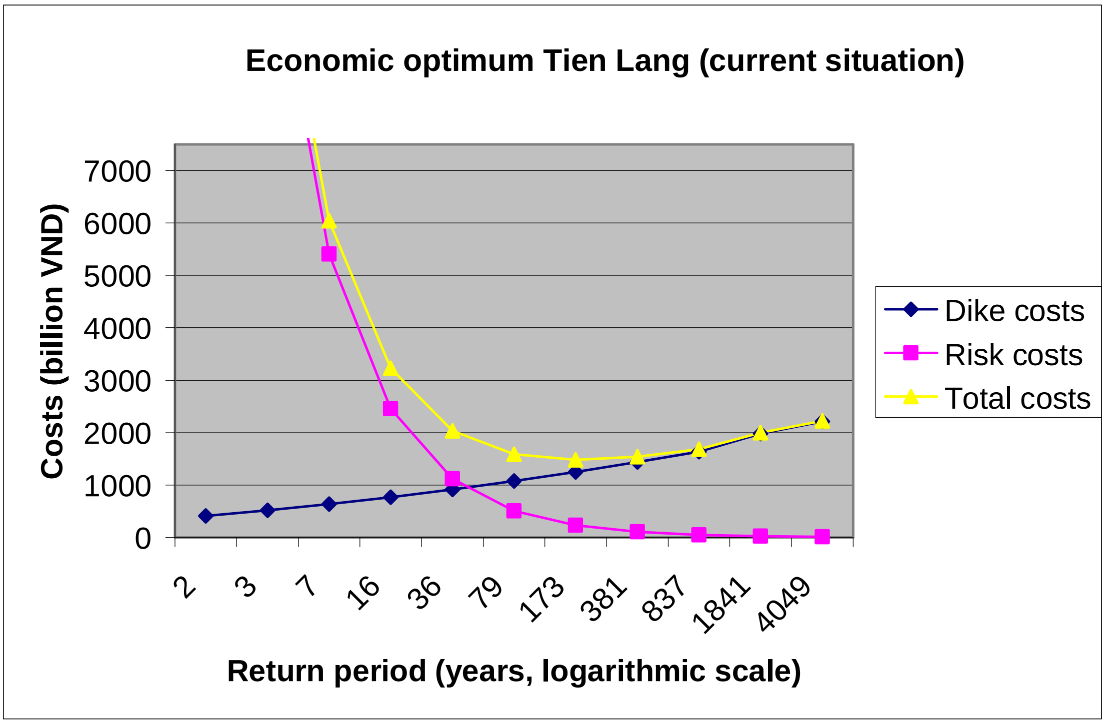

Figure 53: Tien Lang economic optimum (current situation)

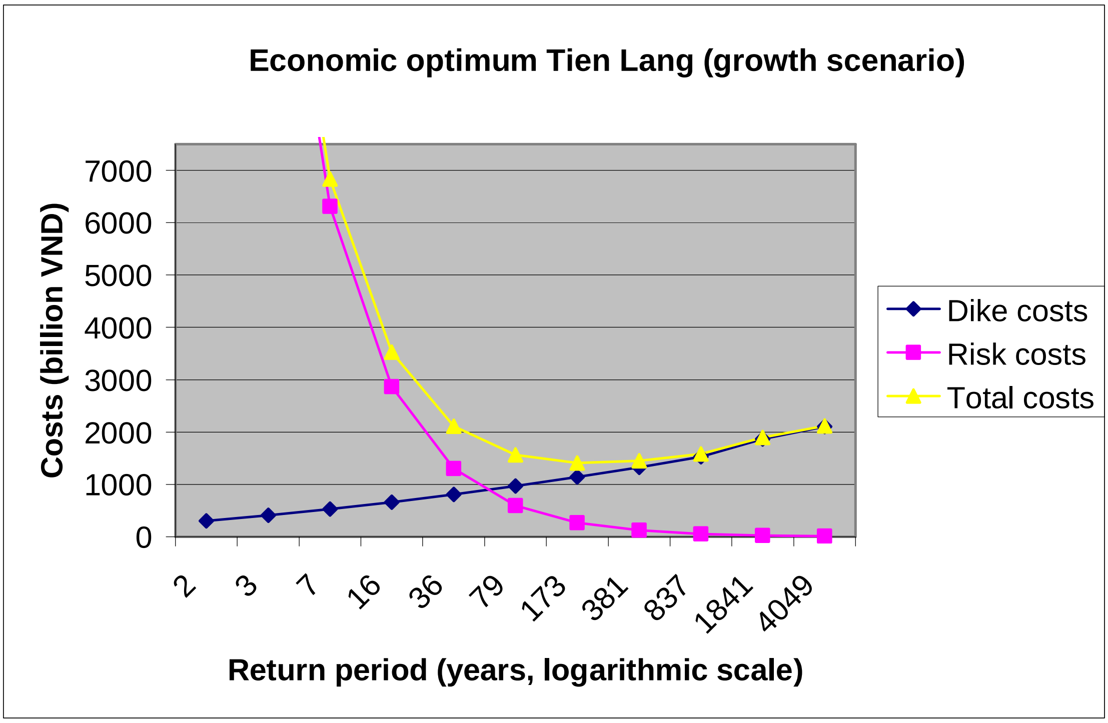

Figure 54: Tien Lang economic optimum (growth scenario)

References

[i] Information brochure
Hanoi Water Resources University 2005

[ii] Country profile Vietnam
CIA World fact book, online report
https://www.cia.gov/library/publications/the-world-factbook/geos/vm.html, April 2008

[iii] Economic growth and poverty reduction, ERD Working paper
Balisacan, A.M. et al.
Economic and Research Department, Asian Development Bank, June 2003

[iv] Viet Nam fact sheet
World Bank
WB, International Development Association, February 2007

[v] Viet Nam Vision 2020
Central Department of Ideology and Culture
The 10th National Congress of the Communist Party of Viet Nam, 2007

[vi] Viet Nam fact sheet
Asian Development Bank
http://www.adb.org/vietnam, April 2007

[vii] Viet Nam economic update
World Bank
April 2008

[viii] Feasibility study report – Emergency Rehabilitation of Calamity Damage Project
Nam Dinh Provincial People's Committee
Asian Development Bank, 2007

[ix] Outlook, Viet Nam News Monthly Publication
'Viet Nam faces up to climate change'
Outlook #51, March 2008

[x] Dikes and Revetments
Pilarczyk, K.W. and Vinh, T.T.
Balkema, Rotterdam, 1999
Reference from IHE MSc Thesis HH471 (Vu, 2003) and IHE MSc Thesis HE172 (Cong, 2004)

[xi] Review design sea dikes Nam Dinh for Emergency Rehabilitation of Calamity Damage Project
Schiereck, G.J.
ADB, Hanoi, December 2007

[xii] Statistical analysis Northern coastal provinces Viet Nam (document in Vietnamese)
Data on land-use and economic development collected for subproject 4
Provincial dike departments Northern Vietnam, 2005

[xiii] Technical Assistance for Sea Dike Research (Vietnam)
Deelprojectvoorstellen dd. 6-12-2007
Delft University of Technology

[xiv] Subproject 4; Masterplan
Nguyen Ba Quy
Project document, revised by Cong, 2008

[xv] Hai Phong port information
Vietnam port association
http://www.vpa.org.vn, 2008

[xvi] Coastal Morphology – A Case Study in Province of Nam Dinh, Red River Delta, Vietnam
Luong Giang Vu
MSc Thesis HH 471, IHE, June 2003

[xvii] Coastal Erosion on a Densely Populated Delta Coast - a case study of Nam Dinh province, Red River delta, Vietnam
Wijdeven, B.
MSc Thesis, Delft University of Technology, October 2002

[xviii] Probability in Civil Engineering
Vrijling, J.K. et al.
Lecture notes Delft University of Technology, 2000

[xix] Risk analysis of coastal flood defences: a Vietnam case
Mai Van Cong et al.
4th International Symposium on Flood Defence, Toronto, Canada, May 2008

[xx] Guideline for sea dike design (14 TCN 130 – 2002)
Nguyen Dinh Thinh et al.
Ministry of Agriculture and Rural Development, 2002

[xxi] Emergency closing dike breaches due to storms
Le Xuan Roanh
Faculty of Ocean & Coastal Engineering, Water Resources University, 2007

[xxii] Safety Assessment of Sea Dikes in Vietnam – A Case Study in Nam Dinh Province
Mai Van Cong
Msc Thesis HE 172, IHE, June 2004

[xxiii] Personal communication, Nguyen Thanh Tung, Department of Dike Management and Flood Control (DDMFC), MARD 2008

[xxiv] Personal communication, Mr. Tien, Dike Department Hai Phong province, 2008

[xxv] Probabilistic design and risk analysis of water defenses in relation to the Vietnamese water defense system
Vrijling, J.K. and Hauer, M.
Mission report, Delft University of Technology, October 2000

[xxvi] Economic decision problems for flood prevention
Van Dantzig D.
Econometrica Vol. 24 pp. 276-287, 1956

[xxvii] Storm surge modelling for Vietnam's coast
Vũ Thị Thu Thuỷ
Msc Thesis HE 136, IHE, June 2003

[xxviii] Disaster Information Viet Nam Damrey September 2005
ADRC-Asian Disaster Reduction Centre
http://www.adrc.or.jp/view_disaster_en.php?lang=&KEY=891, September 2005

[xxix] Vietnam: Typhoon Damrey
Disaster Management Working Group (DMWG) 2005, October 2005