The Impact of Typhoons on the Vietnamese Coastline

- A Case Study of Hai Hau Beach and Ly Hoa Beach

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Preface

This Master’s Thesis is partly the result of a Minor Field Study financed by SIDA (Swedish International Development Cooperation Agency). The thesis work has also been a part of an ongoing cooperation between the Department of Water Resources Engineering at Lund Institute of Technology in Sweden and the Center for Marine Environment Survey, Research and Consultation in Hanoi, Vietnam. This cooperation has continued since 1999 with the overall goal to find a solution to the erosion problems at Hai Hau Beach, located in the Red River Delta.

Since a major part of our work for this study was carried out in Vietnam we wish to express our appreciation to everyone involved at the Center for Marine Environment Survey, Research and Consultation in Hanoi, especially our supervisor Associate Professor Nguyen Manh Hung, but also Professor Pham Van Ninh, Dinh Van Manh, and Nguyen Thi Viet Lien for sharing their knowledge and helping us with our study.

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The MFS Scholarship Programme offers Swedish university students an opportunity to carry out two months' field work in a developing country resulting in a graduation thesis work, a Master's dissertation or a similar in-depth study. These studies are primarily conducted within subject areas that are important from an international development perspective and in a country supported by Swedish international development assistance.

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The responsibility for the accuracy of the information presented in this MFS report rests entirely with the authors and their supervisors.

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Abstract

Title: The Impact of Typhoons on the Vietnamese Coastline
- *A Case Study of Hai Hau Beach and Ly Hoa Beach*

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Supervisor: Prof. Magnus Larson, Department of Water Resources Engineering, Lund University, Lund, Sweden and Assoc. Prof. Nguyen Manh Hung at Center for Marine Environment Survey, Research and Consultation in Hanoi, Vietnam.

Presentation of problem: On average 5-6 typhoons hit the Vietnamese coastline every year. They can cause great destruction and death as they move in over land. When a typhoon passes it brings high water levels, large waves, strong winds, and heavy rain. The high water levels combined with large waves, cause overtopping and erosion of dikes and sand dunes. This can lead to flooding and saltwater intrusion of farmland with water masses destroying crops, and in extreme cases loss of life and property.

Objectives: The main objectives of this study are to quantify the impact of typhoons on the Vietnamese coastline with respect to overtopping and erosion, and to assess future effects for people living in these areas. The study of the consequences of typhoon attacks has been limited to two different areas along the Vietnamese coastline: Hai Hau Beach in Nam Dinh Province and Ly Hoa Beach in Quang Binh Province.

Procedure: Basic data on typhoons attacking the Vietnamese coastline are analysed regarding the properties of the typhoons. The characteristics of the topography and geomorphology along the coastline are compiled. With this information it is possible to estimate the effects of the typhoons on various parts of the coastline in view of flooding, overtopping, and erosion. Finally, an assessment is made of the risk for typhoon attack in the studied areas, as well as the risk for various catastrophic events occurring during a typhoon such as overtopping and severe erosion of dunes and dikes.

Conclusions: Flooding caused by overtopping depends to a large extent on the tide. The tide is diurnal at Hai Hau Beach and during some parts of the year at Ly Hoa Beach. The probability that high tide occurs at the same time as the peak of storm surge is small.

Hai Hau Beach has fairly good protection against wave action along some stretches. The recently built dikes with a reinforced surface provide protection against most waves. These dikes are built with higher crest elevation and are less sensitive to erosion than dikes covered with grass. If the entire coast of 25 km at Hai Hau were protected by reinforced dikes, homes and farmland would be less exposed.

At Ly Hoa Beach the village is very exposed and vulnerable to wave action. The protective structures proposed by UNDP will diminish the risks for the village. The project was intended to be finished in 2002, but construction has not yet started. This means that the people of Ly Hoa live with the constant threat that their homes could be destroyed during a typhoon attack.

Hai Hau Beach and Ly Hoa Beach are two limited stretches along the Vietnamese coastline, but they represent the conditions typical for a large part of the coast. Three quarters of the Vietnamese coastline consists of either sand dunes or delta planes, and the calculation procedures and methodology employed in this study should be applicable to similar parts of the Vietnamese coastline.

Keywords: Vietnam, typhoons, wave runup, wave overtopping, dune erosion, storm erosion, Hai Hau Beach, Ly Hoa Beach.

Sammanfattning

Titel: Tyfoners påverkan på den vietnamesiska kustlinjen
- *En studie av Hai Hau Beach och Ly Hoa Beach*

Författare: Annika Sundström och Emma Södervall

Handledare: Prof. Magnus Larson, Institutionen för teknisk vattenresurslära vid Lunds Tekniska Högskola och Bitr. Prof. Nguyen Manh Hung på Center for Marine Environment Survey, Research and Consultation i Hanoi, Vietnam.

Problempresentation: Vietnam drabbas av i genomsnitt 5-6 tyfoner varje år, och dessa kan orsaka stor förödelse och många dödsfall när de passerar in över land. När en tyfon passerar medför det högt vattenstånd, höga vågor, starka vindar och kraftiga regnfall. Om högt vattenstånd sammanfaller med höga vågor orsakar det översköljning samt erosion av strandvallar och sanddyner längs kustlinjen. Detta leder i sin tur till att saltvatten infiltrerar jordbruksmarken innanför, vilket förstör skördarna under många år framöver.

Syfte: Huvudsyftet med den här studien är att bedöma den påverkan som tyfoner har på den vietnamesiska kusten med avseende på överspolning och erosion, samt uppskatta framtida effekter för befolkningen i kustområdena. Studien behandlar huvudsakligen två olika områden längs Vietnams kust: Hai Hau Beach och Ly Hoa Beach.

Metod: Grundläggande data för tyfoner som drabbar den vietnamesiska kustlinjen analyseras med avseende på dess egenskaper, och information om kustlinjen sammanställs. Med denna information är det sedan möjligt att uppskatta effekterna av tyfoner på olika sträckor av kustlinjen med fokus på översvämning, översköljning samt erosion. Slutligen görs en uppskattning av riskerna som de studerade områdena och dess befolkning utsätts för vid de katastrofala händelser som kan inträffa på grund av tyfoner.

Slutsatser: Översvämningar orsakade av översköljning beror till stor del på tidvattenståndet. Det är flod endast en gång per dag i Hai Hau, och vid vissa tider på året även i Ly Hoa, så sannolikheten för att den högsta tyfonberoende vattenståndsökning infaller samtidigt som högt tidvatten är liten.

Hai Hau Beach har någorlunda gott skydd mot vågor på vissa bitar av kuststräckan. De senast byggda strandvallarna, som har en förstärkt yta, skyddar mot de flesta vågor. Dessa strandvallar är byggda med högre nivå på krönet och är mindre erosionsbenägna än strandvallar täckta med gräs. Om hela kusten på 25 km vid Hai Hau var skyddad med förstärkta strandvallar skulle hem och åkermark vara mindre exponerade för tyfoner.

Situationen i dagsläget vid Ly Hoa är att byn är mycket utsatt och känslig för vågor. Det föreslagna åtgärdsprogrammet från UNDP kommer att minska riskerna för byn. Projektet var tänkt att bli klart under år 2002, men är fortfarande inte påbörjat. Detta betyder att människorna i Ly Hoa lever under ett ständigt hot att deras hem kan komma att förstöras av tyfoner.

Hai Hau och Ly Hoa utgör två begränsade delar av den vietnamesiska kustlinjen, men tillsammans representerar de typiska förhållanden för en stor del av kusten. Tre fjärdedelar av kusten består av antingen sanddyner eller deltan, och använd beräkningsgång och metodik i den här studien kan appliceras på liknande delar av den vietnamesiska kustenlinjen.

Sökord: Vietnam, tyfoner, uppspolning, översköljning, erosion, storm erosion, Hai Hau Beach, Ly Hoa Beach.

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1 Introduction

1.1 Background

Vietnam is a country with a 3 260 km long coastline and a topography which makes it sensitive to flooding and erosion from the sea (Imamura & To 1997). The northern and central parts of Vietnam have mountains and hilly terrain from which rivers lead water to the low plains in the coastal zone. In the north, these plains are parts of a large delta, the Red River Delta, and in the central region they consist of narrow areas extending along the coastline. In the southern part of the country the land is characterized by a large low-lying area, the Mekong Delta. The Vietnamese population primarily lives in the two delta areas and the main industry in these two regions is rice cultivation, which provides an important contribution to the economy of the country (Pilarczyk & Nuoi 2002, Imamura & To 1997).

To prevent flooding and erosion dikes have been built along the coast as well as along the rivers (Pilarczyk & Nuoi 2002). The dikes have not always provided the protection they were built for, and every now and then waves or high river discharge break through and flood the land behind. At the coast, tropical storms and typhoons as well as tide, current, and near shore waves are important factors affecting the design of dikes. Of these phenomena typhoons may cause the most serious and catastrophic effects.

On average 5-6 typhoons hit the Vietnamese coastline each year. They can cause great destruction and death as they move in over land (Quynh et al. 1998). When a typhoon passes it brings high water levels, large waves, strong winds, and heavy rain. The high water levels, combined with large waves, can cause overtopping and erosion of dikes and sand dunes. Among other effects these events can lead to saltwater intrusion of farmland with water masses destroying the crop (Vinh et al. 1996). It is therefore of great interest to understand the effects of typhoons in order to develop protection methods for preventing such damage.

1.2 Objectives

The main objectives of this study are to quantify the impact by typhoons, primarily concerning overtopping and erosion of dikes and dunes, on the Vietnamese coastline and to assess future effects for the people living in the area. More specifically, basic data on typhoons attacking the Vietnamese coastline are analysed regarding the properties of the typhoons themselves (size, speed, tracks, and air pressure), as well as the effects induced in coastal waters and waves. The characteristics of the coastline (morphology, tide, and bathymetry) are also compiled. With this information it is possible to estimate the effects of the typhoons on the coastline in view of overtopping and erosion. Finally, an assessment is made of the risk for typhoon attack in the studied areas, as well as the risk for various catastrophic events occurring during a typhoon such as overtopping and severe erosion of dunes and dikes.

1.3 Delimitations

The consequences of typhoon attacks have, in this study, been limited to concern only the erosion and overtopping in two different areas along the Vietnamese coastline, namely Hai Hau Beach in Nam Dinh Province and Ly Hoa Beach in Quang Binh Province. No consideration has been made with regard to the social or economical consequences of typhoon attacks. The two study areas were selected because the types of coast that they represent suffer severely from typhoon attacks and such coasts constitute three quarters of the Vietnamese coastline.

The coastline at Hai Hau Beach, in the northern Vietnam, is lined with dikes that have been built to protect the coastline from the effects of high waves and water levels. The dikes at Hai Hau Beach consist of fine-grained sediment which makes the material cohesive. The fact that the dikes are covered with grass will even further complicate any calculations making the estimations too uncertain to yield reliable results. Therefore, dike erosion at Hai Hau Beach will not be considered in this study. Ly Hoa Beach, which is situated further south, consists of sand dunes that function as protection against flooding. These sand dunes are suitable for erosion calculations with the model employed here.

Although tropical storms can cause severe damage to the country and especially to the people living in the coastal areas, we have limited our study to concern typhoons only. This means that storms with wind speed lower than 32.7 m/s will not be taken into account in our calculations.

1.4 Procedure

During the first part of the investigation most of the effort was spent searching and reading relevant literature in Sweden. Databases and libraries were searched for articles and books regarding beach erosion and overtopping. The Internet was also used, mainly to compile general information about typhoons.

After preparing for the trip in Lund, six weeks were spent in Vietnam to compile existing data and information from prior studies on typhoons, flooding, and coastal erosion. In order to determine the erosion and probability of overtopping at Hai Hau Beach and Ly Hoa Beach existing typhoon data were collected. The typhoon-related parameters included storm surge, sea water level, position of centre, pressure at centre, velocity, and direction for the years 1962 to 1991. Several visits to different institutes in the Hanoi area were made. Besides the Center for Marine Environment Survey, Research and Consultation (CMESRC), the Centre for Estuary and Coastal Engineering, Department of Dike Management and Flood Control, VN Integrated Coastal Zone Management, and Weather Forecasting Department were also visited.

Two field trips were performed to get an overall picture of the two study areas at Hai Hau Beach and Ly Hoa Beach. During the field trips limited surveying was made to get additional background data for the calculations. Measurements of the hill slope and grain size were carried out and some interviews were also made with the local people with the help of an interpreter. Documentation regarding vegetation, farming, and buildings were also made.

The compiled information was employed to calculate maximum wave height during typhoon attacks, erosion of the sand dunes, run up height, and the probability of overtopping. For erosion calculations an analytical model, written in Microsoft excel, that utilizes wave height, water level, grain size, slope, and strength of slope material as input parameters, was used. To estimate overtopping and run up height commonly employed formulas from coastal hydraulics were used. For a more detailed description and justification of the methods chosen see chapter 2.

2 Typhoons

2.1 Origin

Tropical cyclones consist of warm, humid, rotating air, and they occur over water in a limited area on the earth, usually between 10° and 30° latitude in both hemispheres (Stull 2000). Vietnam lies within the boundaries of the area where tropical cyclones can occur. Tropical cyclones form over the ocean where the sea-surface temperature is at least 26 °C and the water depth is 60 m or more (Stull 2000). In the northern hemisphere they circulate counter-clockwise about their centres and in the southern hemisphere they circulate clockwise because of the Coriolis force[1] (Ahrens 1991).

In the western North Pacific, which the Vietnamese coastal areas belong to, tropical cyclones are called *typhoons* when their maximum sustained wind speeds exceed 32.7 m/s. The same types of storms are known by different names depending on where in the world they occur. They are called *hurricanes* in the North Atlantic and *cyclones* in India and Australia, but in this report the term typhoon will be used consistently (Ahrens 1991).

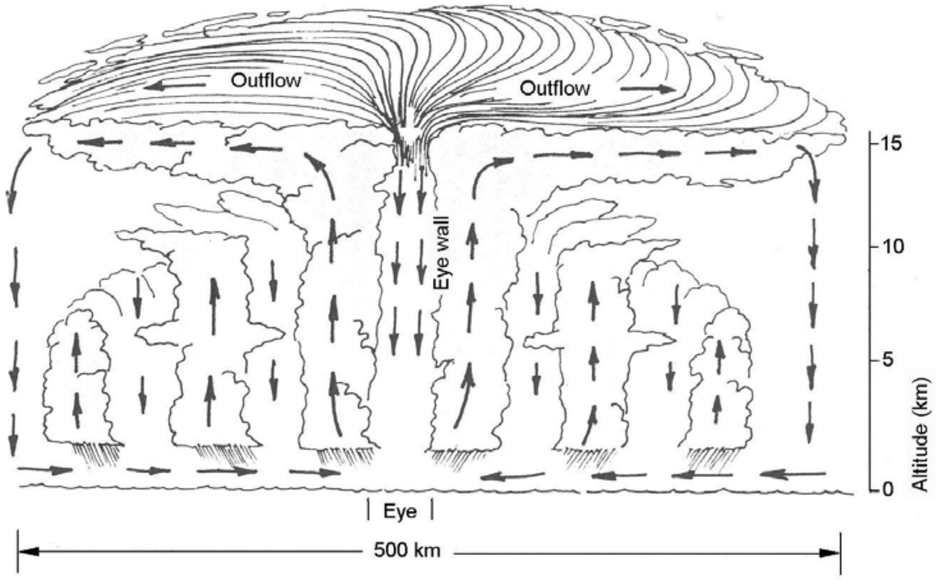

Figure 2.1 *Cross section of a typical typhoon (Ahrens 1991).*

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[1] "Force due to the Earth's rotation, capable of generating currents. It causes moving bodies to be deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The "force" is proportional to the speed and latitude of the moving object. It is zero at the equator and maximum at the poles." (U. S. Army Corps of Engineers 2001)

Figure 2.1 shows that a typhoon consists of many thunderstorms that circulate within the storm. In the middle of the storm, in the eye, there are clear skies, light wind, and low surface pressure. Warm humid air, flow over the sea surface towards the centre of the typhoon, where it rises and condensate. This inward flow leads to intense thunderstorms with heavy rainfall as a result. It is in the eye wall that the heaviest precipitation and the strongest winds occur. When the rising air hit the stratosphere it starts spreading and moving out towards the periphery of the storm where it finally subsides (Stull 1991). Typhoons can last from 3 hours to 3 weeks but most commonly they last between 5 to 10 days. The typhoons subside when they move over land or over cool water because of the friction that land causes and the lack of humid air as a heat source (Ahrens 1991).

2.2 Effects

When typhoons move in over land they can cause severe damage often resulting in human, economic, and social catastrophe for the country. Most typhoons induce significant storm surge[2] which, especially in combination with high tide levels and waves, can lead to flooding in the coastal areas destroying houses and coastal structures such as dikes. Failure of sea dikes results in salt water intrusion, which can contaminate fresh water aquifers near the coast, destroy crops and make farmland unusable for many years to come (VCZVA 1996).

The strong winds, of more than 32.7 m/s, cause severe storm damage, easily destroying poorly constructed houses and other structures. Besides storm surges and strong winds the typhoons also generate heavy rainfall of long duration, which can cause flooding in connection with surface runoff. In fact, most of the people killed in typhoons drown in fresh water (NOAA 2003).

Storm surge, waves, and currents that reach into harbours may cause severe damage to ships and marinas (NOAA 2003). Typhoons that occur in the Pacific Ocean, but do not reach the coast, can generate long period waves of up to 16 seconds. These waves affect the motion of ships in harbours and should be considered when designing a harbour (Nagai et al. 1998). There are many examples of typhoons leaving a great number of casualties behind. Two examples for Vietnam are, typhoon Cecil in 1985 that caused the death of 900 people, while typhoon Dan in 1989 killed 352 people (Quynh et al. 1998).

The worst case scenario for typhoon attacks is if two typhoons apt to land fairly close to each other during the same season. When this happens the people will not have had time to reconstruct houses and protective structures before the next typhoon hit. An example of this is the typhoons Andy and Cecil that both struck at the central parts of Vietnam in October 1985. They caused the most damage to this area over the past 100

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[2] “A rise above normal water level on the open coast due to the action of wind stress on the water surface. Storm surge resulting from a typhoon also includes that rise in level due to atmospheric pressure reduction as well as that due to wind stress.” (U. S. Army Corps of Engineers 2001)

years (Imamura and To 1997). The two typhoons struck with only two weeks in-between.

2.3 Storm Surge

The three main effects induced by a typhoon are rain, wind, and storm surge, of which the latter is the most dangerous. In the eye of a typhoon the atmospheric pressure is much less than the ambient. This low air pressure and the wind blowing the water against the coast causes a dome of sea water to form in the open sea. At the beginning this dome could be one metre high, but as the typhoon moves towards land it will grow much larger. If the storm surge coincides with high tide, severe flooding will occur. The duration of the surge depends on the size of the storm, its forward speed, and the angle of the storm track relative to the coast, among other factors (NOAA 2003).

The level to which the storm surge reaches is also determined by the slope of the continental shelf. If the slope is mild it will allow the storm surge to reach higher, whereas areas with steeper slopes will not experience as high storm surge (NOAA 2003).

2.4 Wave Climate

The wave field generated by typhoons has been the subject of a number of studies. However, it is difficult to measure the actual wave height within a typhoon due to their unpredictable paths, infrequent occurrence, and extreme weather conditions. Despite this, a combination of in situ buoy measurements, satellite observations, and numerical hindcasts for over 30 years has made it possible to describe and predict the waves within a typhoon (Young 2003).

The wave field does not correspond directly to the wind field since the wave field is more asymmetric than the latter. This has to do with the concept of *extended fetch*. Extended fetch means that to the right of the storm centre, provided that the storm rotates counter clockwise, the waves move with the forward motion of the storm. On the other hand, waves to the left of the storm centre move opposite the forward motion of the storm and therefore out of the wind field. Because of the extended fetch, waves to the right of the storm centre in the northern hemisphere, and left of the centre in the southern hemisphere grow larger than the waves on the opposite side of the centre (Young 2003).

In figure 2.2, the generation of waves within a typhoon is schematically shown. The forward motion of the storm is up the page (see the arrow in the storm centre). Notice the two areas to the right and to the left of the storm eye showing the areas of extended and short fetch, respectively. Also notice the swell radiating out, slightly from the right, ahead of the storm centre. This swell will cross the locally generated waves in an almost 90º angle generating close to pyramidal waves (Young 2003).

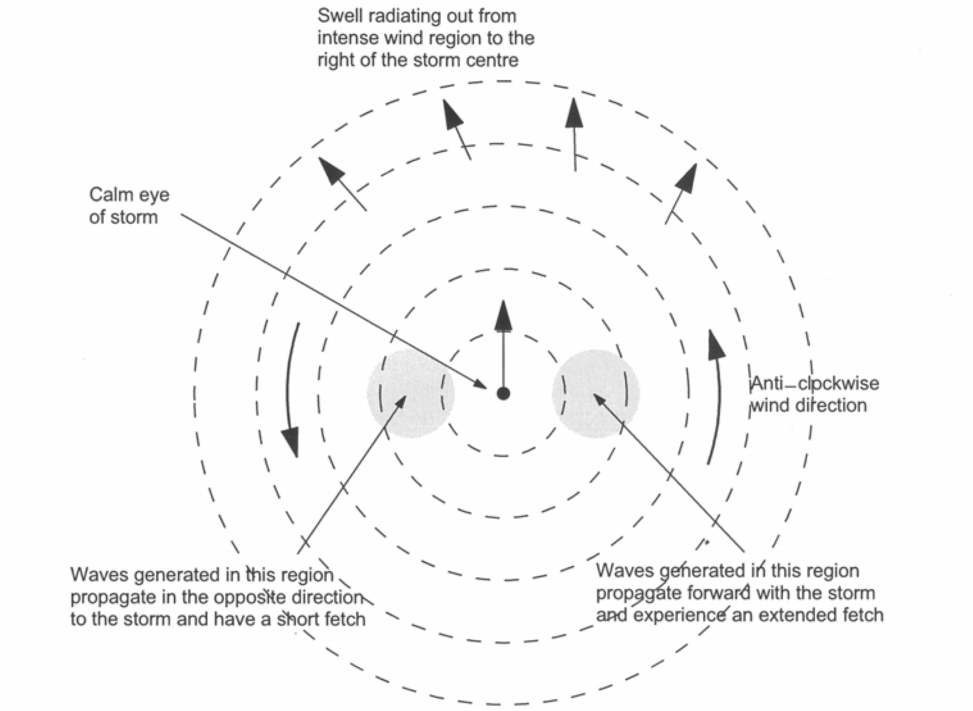

Figure 2.2 *Schematic picture of the waves within a translating typhoon (Young 2003).*

The typhoon wave field is not only dependent on the present wind field, but also the earlier wind fields, bathymetric effects, and pre-existing waves from other wind systems. Despite this, wave fields of a typhoon can often be satisfactorily described by a small number of parameters (U. S. Army Corps of Engineers 2001).

2.5 Wave Model

For a typhoon wave prediction model to provide accurate result the typhoon must meet the following criteria (U. S. Army Corps of Engineers 2001):

- Typhoon intensity must be relatively constant
- Typhoon track is approximately straight
- Typhoon forward speed is relatively constant
- Typhoon is not affected by land or by bathymetric effects
- No strong secondary wind and/or wave system affects the conditions

The wave prediction model used in this study is Young’s (2003) model for waves generated by typhoons. In contrast to other wave models, the wave heights in this model are not only a function of the wind speed, but the relationship between the forward motion of the storm, V_{fm}, and the group velocity of the waves, C_g, is also taken into account. The concept of extended fetch is an important factor, because when waves propagate in the same direction as the forward motion of the storm they stay in the intense wind regions for a longer time period and therefore receive maximum energy input from the wind. If the group velocity of the waves, C_g, is larger than V_{fm} the waves will move ahead of the storm and if V_{fm} is larger than C_g the waves will be left behind in the light winds. Consequently the largest waves occur when the group velocity of the typhoon waves is approximately equal to the forward motion of the typhoon (Young 2003).

2.5.1 Maximum Wind Speed

The maximum wind speed within the storm occurs just outside the storm eye, in the eye wall (see figure 2.1). In the compiled data the difference in pressure at landfall[3], ΔP, is given. ΔP is the difference between surrounding air pressure, P_∞, and minimum pressure in the typhoon, P_{min}. To determine the maximum sustained wind speed, V_{max}, the minimum pressure is needed, which can be obtained by using the following formula (Ninh et al. 1991):

$$P_{\min} = P_\infty - \Delta P \tag{2.1}$$

In equation 2.1 P_∞ is equal to 1010 mbar. The maximum sustained wind speed, corrected to 10 m above the sea surface in the eye wall, can then be determined by:

$$V_{\max} = 765 - 0.75 P_{\min} \tag{2.2}$$

The calculated error in V_{max} with this formula is 2 to 4 m/s according to Ninh et al. (1991). This formula for the maximum wind speed was developed by CMESRC. In Young's (2003) model another formula is used to calculate V_{max}, but the formula from CMESRC has been shown to give accurate values of the wind speed for the local conditions prevailing in Vietnam.

2.5.2 Significant Wave Height

In order to implement the concept of extended fetch an equivalent fetch factor, x, is defined in terms of V_{fm}, V_{max} and R' (Young 2003),

$$\frac{x}{R'} = \psi\left[V_{\max}^2 + bV_{\max}V_{fm} + cV_{fm}^2 + dV_{\max} + eV_{fm} + f\right] \tag{2.3}$$

where $a = -2.175 \times 10^{-3}$, $b = 1.506 \times 10^{-2}$, $c = -1.223 \times 10^{-1}$, $d = 2.190 \times 10^{-1}$,
$e = 6.737 \times 10^{-1}$ and $f = 7.980 \times 10^{-1}$. The quantity Ψ is a scaling factor defined as:

$$\psi = -0.015V_{\max} + 0.0431V_{fm} + 1.30 \tag{2.4}$$

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[3] "Landfall is the position along a coast where the center of a typhoon passes from ocean to land." (Ahrens 1991)

R' is a spatial scale parameter given by:

$$R' = 22.5\times10^{3}\log R - 70.8\times10^{3} \tag{2.5}$$

The radius of the storm eye, R, is obtained from table 2.1.

Table 2.1 *The radius of the storm eye, R in km, determined from the difference in pressure, ΔP in mbar (after Ninh et al. 1991).*

ΔP (0-10) **ΔP (tens)**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	20,0	20,9	22,0	23,0	23,5	24,4	25,6	25,9	27,0	27,6
2	28,0	29,1	29,4	30,6	30,9	31,5	32,0	33,0	33,5	34,1
3	34,4	34,8	35,6	36,5	37,0	37,6	38,0	38,5	39,1	39,4
4	40,0	40,6	40,9	41,5	42,0	42,6	43,0	43,5	44,1	44,4
5	44,6	45,4	45,7	45,9	46,5	47,0	47,6	47,6	48,0	48,5
6	48,9	49,4	49,4	50,0	50,6	50,9	51,5	52,0	52,4	52,6
7	53,0	53,5	54,1	54,4	55,0	55,6	55,9	55,9	56,5	56,5
8	56,5	57,0	57,6	58,0	58,0	58,3	58,5	58,5	59,1	60,0

The maximum significant wave height, H_s^{max}, can then be determined from,

$$\frac{gH_s^{\max}}{V_{\max}^2} = 0.0016\left(\frac{gx}{V_{\max}^2}\right)^{0.5} \tag{2.6}$$

2.5.3 Peak Wave Frequency

To obtain the peak wave frequency, f_p, the relationship between the non-dimensional energy, ε, and the non-dimensional peak frequency, v, can be employed (Young 2003),

$$\varepsilon = 7.13\times10^{-6}\,v^{-3.03} \tag{2.7}$$

where the non-dimensional variables are defined by:

$$v = \frac{f_p V_{\max}}{g} \tag{2.8}$$

$$\varepsilon = \frac{g^2 E}{V_{\max}^4} \tag{2.9}$$

The total energy can be related to the significant wave height through:

$$H_s = 4\sqrt{E} \tag{2.10}$$

2.5.4 Wave-Height Reduction

The significant wave height obtained in equation 2.6 is valid for deep water conditions. Tonkin Bay, where the two study sites are located, cannot be considered as deep water. Therefore the wave height should be reduced for bottom friction to avoid an over-estimation of the wave height. This reduction can be obtained by using an energy balance equation at an assumed equilibrium state,

$$W = D_B + D_f \tag{2.11}$$

where W is the wind energy inducing the wave (per unit time and surface area), D_f is the energy dissipation from bottom friction, and D_B is the dissipation due to white-capping and breaking at the surface (Komen et al. 1994). The energy input, W, may be derived from the energy balance in deep water, where $W=D_{B0}$ (D_{B0} is the dissipation in deep water due to white-capping). Energy dissipation from white-capping is given by (Chawla & Kirby 2002),

$$D_B = f_B \frac{2\pi}{T} \frac{1}{8} \rho g H^2 \tag{2.12}$$

and dissipation from bottom friction by (Nielsen 1992),

$$D_f = \frac{2}{3\pi} f_b \rho K_v^3 H^3 \tag{2.13}$$

In equation 2.13 f_B is a dissipation factor for white-capping, H is the significant wave height at depth h, f_b is a dissipation factor for bottom friction, and K_v is defined by,

$$K_v = \frac{1}{2} \frac{gT}{L} \frac{1}{\cosh\left(\frac{2\pi h}{L}\right)} \tag{2.14}$$

where L is the wavelength at depth h and T is the wave period.

If equations 2.12 and 2.13 are substituted into equation 2.11, the following equation results:

$$H_{in} = \sqrt{H^2 + \frac{8}{3\pi^2}\frac{f_b}{f_B}\frac{T}{g}K_v^3 H^3} \tag{2.15}$$

Equation 2.15 must be solved numerically to obtain the unknown wave height, *H.* The height H_{in} is the input wave height derived from the energy balance equation for deep water. By comparing calculated wave height with measured wave height the relationship between f_b/f_B can be determined. Then the reduced wave height, *H*, at the location of interest can be calculated for any given H_{in}.

2.6 Runup Model

A runup[4] model for random waves on gentle slopes was used to estimate the risk of overtopping. This model takes into consideration the interaction between the up-rush and the back-wash that becomes significant when the beach slopes are gentle. The maximum wave runup height, R_{max}, can be calculated from (Mase & Iwagaki 1984),

$$R_{\max} = H_0 d\left(\frac{\tan\beta}{\sqrt{H_0 / L_0}}\right)^e \tag{2.16}$$

where d = 2.319 and e = 0.771 for R_{max}.

The beach slope, $\tan\beta$, is defined as the average slope between the breakpoint and the runup limit (Mayer & Kriebel 1994),

$$\tan\beta = \frac{R + h_b}{x_R + x_b} \tag{2.17}$$

where h_b is the incipient breaking depth, x_b is the horizontal distance from the shoreline to the break point, and x_R is the horizontal distance from the runup limit to the shoreline. The distance x_R is related to the runup height, *R,* and the slope of the beach face, *m,* as $x_R=R/m$ (see figure 2.3).

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[4] "The upper levels reached by a wave on a beach or coastal structure, relative to still-water level." (U. S. Army Corps of Engineers 2001)

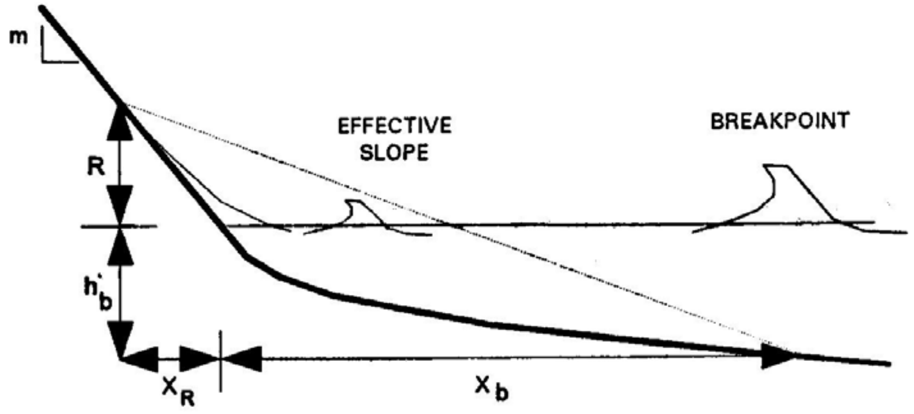

Figure 2.3 *Definition of effective slope for a beach profile (Mayer & Kriebel 1994).*

2.7 Erosion Model

It is important to predict the impact of typhoons on the coastal dunes, since the dunes often are the final defence line against high waves and storm surge. Erosion caused by typhoon waves mainly generates cross shore sediment transport, meaning that the prevailing transport of eroded material is from the sand dune out into the sea as opposed to along the shoreline. In order to predict the dune erosion an analytical model developed by Larson et al. (2003) was used (see equation 2.18). The model calculates recession distance and eroded volume for a sand dune during severe storms. The analytical model is based on wave impact theory (Fisher & Overton 1984, Overton et al. 1994), which estimates the sediment transport from a dune by the waves directly hitting it, and the sediment volume conservation equation.

$$\Delta V_E = 8\frac{C_S}{T}\left(\left(\frac{T_S}{2}-t_L\right)\left(\frac{1}{2}R_T^2+z_D^2\right)-R_T^2\frac{T_S}{4\pi}\sin\left(2\frac{\pi * t_L}{T_S}\right)-2R_T z_D\frac{T_S}{\pi}\cos\left(\frac{\pi * t_L}{T_S}\right)\right) \tag{2.18}$$

where,

$$t_L = \frac{T_s}{\pi}\arcsin\left(\frac{z_D}{R_T}\right) \tag{2.19}$$

Definitions of the parameters are given in table 2.1 and figure 2.4.

Table 2.1 *Definitions for erosion model equation 2.18.*

C_S	empirical coefficient
R_a	runup height amplitude during surge (m)
R_i	runup height at t=0 (m)
R_T	$= R_a + z_a$ (m)
T	wave period (s)
t_L	time when bores start impacting the dune during storm
T_S	duration of surge (s)
V_E	eroded volume at a specific time (m^3/m)
z_a	amplitude of water level variation during surge (m)
z_D	$= z_i - R_i$ (m)
z_i	initial elevation of dune foot for varying water level (m)

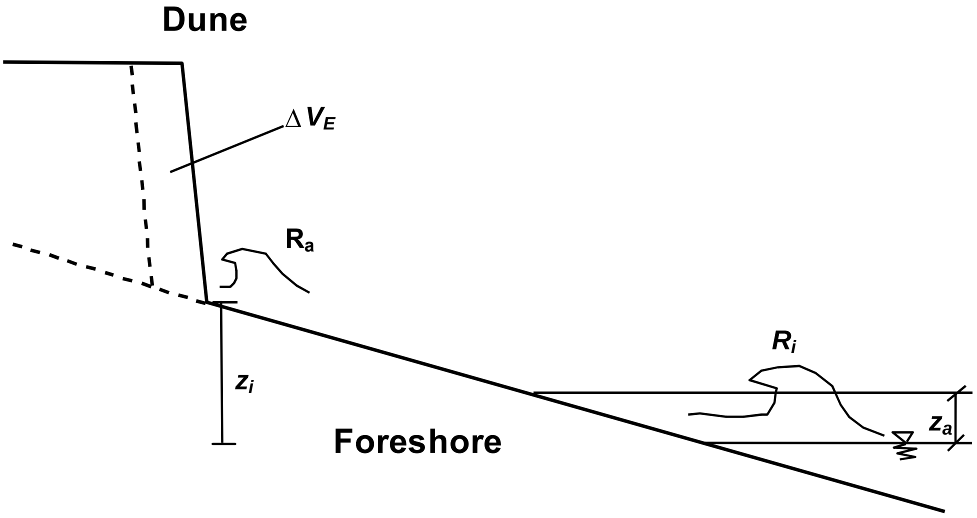

Figure 2.4 *Definition sketch for modelling erosion due to impact of runup waves (after Larson et al 2004).*

In order to obtain a useful analytical model some simplifying assumptions were made by Larson et al. (2004). First, the relationship between the impact and weight of the eroded sediment is assumed to be linear. Second, the foreshore slope of the beach can be assumed to be constant during retreat. Equation 2.18 is applicable for storm surge having a sinusoidal variation with time, which, for simplification, was assumed for the storm surge events used in this study.

The coefficient C_s quantifies the rate at which equilibrium is approached. For the calculations in Ly Hoa an approximation of C_s for practical applications is used, with $C_s = 1.5 \times 10^{-4}$ (Larson et al. 2004). A variation of $\pm 0.5 \times 10^{-4}$ on C_s was employed in the calculations to investigate the sensitivity of the predictions.

3 Vietnamese Coastal Zone

Vietnam has an area of almost 332 000 km^2 and is shaped like an ‘S’ (see map in figure 3.1). In the northern part of the country the terrain is dominated by mountains. Many rivers pass through this area of which the Red River and the Thai Binh River carry most water (Pruszak 1998). The rivers run out on the Red River Delta Plain, which is a large triangular delta that reaches the northern coast (Vinh et al. 1996). The central part of Vietnam is narrow with mountains in the inland and low plains along the coast. Because of this topography, the rivers run fast and the discharge increases rapidly in connection with heavy rainfall. The southern part of the country is characterized by a large low-lying land area, the Mekong Delta, which covers an area of about 40 000 km^2 (Vietnam 1989).

Of the Vietnamese coastline, slightly more than half is sandy or muddy low-lying delta formations, almost one quarter consists of sand dunes, and the rest is hard rock (Zeidler & Nhuan 1997). The bed-rock in large parts of Vietnam consists of limestone, but the mountains near Danang in central Vietnam and the coastal range near Nha Trang in the south are composed of granite (Lonely Planet 2001).

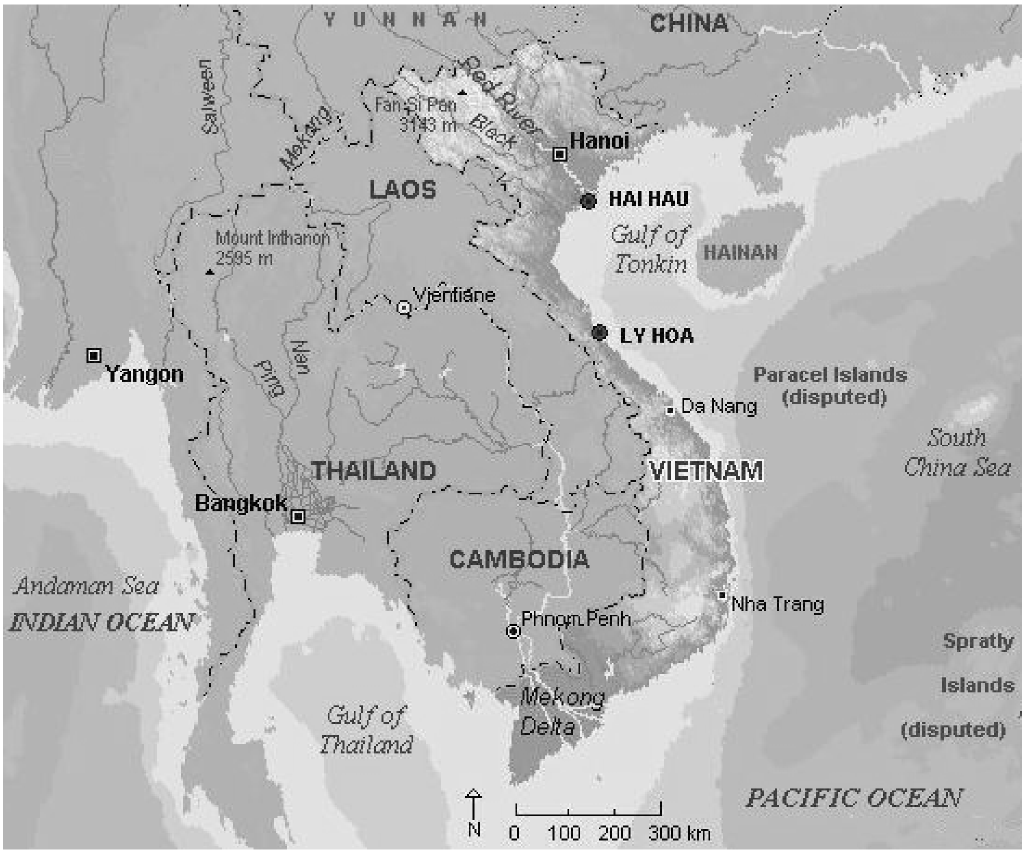

Figure 3.1 *Map of Vietnam with the two study sites Hai Hau Beach and Ly Hoa Beach (after Encarta 2000).*

3.1 Hai Hau Beach

3.1.1 Morphology and Land Use

Hai Hau district is at the rim of the Red River Delta and is one of three coastal districts in the Nam Dinh province (Vinh et al. 1996). The boundaries for Hai Hau district is the Ninh Co River in the south-west and the Ngo Dong River (dammed in 1955) in the north-east (see figure 3.2).

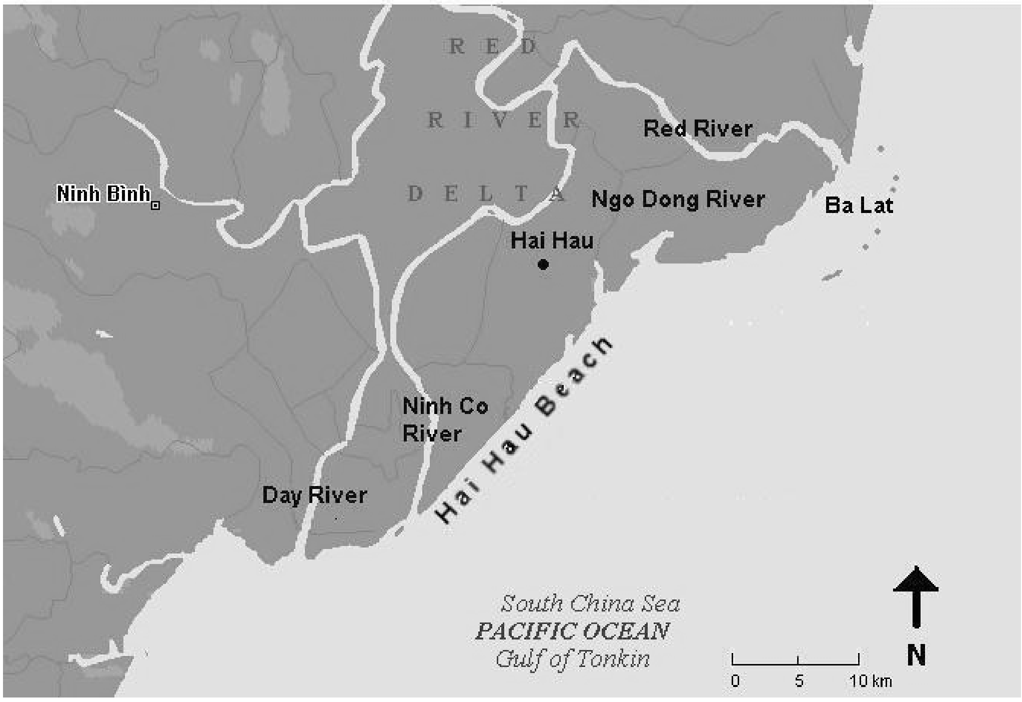

Figure 3.2 *Map of Hai Hau Beach (after Encarta 2000).*

The landscape of Hai Hau has been formed by deltaic and coastal processes. The Red River has through millennia transported sediment out into the Gulf of Tonkin where it has settled. At the coastline the layer of deposits is as thick as 200 m. The deltaic deposits are up to 30 m and are underlined by coarser grains deposited during the ice-ages (Mathers & Zalasiewicz 1999). The typical grain-size of the deltaic deposits varies between 0.001 mm and 0.25 mm, and these fine fractions are easily transported by water (Hung et al. 2001). See **Appendix I** for some typical grain-size distributions from the shoreline area of the studied beach**.** The mobility of fine grains in the delta plain leads to a very gentle slope towards the sea. The sediment transported by the rivers deposits at the river mouth during summer, and is redistributed along-shore by wave-induced currents during winter (Vinh et al. 1996).

Hai Hau district is one of the most densely populated rural areas in the world, which makes the area sensitive to disruptions in the local economical and farming conditions (Imamura & To 1997). The dominating activity is rice cultivation, which occupies most of the available farmland. However, access to the sea has led to development of alternative sources of income. In Hai Hau district shrimp farms and salt extraction fields are fairly common and fishermen earning their daily income can also be observed at the seashore (Häglund & Svensson 2002). The people living in Hai Hau district are vulnerable to the forces of the sea, since the area is flat and the houses are built almost at sea level. Dikes provide some protection, but the houses built between the two lines of dikes, (see chapter 3.1.2), will most likely not last long if the seaward dike is breached. Even though the people living in exposed houses would like to move, it is not possible because of the dense population and poverty in the area. Monthly income can be as low as US$ 7 for the inhabitants of Hai Hau Beach. There are however, evacuation plans available for the area in order to provide safety for the people living there in case of typhoon attack (Häglund & Svensson 2002).

3.1.2 Coastal Processes and Protection

Hai Hau Beach suffers from severe erosion[5]. The retreat of the sea shore has been estimated to a rate of 29 m per year (Vinh et al. 1996). Two rivers that discharge into the sea close to Hai Hau Beach, the Day River and the Balat River, are reported to have the highest sediment load of the river branches in the Red River Delta. Despite this, Hai Hau is one of the most erosion prone beaches along the delta coast. Many investigations have been carried out to establish the cause of this problem, and three probable factors have been considered.

Firstly, in 1955 a branch of the Red River, close to Hai Hau Beach, was dammed, which stopped the sediment transport to the sea. Secondly, the construction of Hoa Binh Reservoir in the Red River catchment was completed in 1987. It is estimated that 70 million tons of sediment is deposited there each year (Zeidler & Nhuan 1997). These two factors alone cannot explain the erosion at Hai Hau Beach, since the retreat has been observed for at least a century. Hung et al. (2001) investigated a third possible explanation where they suggest that the prevailing wave climate in combination with the shoreline orientation induce gradients in the longshore sediment transport which leads to erosion at Hai Hau Beach. By using wave transformation and sediment transport calculations, Hung et al. concluded that their hypothesis is the most likely explanation for the erosion at Hai Hau Beach.

A mechanism that may also affect the coastal processes at Hai Hau Beach is tide. The north coast is exposed to a regular diurnal tide (Hong & San 1994). This type of tidal variation occurs when the tide oscillates in a water-body and produces a wave period with only one single high tide per day. Diurnal tides occur in partially enclosed basins (Komar 1998) such as the Gulf of Tonkin which borders Hai Hau Beach. The highest

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[5] The wearing away of land by the action of natural forces. On a beach, the carrying away of beach material by wave action, tidal currents, littoral currents, or by deflation. (U. S. Army Corps of Engineers 2001)

tide in Vietnam is found at the coast bordering the Gulf of Tonkin and measures 1.8 m HD (HD = Hon Dau Datum, which is located 0.14 m above MSL) (VCZVA 1996). The extreme tide at Ba Lat (see figure 3.2) for a 19-year period is 1.57 m above MSL (Lien 2003). Measurements were made during the years 1972 to 1990.

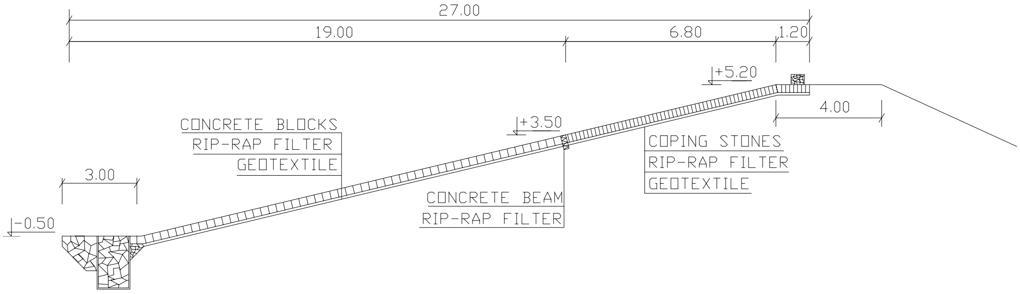

Figure 3.3 *Cross section of a typical dike at Hai Hau Beach (after Dzung 2003).*

The retreat of the coastline in combination with the threat of typhoons has forced the local population to build sea dikes along the coastline for protection. Dikes are built alongshore and have a core of sand and clay with a protective top layer. At the most exposed parts of Hai Hau Beach the dikes have a revetment of precast concrete blocks at the lower section. Further up, the revetment consists of loose rock placed in gravel. The crest elevations of these dikes are about 5.50 m above MSL (Dzung 2003). Less exposed dikes or simpler ones, typically not funded by the Vietnamese government or international aid, have a revetment of loose rock at the lower part and are covered by grass on the remaining part of the dike. These dikes have a crest level of between 4.0 to 4.8 m above MSL (Dzung 2003). Typical dikes have a seaward slope of 1:4, a crest width of 4 m, and the inland slope is 1:2 (figure 3.3). The gentle seaward slope reduces the erosion as well as the wave run-up (U. S. Army Corps of Engineers 2001). The inland slope is covered by grass, and on some parts of the dike and along the seafront, *Casuarina trees* are planted to reduce wind and to bind the soil (Häglund & Svensson 2002).

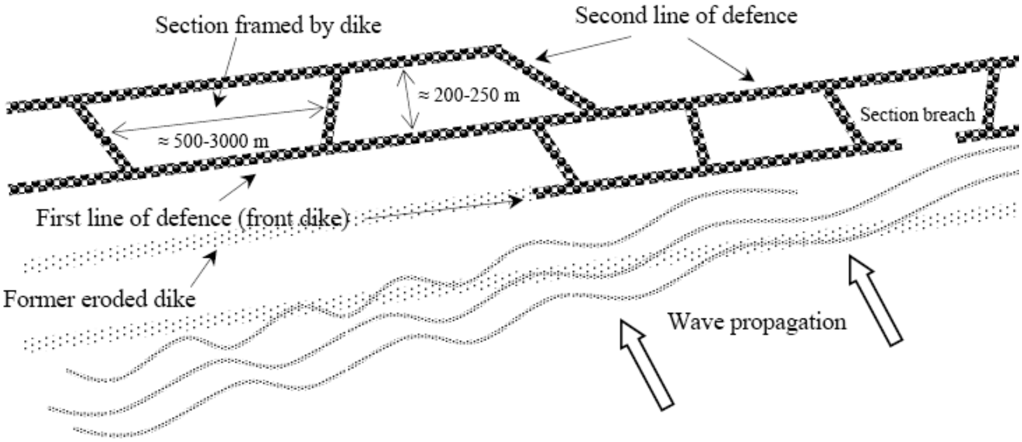

Figure 3.4 *Sketch of double dike system at Hai Hau Beach (Häglund & Svensson 2002).*

Hai Hau Beach is protected by dikes along 75 per cent of the coastline. For the most part two lines of dikes are built so that the hinterland will still be protected even if a section of dike breaches (figures 3.4, 3.5, and 3.6). The dikes are constructed with varying strength depending on whether they protect government land or not. Private land has to be protected by the landowners themselves. Due to lack of funds, equipment, and engineering knowledge, these dikes are normally less durable.

Figure 3.5 *The first line of earth and clay dikes at Hai Hau Beach.*

Figure 3.6 *The second line of rock-reinforced dikes at Hai Hau Beach.*

In some places along Hai Hau Beach groins have been constructed out of loose rock perpendicular to the beach. Groins are built to reduce the longshore sediment transport. The positioning of groins affects the longshore transport of sediment and how the sediment is deposited along the shoreline. According to Häglund and Svensson (2002) the effects of groins at Hai Hau Beach is questionable due to their poor design and construction.

The dikes at Hai Hau breach on average once every ten years (Vinh et al. 1996). When this happens the dike has to be reconstructed or a new line of defence has to be built further inland. The work is done by the local farmers and fishermen (see figure 3.7), and at Hai Hau Beach the men are required to work 40 days per year with dike repair, maintenance, and construction (Vinh et al. 1996). The clay for the core is obtained a few kilometres away from the coastline and rocks for revetment are stored on the crest of the dike for emergency protection purposes.

Figure 3.7 *Local farmers improving the front dike at Hai Hau Beach.*

3.2 Ly Hoa Beach

3.2.1 Morphology and Land Use

Ly Hoa Beach is situated in Quang Binh Province in the central part of Vietnam (figure 3.1). More precisely, Ly Hoa Beach is a part of Hai Trach Commune in Bo Trach District, one of seven districts in Quang Binh. The beach stretches from the mouth of Ly Hoa River and 1500 m north-west (see figure 3.8). The area is characterized by sand dunes (see figure 3.9), in places reaching an elevation of 7 m above MSL. The beach consists of over 90 per cent sand (see **Appendix II**). The southern part of the beach stretches in front of Ly Hoa River through a spit formation, and since the river outlet has moved south over time it could in the future breach the spit according to Hung (2003).

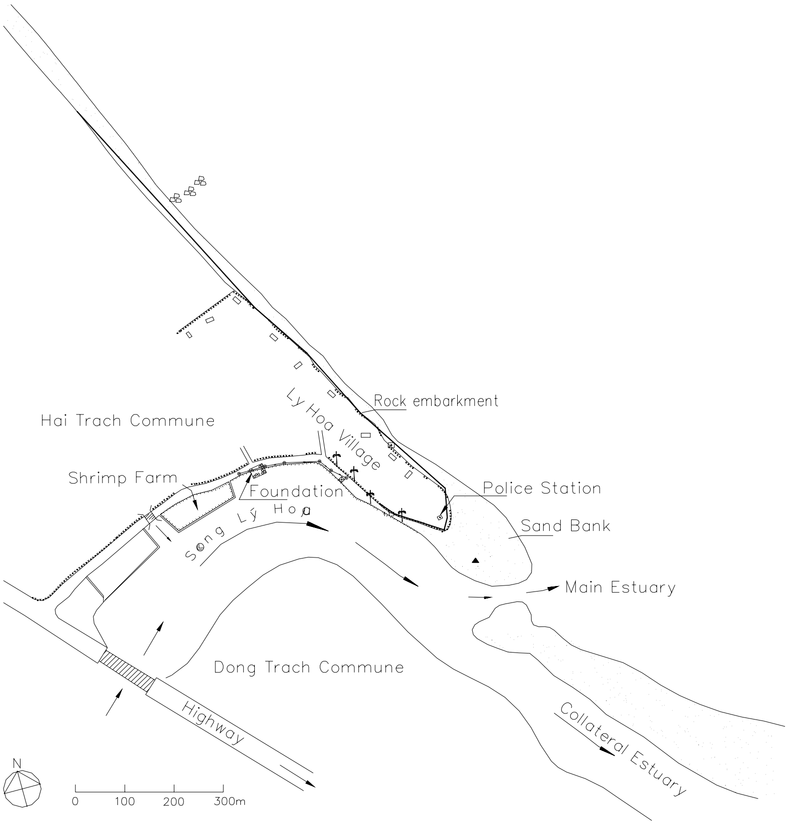

Figure 3.8 *Map of Ly Hoa Beach (Nghia 2003).*

Fishery is one of the main occupations in Quang Binh (Quang Binh 2003), and even more so in the Hai Trach Commune. The fishermen of Hai Trach live with their families on the spit between Ly Hoa River and the sea, and altogether there are about 1100 people living at this exposed site (UNDP a 2003).

Figure 3.9 *View of Ly Hoa Beach (note the wild pineapple that covers the sand dunes on the left side of the picture).*

3.2.2 Coastal Processes and Protection

At Ly Hoa the people are threatened both by the action of the river as well as by the sea. Ly Hoa River makes a sharp right turn in Hai Trach (see figure 3.10) because of the spit development, and since the commune is situated on the left side of the river it will be exposed to erosion of the bank. The river undercuts the river bank and transports the eroded sediment out to sea. From the sea, the largest threats are typhoons and north-east winds during the winter monsoon (UNDP b 2003), causing flooding as well as erosion.

Figure 3.10 *The river of Ly Hoa makes a sharp right turn in Hai Trach.*

The central coast of Vietnam is exposed to an irregular tide (Hong & San 1994), which sometimes gives one single high tide per day (diurnal tide), and on other days, two low and two high waters per day (semidiurnal tide). The high tide level at the coast in central Vietnam is about 0.4 m HD (HD = Hon Dau Datum, which is located 0.14 m above MSL), which is a lower value than the tide in both northern and southern Vietnam (VCZVA 1996). The extreme tide in Ly Hoa, for a 19-year-period, is 1.03 m above MSL (Lien 2003). Measurements were made between 1972 and 1990.

To protect homes from wave action, wild pineapple has been planted on the seaward side of the sand dunes (see figure 3.11). A revetment was recently constructed to protect the sand dunes against wave attack (see figure 3.12). One of the main aims of this revetment is to prevent the erosion to reach the nearby located police station. Hai Trach is in focus for governmental and international aid, and the United Nations Development Program (UNDP) has developed a resettlement program for the entire community. The plan was to move 220 families 3 km further inland before November 2000 in order to protect them from beach and river mouth erosion (UNPD a 2003). The village was not moved though, and in 2001 a report was presented that came to the conclusion that it will be less expensive to protect the beach and the people living there instead of moving them (UNDP c 2003).

Figure 3.11 *Wild Pineapple at Ly Hoa Beach planted to prevent erosion and overtopping.*

Figure 3.12 *Recently constructed revetment at Ly Hoa Beach.*

During a field visit to Ly Hoa in November 2003, construction of the protection works against erosion was taking place. Local men were constructing the erosion protection on the river side of the spit. Large rocks were put in net cages, and these were then placed in the water to prevent more sand from eroding. An example of these cages, but placed on the seafront, can be seen in figure 3.13. This work is funded by the Vietnamese government, whereas another part of the project will be funded by UNDP. The UNDP-funded project involves the construction of T-shaped breakwater units to protect the seashore from erosion and wave action. Two units are planned and each one will be 150 m long with wings of 180 m. However, in November 2003 there were no signs that the seashore protection was under construction.

Figure 3.13 *Rocks in net cages at Ly Hoa Beach to protect the coast from eroding.*

4 Typhoons in Vietnam

The climate in Vietnam is dominated by the tropical monsoon[6]. Due to the monsoon the average temperature is lower than in the surrounding countries located on the same latitude. The humidity is high with an average of 84 percent throughout the year (Vietnam 1989). Because of the influence of the monsoon, Vietnam's complicated topography and its differences in latitude, the climate varies from place to place. During the dry winter season, from November to April, the north monsoon winds (winter monsoon; see figure 4.1) blow from the northeast along the Chinese coast, across the Gulf of Tonkin, leaving northern Vietnam cloudy with occasional light rain, while the southern parts stay sunny and dry (Vietnam 1989).

The summer season from May to October is dominated by the southern monsoon (summer monsoon; see figure 4.1) with south-westerly winds. These winds are induced by heated air rising from the Gobi Desert, situated at the border between China and Mongolia. When the heated air rises, it induces moist air to flow in from the sea over land with heavy rainfall as a consequence. The rainy season occurs during the summer with almost 90 percent of the annual precipitation (Vietnam 1989). Rainfall is substantial, with an annual precipitation exceeding 1000 mm almost all over the country. In the mountains and plateaus, especially those facing the sea, the precipitation is twice as high. In between the north and the south monsoon there are light winds blowing from variable directions (Vietnam Embassy 2003).

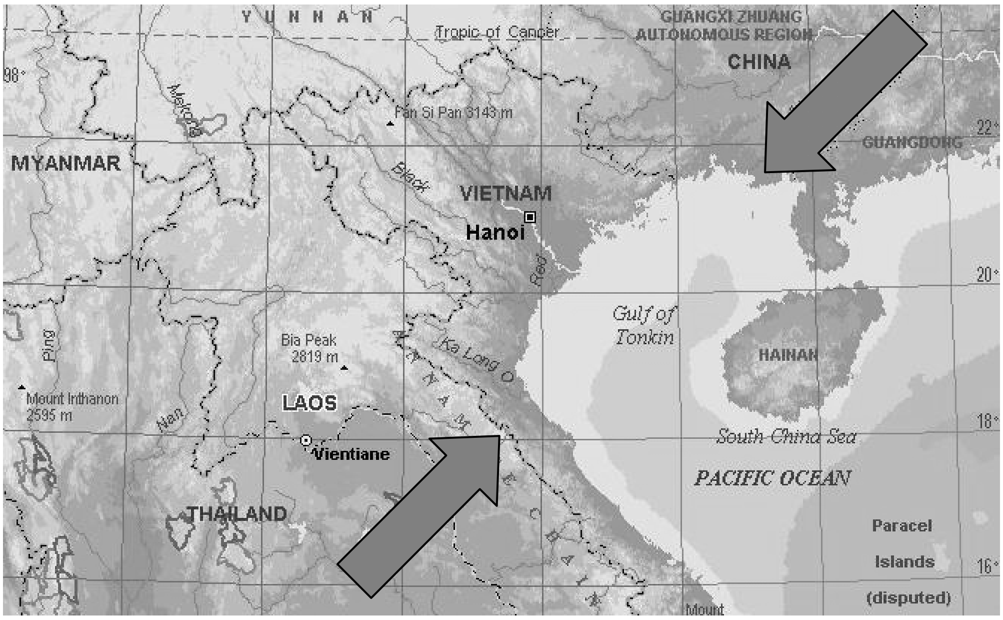

Figure 4.1 *Directions of the monsoon winds in northern Vietnam. The arrows show the main wind direction of the summer and winter monsoon (after Encarta 2000).*

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[6] "The monsoon is a seasonally reversing wind pattern that brings heavy rains into the Asian subcontinent in summer and hot, dry conditions in the winter." (Wiley InterScience 2003)

The temperature is high in southern and central Vietnam throughout the year, and the lowest temperatures occur in the north during the north monsoon when cool air blows in from the China Sea. For a few days every winter snow can be found on the highest peaks in northern Vietnam (Vietnam Embassy 2003). The temperature varies with the highest temperature differences over the year in the north and in the highlands. In the north the temperature varies from 5 ºC in December and January to more than 37 ºC in April, whereas in the south the temperature lies within the 21-28 ºC range all year round (Vietnam 1989).

Every year, on average, 5-6 typhoons affect the Vietnamese coastline. Most of the typhoons that impact the coast of Vietnam occur along the north and central part of the coastline, moving in from the east. The typhoon season starts in March and ends in December with a peak in September and October. In northern Vietnam the typhoons tend to make landfall mainly in August to September, in the central parts in September to October, and in the southern parts mainly in October to November. This is because of the seasonal changes in water and air temperatures and the fact that a typhoon requires a water temperature of more than 26 ºC to form (Imamura & To 1997).

Along the coast in northern and central Vietnam, dikes have been built to protect the land from typhoon attacks. The heavy rainfall and the storm surge induce severe flooding when the storm moves in over land, causing the dikes to breach. As a result the coast erodes and pebbles, earth, sand, and clay get transported out to sea making it more difficult to repair the dikes. Also, when the dikes breach the fields behind are flooded with salt water, leaving the soil useless for many years to come (Pilarczyk and Nuoi, 2002).

4.1 Hai Hau Beach

4.1.1 Storm Tracks

Hai Hau Beach is located in northern Vietnam, just above 20º latitude, and therefore the area is affected by typhoon attacks mainly during the end of the summer (see **Appendix III**). The probability of a typhoon attack varies over the year with a peak in August and September. During January to April there is no risk for typhoon attack at Hai Hau Beach (see table 4.1). The table shows that whenever a typhoon occurs out of the Vietnamese coast, which is 5-6 times each year, the risk that it will reach Hai Hau Beach is up to 80 per cent.

Table 4.1 *The probability of a typhoon attack at Hai Hau Beach for a given month each year, whenever a typhoon occurs offshore of the Vietnamese coast (Toan & Dac 1978).*

Month	Probability
May	0.0-0.1
June	0.1-0.2
July	0.4-0.6
August	**0.8**
September	**0.8**
October	0.4
November	0.4
December	0.1

4.1.2 Storm Surge

On the rocky islands just outside the Red River Delta the maximum storm surge during a typhoon can be 1 to 1.5 m above mean sea level (MSL), but as the surge progresses towards the coast it can grow much higher. In front of dikes and other shore protection constructions storm surge as high as 2.5 to 3.0 have been observed (VCZVA 1996). Still only 4 per cent of the storm surge events reach a height of more than 2 m, where as 30 per cent of the typhoons cause a storm surge higher than 1 m (Ninh et al. 2001).

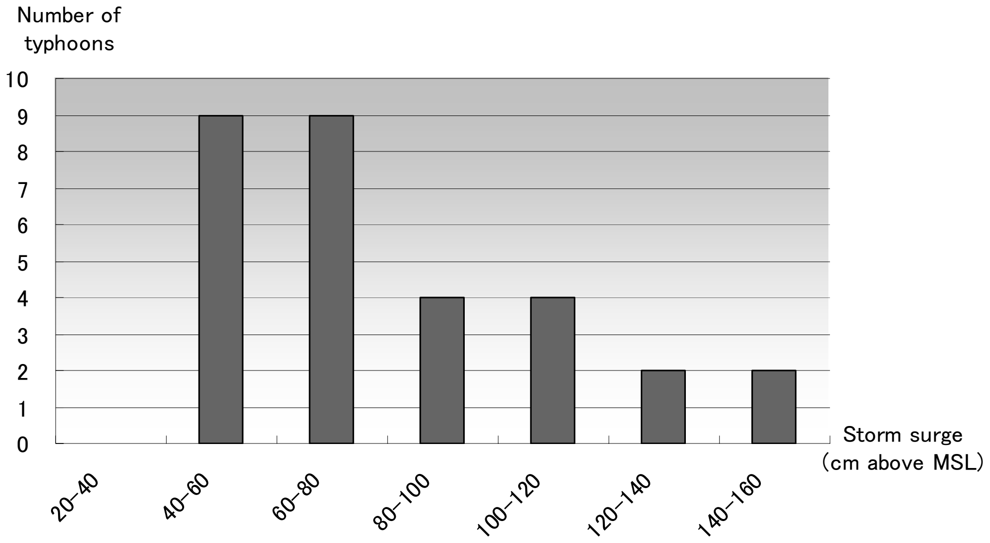

Figure 4.2 *Recorded maximum storm surge at Hai Hau Beach during typhoon attacks.*

From data on the typhoons impacting Hai Hau Beach between the years 1962 to 1991 the maximum storm surge levels where compiled (see figure 4.2). The measurements were made at the measuring station closest to Hai Hau Beach, which is Phu Le (see **Appendix IV**). The error in the measurements is estimated to be about 20 cm.

Therefore none of the surge levels between 0 and 20 cm were taken into consideration. For these typhoons most surge events reach a height of 40 to 80 cm above MSL. None of them caused a surge level that was higher than 160 cm above MSL.

A frequency analysis (Yevjevich 1972) of the storm surge levels at Hai Hau Beach was made and plotted in a chart with a logarithmic scale on the x-axis (see figure 4.3). The figure shows that the level of storm surge for a return period of 50 years is 1.89 m above MSL.

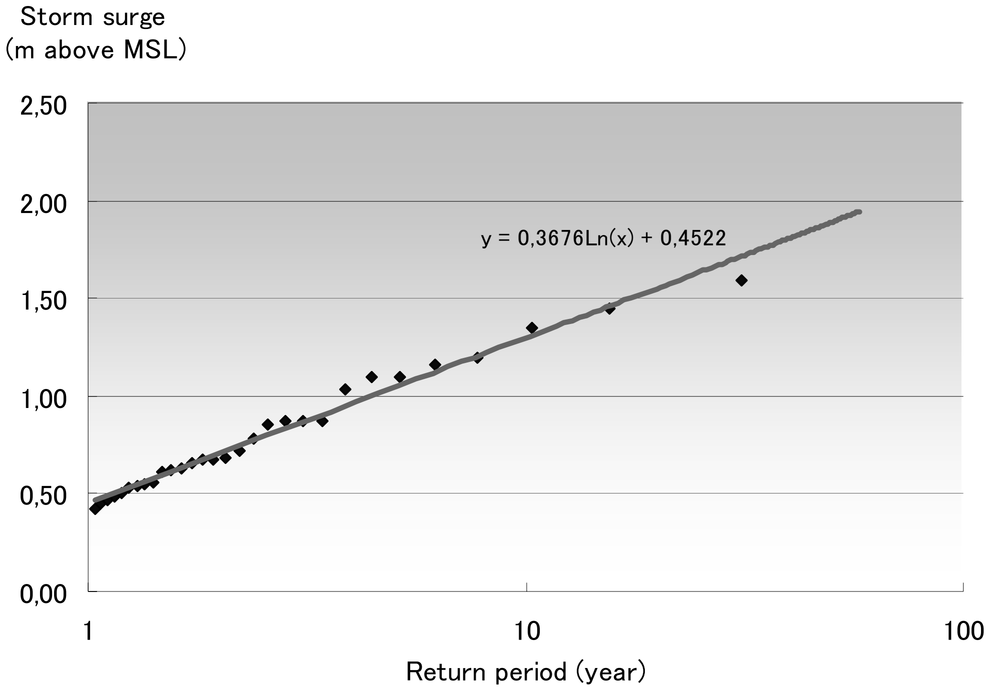

Figure 4.3 *Statistical estimate of storm surge at Hai Hau Beach.*

4.1.3 Wave Climate

The wave regime in Vietnam depends on the monsoon and typhoons. In the north it is the north monsoon and typhoons occurring in the autumn and winter that determine the wave climate. Since typhoons progress from east to west, Hai Hau Beach lies in the shadow of Hainan Island in the Gulf of Tonkin (see figure 3.1). As a result, the island protects the coastline, including Hai Hau Beach, by reducing the wave heights during typhoon attacks (Pilarczyk & Nuoi 2002).

As discussed in section 2.5, the wave heights calculated from the typhoons between the years 1962 to 1991 was reduced for bottom friction. The value on the reduction factor f_b/f_B (see formula 2.15) was estimated by using wave heights from Young's formula valid for deep water as input to equation 2.15 and comparing calculated wave heights with measured wave heights recorded during a typhoon. The measured wave heights, collected during the typhoon Fritz in 1997, were presented by Nagai et al.

(1998). The wave heights were measured at the mouth of Danang Bay, a location where the water depth was 24 m. Comparing the calculated reduction factor to values of f_b and f_B used by Nielsen (1992) and Chawla and Kirby (2002) shows that the obtained relation for f_b/f_B, lays within the range of their values.

The probability that a significant wave height exceeds a certain value for the studied typhoons is shown in figure 4.4. The probability was obtained by using plotting position formula (Yevjevich, 1972). The wave heights represent the waves at a depth of 24 m. In the case of Hai Hau Beach, it is expected that the waves will be somewhat further reduced because of Hainan Island. However, no effort was made to quantify the sheltering effect of the island on the calculated wave heights at Hai Hau Beach, since this was not possible with the existing data. Thus the predicted wave heights should be on the conservative side.

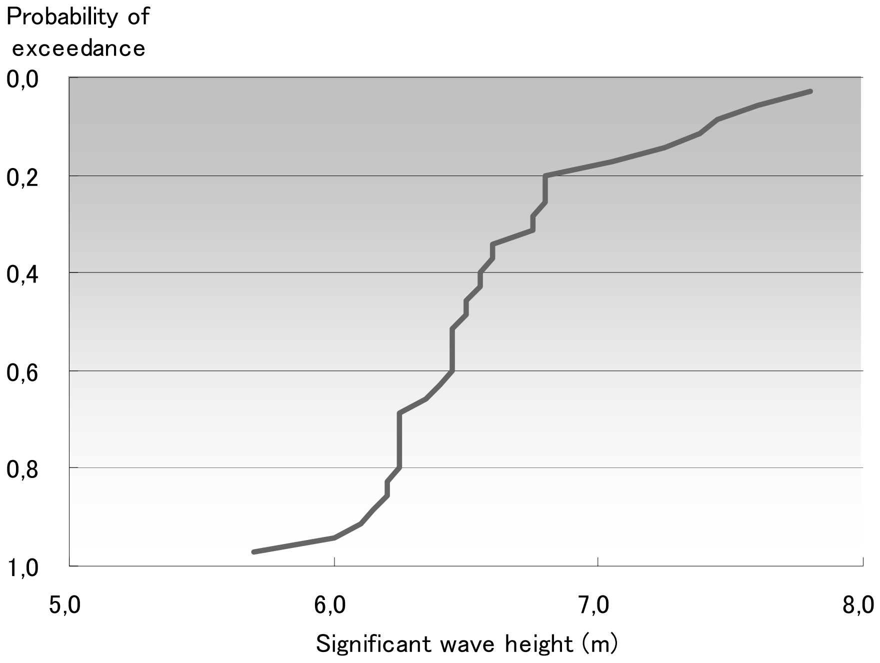

Figure 4.4 *The probability that the significant wave height exceeds a certain value during a typhoon.*

Figure 4.4 shows that most of the significant wave heights generated by typhoons are between 6 and 7 m. Corresponding probability distribution for the peak spectral period for the studied typhoons using the plotting position formula are displayed in the figure 4.5. The figure shows that most of the typhoons generate wave periods between 13 and 14 seconds. For detailed results of the wave calculations for the Gulf of Tonkin for the different typhoons see **Appendix V**.

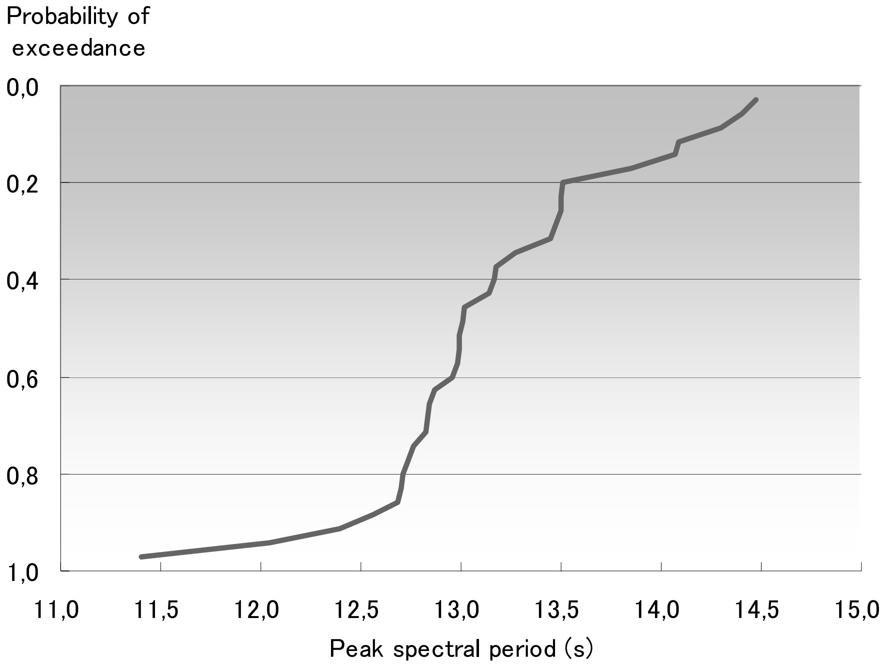

Figure 4.5 *The probability that the peak spectral period exceeds a certain value during a typhoon.*

The criteria described by U. S. Army Corps of Engineers (2001) and stated in chapter 2.5 are not completely met by the typhoons in this study. However, these criteria are for idealized conditions and will probably never be completely fulfilled. The largest errors are caused by the bathymetric effects, and for those corrections were made.

A comparison of the present results for significant wave height with those measured and simulated by Nagai et al. (1998), shows that the latter obtained slightly higher values than the calculated wave heights in this study. Nagai et al. (1998) found that for a return period of 50 years, the offshore typhoon waves off the coast of Danang Bay gave a significant wave height of 9.7 m. For the wave heights calculated in this study the return period of 50 years was 8.24 m (see figure 4.6). The return period was obtained by a frequency analysis (Yevjevich 1972) of the calculated significant wave heights which was plotted in a chart with a logarithmic scale on the x-axis.

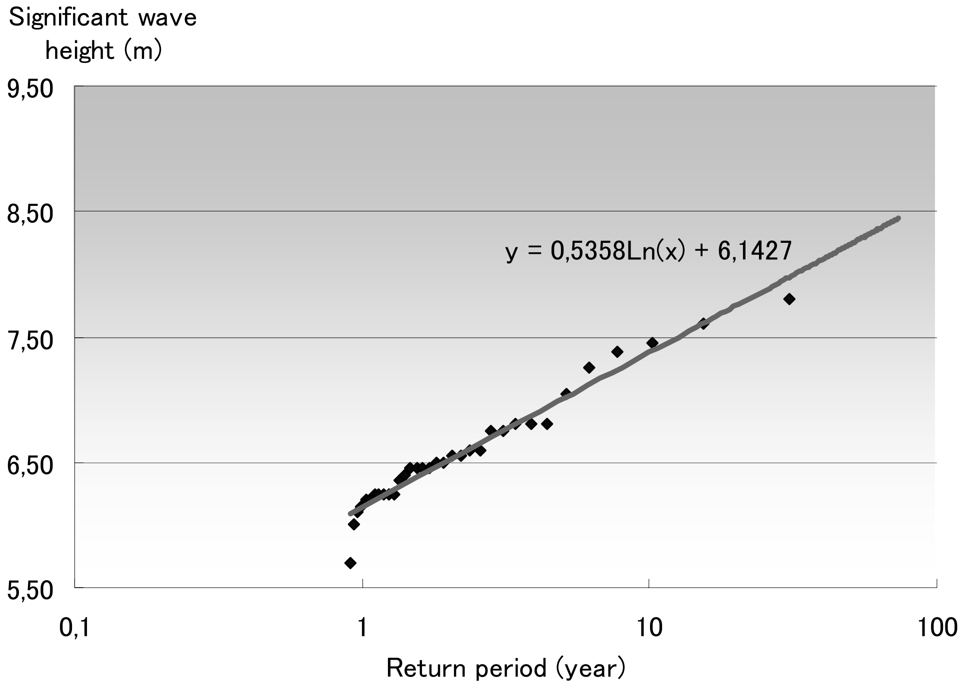

Figure 4.6 *Statistical estimate of the significant wave height for typhoons in Gulf of Tonkin.*

The difference in wave heights might be explained firstly by the fact that Nagai et al. (1998) define typhoons as storms with wind speed higher than 17 m/s, but in this study the lower wind limit for typhoons is set to 32.7 m/s. By including weaker storms in the frequency analysis, Nagai et al. (1998) obtain a steeper gradient, which will result in a higher significant wave height the longer the return period is. Secondly, Nagai et al. (1998) use a different statistical estimate which might also contribute to the higher value for the wave height. Thirdly, the difference could be explained by the calculated reduction. In this study the reduction was calibrated with one typhoon only, which could imply an overestimated reduction.

4.2 Ly Hoa Beach

4.2.1 Storm Tracks

Ly Hoa Beach is located further to the south than Hai Hau Beach, between 17° and 18° latitude, and is therefore affected by typhoons later in the year, normally in September and October (see **Appendix III**). Table 4.2 shows the probability for typhoon attacks at Ly Hoa Beach every time a typhoon hits Vietnam. The table shows that whenever a typhoon occurs offshore of the Vietnamese coast, which is 5-6 times each year, the risk that it will reach Ly Hoa Beach is up to 80 per cent.

Table 4.2 *The probability of a typhoon attack at Ly Hoa Beach for a given month each year, whenever a typhoon occurs out of the Vietnamese coast (Toan & Dac 1978).*

Month	**Probability**
May	0.0-0.1
June	0.1-0.2
July	0.4-0.6
August	0.4-0.6
September	**0.8**
October	**0.6-0.8**
November	0.3-0.4
December	0.0-0.1

4.2.2 Storm Surge

Along the central part of the Vietnamese coast storm surges are generally lower than in northern Vietnam, rarely exceeding 1 m (VCZVA 1996). Figure 4.7 shows the height of the storm surges for typhoons affecting Ly Hoa Beach from 1962 to 1991. The data clearly shows that most of the storm surges are lower here than at Hai Hau Beach, with most surges between 20 and 40 cm above MSL. The highest storm surge for the measured period is higher at Ly Hoa Beach than at Hai Hau Beach though. The measurement error for the storm surge is 20 cm and therefore the surge levels between 0 and 20 cm have not been considered. The measurements are made at the measuring station closest to Ly Hoa Beach, which is Thanh Khe (see **Appendix IV**).

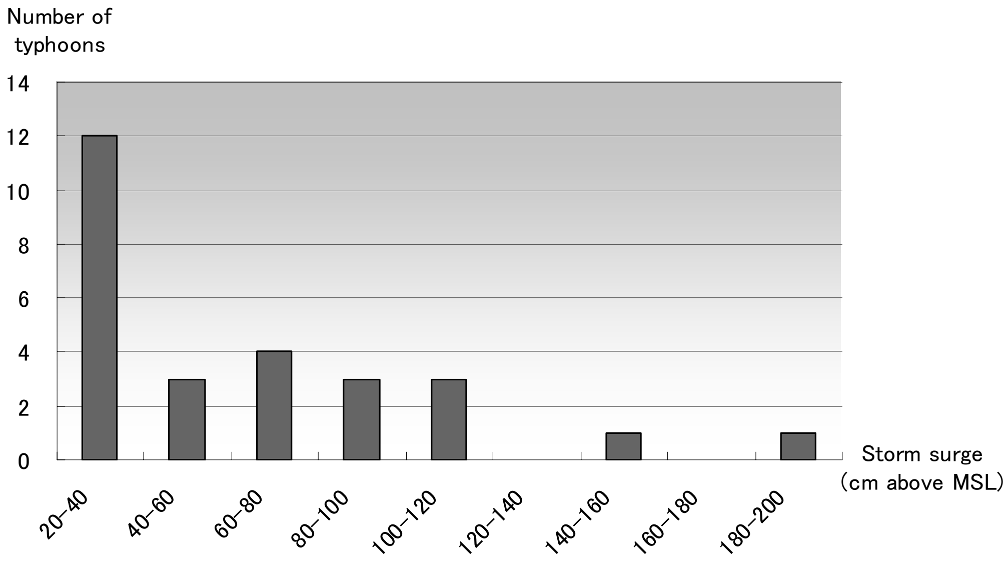

Figure 4.7 *Recorded maximum storm surge at Ly Hoa Beach during typhoon attacks.*

A frequency analysis (Yevjevich 1972) of the storm surge levels at Ly Hoa Beach was made and plotted in a chart with a logarithmic scale on the x-axis (see figure 4.8). The figure shows that the storm surge level for a return period of 50 years is 1.95 m above MSL.

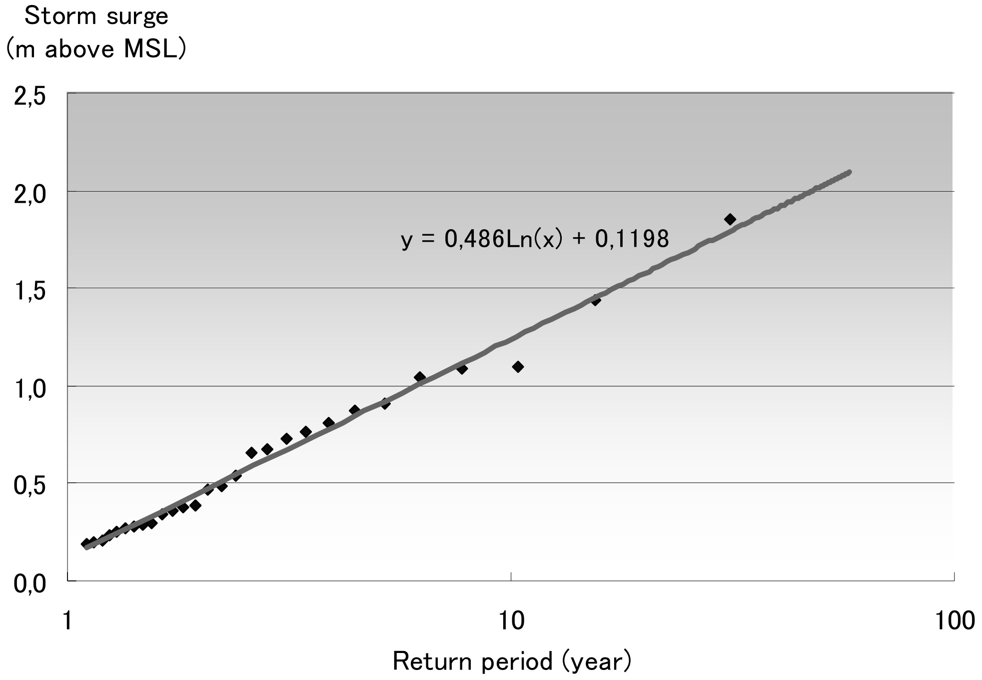

Figure 4.8 *Statistical estimate of storm surge at Ly Hoa Beach.*

4.2.3 Wave Climate

The wave regime in central Vietnam depends on the northern monsoon and typhoons in addition the southern monsoon. Since Ly Hoa Beach lies further south than Hai Hau Beach the area is not sheltered by Hainan Island to the same extent as Hai Hau Beach. Deepwater waves found here, therefore are the highest in Vietnam with significant wave heights of approximately 10 m for a 1 in 10 years wave and with a wave period of about 10 to 12 s (VCZVA 1996). Considering figure 4.6 and the wave heights calculated by Nagai et al. (1998) 10 m seems too high for a ten year return period. But since VCZVA does not present how the wave height was obtained, it is difficult to compare the different results.

The calculated deep water waves and corresponding wave period generated by typhoons are shown in figure 4.4 and 4.5. Since Ly Hoa is not sheltered by Hainan Island, the calculated waves should be closer to the true conditions than for Hai Hau.

5 Analysis of Typhoon Impact

5.1 Flooding

Overtopping[7] of coastal defence structures lead to flooding and destruction of farmland. Also, if water flows over the top of a dike (dune), the integrity of the structure (dune) might be threatened and breaching could occur. Therefore, it is of great importance to calculate the probability of overtopping. In order to determine that risk, runup referenced to the still-water level is compared with the elevation of the structure. The wave used to calculate the runup is the maximum significant wave height, which in this case will occur when the typhoons are about to make landfall in Hai Hau Beach and Ly Hoa Beach. The calculations have therefore been made with the assumption that every typhoon makes landfall at Hai Hau Beach and Ly Hoa Beach respectively. This yields the worst case scenario concerning overtopping and flooding.

The storm surge data, on the other hand, consist of the measured storm surge level for every typhoon at measuring stations near Hai Hau Beach and Ly Hoa Beach. The measuring station closest to Hai Hau Beach is Phu Le, and the measuring station closest to Ly Hoa Beach is Thanh Khe (for positions of the measuring stations see maps in **Appendix IV**). Both measuring stations are situated in rivers close to the two beaches. The highest storm surge level measured for every typhoon at different measuring stations cannot, because of varying geographical conditions, be directly applied to another place other than where it was measured. A worst case scenario for storm surge during typical typhoons is difficult to simulate, and measured storm surge levels were used in the calculations instead.

Two different scenarios have been studied at two locations on each beach. The results of the overtopping calculations are displayed in figures 5.1, 5.2, 5.5 and 5.6. The horizontal line shows the maximum elevation of the sand dune or the structure (i.e. dike) where the runup occurs. The left bar for each typhoon shows the calculated runup height with storm surge and high tide as still water level, and the right bar shows the calculated runup height with storm surge, but without the high tide.

Note that the probability that high tide coincides with the storm surge is quite small, since the tide fluctuates during the day and over the year. The high tide used in the flooding calculations is the highest tide measured during a 19-year period, and the risk of it occurring during the peak of storm surge is small.

5.1.1 Hai Hau Beach

At Hai Hau Beach calculations were made on one dike with rock-revetments (section 1) and one without (section 2). The dike without revetments has a grass cover and is slightly lower then the other one. The cross section and location of the rock-

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[7] “Passing of water over the top of a structure as a result of wave run-up or surge action.” (U.S. Army Corps of Engineers, 2001)

reinforced dike is shown in **Appendix VI**. The height of the dike at section 1 is 5.50 m and at section 2 it is 4.50 m above MSL. The high tide level at Hai Hau Beach used in these calculations is 1.57 m above MSL. This is the highest tide measured at Hai Hau for the years 1972 to 1990 (Lien 2003). Figures 5.1 and 5.2 show the maximum runup elevation for the different typhoons at the two sections and the limit for which the dikes are being washed over. For detailed results of the runup calculations for Hai Hau Beach and Ly Hoa Beach for the different typhoons see also **Appendix VII**.

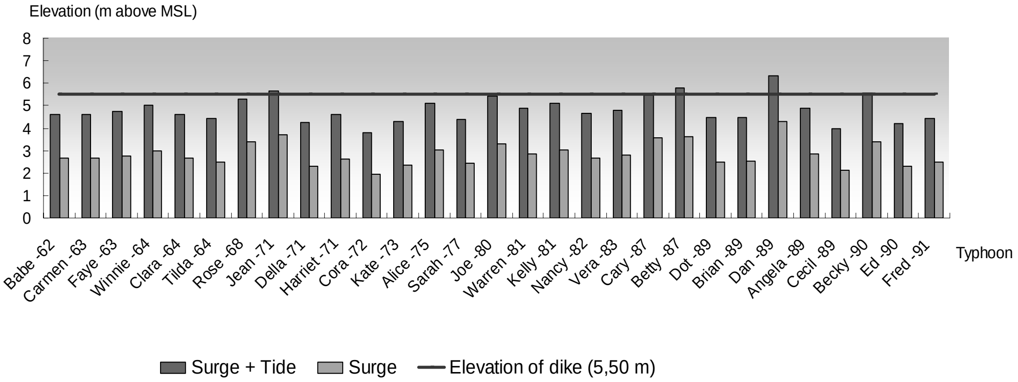

Figure 5.1 *Runup elevation and overtopping of rock reinforced dike (1st section) at Hai Hau Beach.*

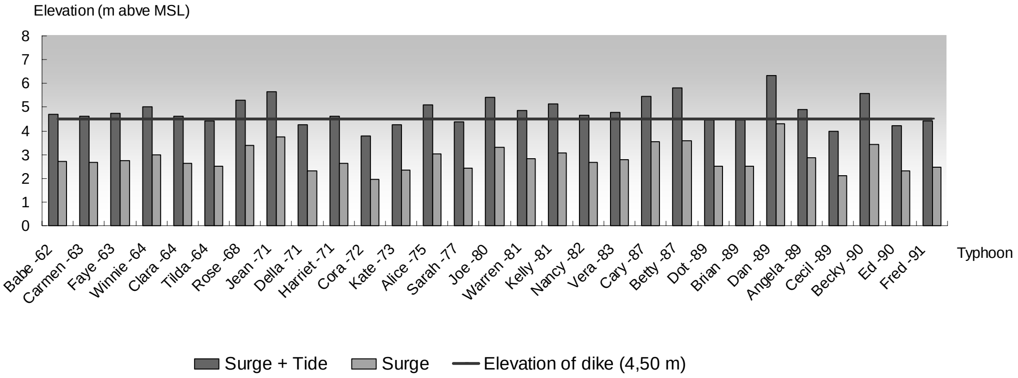

Figure 5.2 *Runup elevation and overtopping of grass dike (2nd section) at Hai Hau Beach.*

It is obvious that the tidal elevation makes a large impact on the results. Figure 5.2 shows the typhoons for which overtopping will occur when a typhoon makes landfall on a grass dike at Hai Hau Beach. For the grass dike, 66 per cent of the typhoons cause overtopping if the typhoon attacks at high tide. The same situation, but with average tidal level, does not cause any overtopping at all. Figure 5.1 illustrates the overtopping for rock-reinforced dikes. For this case, 14 per cent of the typhoons cause overtopping if high tide prevails and none for mean tide conditions.

The probability for overtopping during both high and mean tide at the two sections at Ly Hoa Beach is summarized in table 5.1. In the table, the probability for overtopping is not considered jointly with the probability for a typhoon to hit the coast. The probability for overtopping can be multiplied with the probability for a typhoon to hit the area in order to obtain the overall probability for overtopping due to a typhoon. The risk for overtopping when a typhoon reaches Vietnam at high tide is 11 per cent for the higher section, and 52 per cent for the lower section. The same scenario during mean tide does not cause overtopping for the two sections.

Table 5.1 *The probability of overtopping of the dikes at Hai Hau Beach for each typhoon that hit Vietnam.*

Hai Hau	**Section 1**	**Section 2**
High tide	0,11	0,52
Mean tide	0,00	0,00

It should be kept in mind that some simplifications have been made when calculating overtopping. The beach profile has been simplified by assuming that it is an even surface without irregularities. The measurement errors for storm surge (±20 cm) and for wind velocity (±2-4 m/s) influence the results as well. The data for storm surge were corrected for tidal variations by Ninh et al. (1991), but despite this the storm surge in the collected data did fluctuate with approximately the same period as the tide. This could mean that the tide corrections were not completely successful, and that the storm surge used may have an even larger error than the stated 20 cm. Since the measuring station for storm surge is in a river, the height of storm surge could be slightly different than if it was measured at the seashore.

In Hai Hau Beach there are people living between the first and the second line of defence. Figure 5.3 shows a farmer's house just behind the first dike. At a visit to the site in November 2003 there had been rainfall the day before, which increased the discharge in the river behind the dike, and water surrounded the house.

When a typhoon hits this area during high tide, there is a 14 per cent risk that the area between the first and the second line of defence will be flooded, if the first line of defence is of the reinforced type (compare with figure 5.1). The flooding can destroy houses but may also erode the dikes from behind, causing them to breach.

Figure 5.3 *A farmer’s house just behind the first dike line at Hai Hau Beach.*

The area is used as farmland, and dike overtopping causes salt water intrusion that destroys crops as well as contaminating fresh water aquifers near the coast. Once the soil has been contaminated it will take many years before it can be used for agricultural purposes again. The fresh water aquifers will also require a long time period to recover. Another problem is the saltwater carried by the strong winds hundreds of meters inland causing damage on vegetation. Not only will overtopping cause direct tragedy for people living in the area, but it also affects the economy of local farmers and, as a consequence, the nation as a whole. Some of the cultural buildings and old churches from the French colonization are also being destroyed, partially because of flooding problems (see figure 5.4).

Figure 5.4 O*ld church from the French colonization ruined partially because of flooding.*

5.1.2 Ly Hoa Beach

For Ly Hoa Beach the first section studied with regard to overtopping is located at the northern part of the beach with a tall sand dune having a maximum elevation of 6.24 m above MSL (for typical cross sections see **Appendix VIII**). The other section is near the village where the sand dunes are much lower, only 3.30 m above MSL. The high tide level is 1.03 m above MSL. This is the highest tide measured at Ly Hoa over the years 1972 through 1990 (Lien 2003). The results of the runup calculations for each typhoon are shown in figures 5.5 and 5.6.

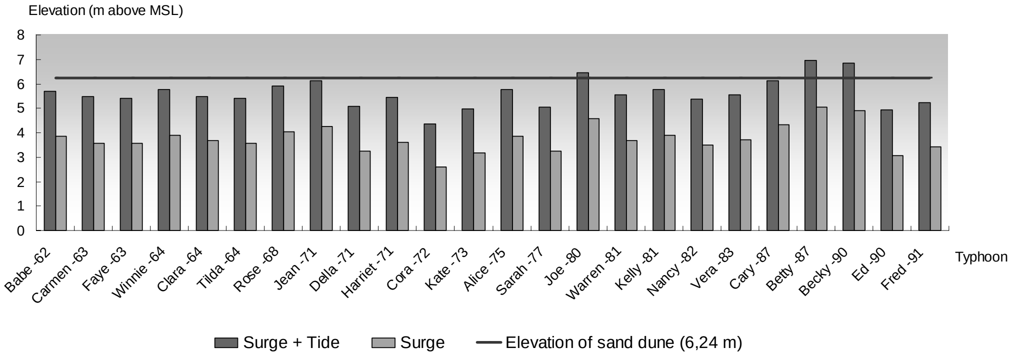

Figure 5.5 *Runup elevation and overtopping of the 1*st *section at Ly Hoa Beach.*

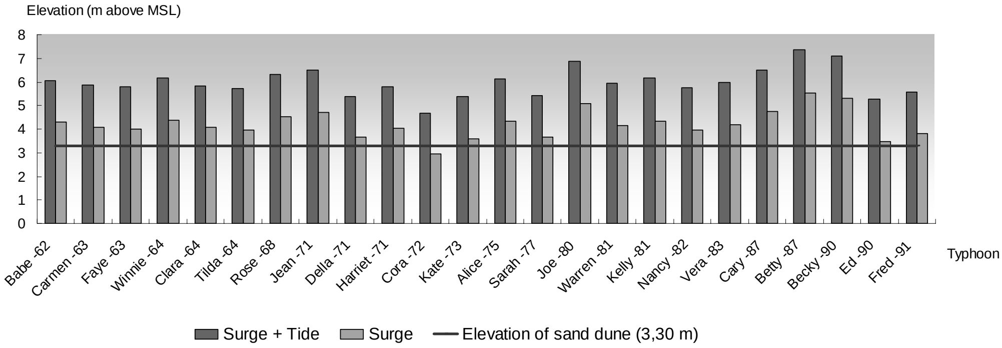

Figure 5.6 *Runup elevation and overtopping of the 2*nd *section at Ly Hoa Beach.*

Also in Ly Hoa the tide plays an important role when the typhoon moves in. Figure 5.5 indicates when overtopping occurs at the high sand dune. Without the tide there will be no overtopping at all, but for high tide 17 per cent of the typhoons will cause overtopping. The second location (figure 5.6), near the village with the low sand dune, is shown to be a very dangerous location. Almost every typhoon, both during high and mean tide conditions, will wash over the dune flooding the land behind.

The probabilities for overtopping during both high and mean tide at the two sections of Ly Hoa Beach are summarized in table 5.2. The probability for overtopping has not been considered jointly with the probability of a typhoon hitting the coast. The probability of overtopping can be multiplied with the probability of a typhoon to hit the area in order to obtain the overall probability for overtopping due to a typhoon. The risk for overtopping when a typhoon reaches Vietnam at high tide is 10 per cent for the higher section, and 80 per cent for the lower section. The same scenario during mean tide does not cause overtopping for the higher section. For the section at the village Ly Hoa, i.e. the lower one, the risk for overtopping is 77 per cent during mean tide.

Table 5.2 *The probability of overtopping of the dikes at Ly Hoa Beach for each typhoon that hit Vietnam.*

Ly Hoa	**Section 1**	**Section 2**
High tide	0,10	0,80
Mean tide	0,00	0,77

The same simplifications for the calculation of overtopping were made for Ly Hoa Beach as for Hai Hau Beach. The beach profile has been simplified by assuming that it is an even surface without irregularities. The measurement errors for storm surge (±20 cm) and for wind velocity (±2-4 m/s) influence the results as well. The data for storm surge were corrected for tidal variations by Ninh et al. (1991), but despite this, the storm surge in the collected data did fluctuate with the same period as the tide. This could mean that the tide corrections had not been successful, and that the storm surge used could have an even larger error than the 20 cm that was given in the data. Since the measuring station for storm surge is in a river, the height of storm surge could be slightly different than if it were measured at the seashore.

Examining the situation for Ly Hoa residents in terms of the results obtained in this study, Ly Hoa is a dangerous place to live in. For each typhoon, the probability that it affects Ly Hoa area is almost one, and combined with the results of calculated overtopping the village will be flooded by typhoon waves at least once for most typhoons (see table 5.2). There is no farmland behind the low section of the sand dunes, but most of the population of 1100 people live there. It is obvious that the situation for the inhabitants of Ly Hoa is not satisfactory.

5.2 Erosion

5.2.1 Ly Hoa Beach

Ly Hoa is suffering from beach erosion and is subject to mitigation measures. The plan is to build two T-shaped structures that will both control the sand and function as breakwaters. Since this protection is not yet built, the sea still has an unchanged impact on Ly Hoa Beach. The ongoing retreat of the beach affects the lives of the people in the village and the degree of erosion is, thus, important to know. Since Ly Hoa Beach consists of sand, the erosion can be estimated by employing the model introduced by Larson et al. (2003). The amount of erosion depends mainly on storm surge level and duration as well as the wave height and period. The probability of a certain sand dune retreat in terms of eroded volume when a typhoon strikes is presented in figure 5.7, and the corresponding distance of this retreat is shown in figure 5.8.

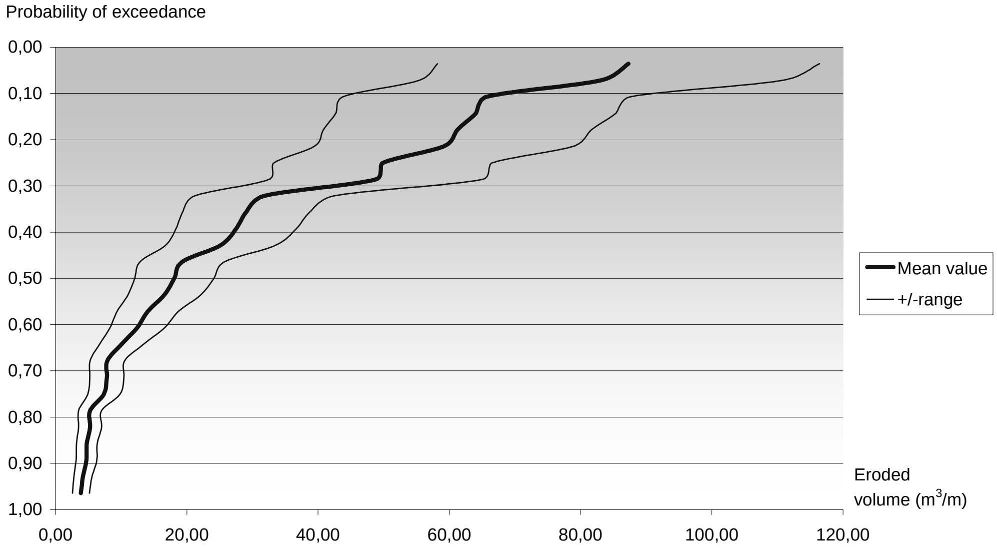

Figure 5.7 *The probability that eroded volume from the dune during typhoon attack exceeds a certain value.*

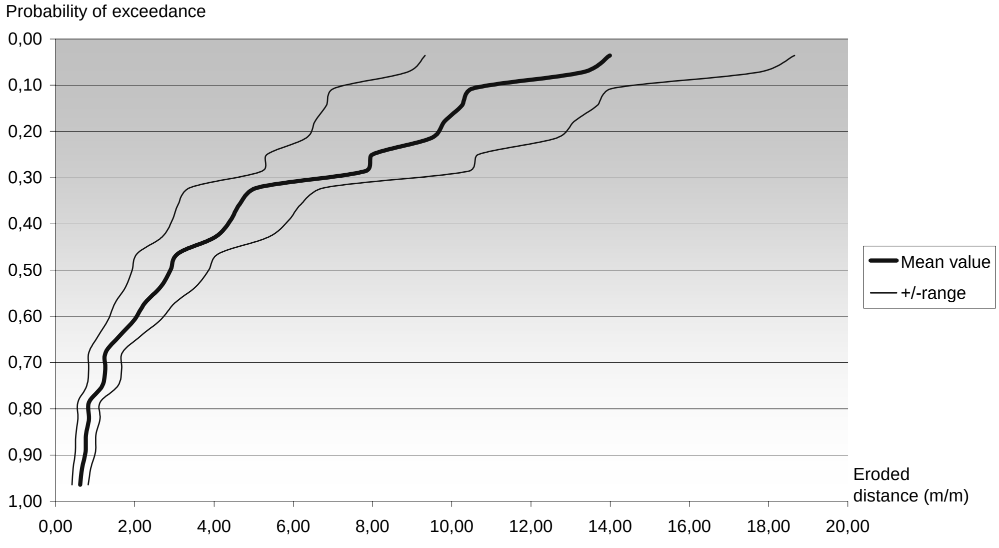

Figure 5.8 *The probability that the dune foot retreat (eroded distance) during typhoon attack exceeds a certain value.*

The eroded distance is obtained by assuming a schematised retreat as presented in figure 2.4. The presented retreat is horizontal and has been extracted for the eroded volume and calculated for the slope of a sand dune at Ly Hoa Beach (see **Appendix VIII**). The site for which the calculations of the erosion have been made consists of a 6.24 m high sand dune. This is the same site that was used in one of the overtopping calculations. The variation in the transport coefficient is fairly large and the results for a range of values are therefore presented in the figure as well. For all typhoons that strike at Ly Hoa, half of them will erode more than 2.70 m of the sand dune. A few typhoons will erode more than 10 m, which is the crest width of the dune. Over the years the erosion reshapes the sand dune and this may result in a lower structure that will increase the risk of overtopping. A frequency analysis (Yevjevich 1972) of the eroded distance and volume at Ly Hoa Beach was made and plotted in charts with a logarithmic scale on the x-axis (see figure 5.9 and 5.10). The analysis shows an eroded volume of 116 m^3, and an eroded distance of 18.6 m for a 50 years return period.

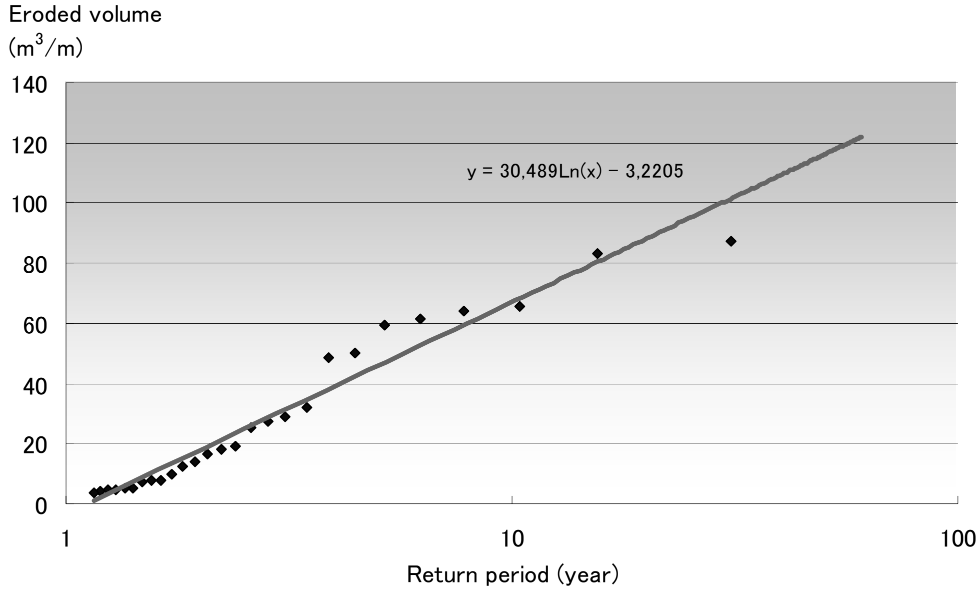

Figure 5.9 *Statistical estimate of the eroded volume by typhoons at Ly Hoa Beach.*

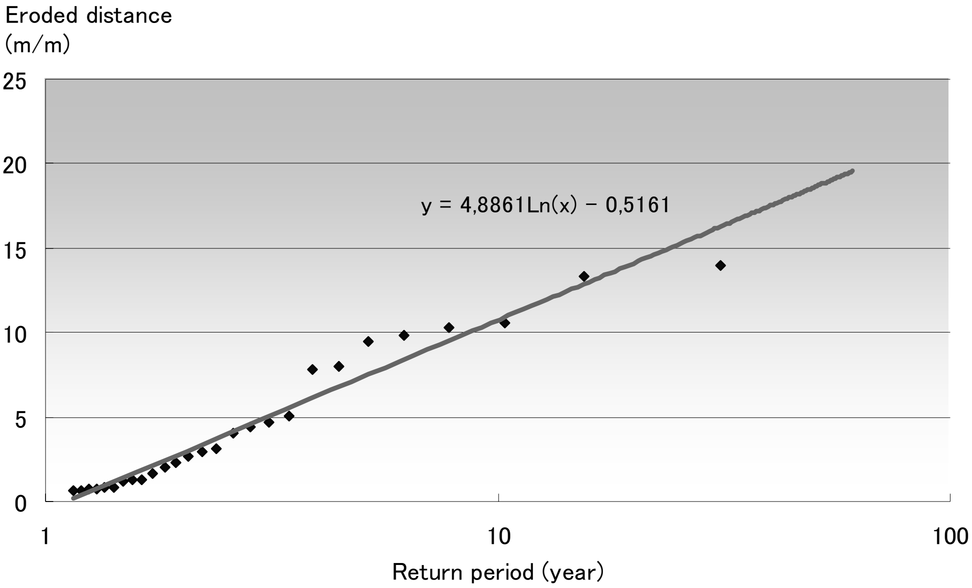

Figure 5.10 *Statistical estimate of the eroded distance by typhoons at Ly Hoa Beach.*

The results for dune erosion during typhoon attack could not be verified by in-situ measurements, but should be within the expected range. The empirical constant used in the calculations is an approximation and is not developed for the specific conditions at Ly Hoa Beach. On parts of the sand dunes at Ly Hoa Beach wild pineapple are planted to protect the beach from erosion. This might imply an overestimation for the calculated erosion compared to the actual erosion.

6 Conclusions

Typhoon attack on the two beaches at Hai Hau and Ly Hoa are recurrent events, leading to significant destruction in some cases. Flooding caused by overtopping depends to a large extent on the tide. The tide is diurnal at Hai Hau Beach and during some parts of the year at Ly Hoa Beach, and the probability that high tide occurs at the same time as the peak of storm surge is small. These characteristics of the tide will only diminish the frequency of the overtopping occurrence, and not the consequences of the overtopping when it happens.

Hai Hau Beach has fairly good protection against wave action along some sections. The recently built dikes with a reinforced surface provide protection against most waves. These dikes are built with higher crest elevation and are less erosion prone than dikes covered with grass. If the entire coast of 25 km at Hai Hau were protected by reinforced dikes, homes and farmland would be less exposed. Not only will overtopping cause direct tragedy for people living in the area, but it will also affect the economy of both the local farmers as well as for the nation as a whole. Some of the cultural buildings and old churches from the French colonization period are also being destroyed, partially because of flooding problems.

Ly Hoa Beach is presently very exposed and vulnerable to wave action and flooding. The proposed construction by UNDP will reduce the risk for the village. The project was supposed to be finished in 2002, but it has not yet been started. This means that the people of Ly Hoa still live with the constant threat that their homes could be destroyed by typhoon waves.

The rate of erosion at Hai Hau Beach was not possible to calculate within the scope of this study. Since erosion is clearly a problem, it is important to understand how much the dikes erode each time a typhoon strikes. However, the dikes are either covered with grass or reinforced with rocks, and at present there is no reliable erosion prediction model developed that takes these conditions into consideration. The dikes at Hai Hau Beach have also a core of fine cohesive grains, which must be considered in the modelling of the erosion. Both these circumstances present a difficult challenge, and an erosion-model for Hai Hau Beach, should be verified by comparing the results with accurate measurements.

The overtopping calculations presented in this report have not been validated by direct measurements. It is suggested that observations of the two areas are made before and after a typhoon strikes, to validate the results of the runup calculations. These observations have to be conducted over a long period to obtain reliable results. Thorough interviews with local people can help to understand the occurrence and extent of flooding caused by typhoons.

This study has not considered all effects of typhoons on the coastline. In order to obtain an overall picture of the total destructive effects of typhoons on the coastline, the impact of wind and rain must be assessed. Most of the people killed in typhoons drown in fresh water caused by the heavy rainfall. The social and economical aspects must be taken into consideration as well. Not only is the knowledge of the costs of protective measures important, but knowing the social and financial losses that typhoons can cause should be a strong incentive for the government and organisations to invest in action programmes.

Hai Hau Beach and Ly Hoa Beach are two limited segments of the Vietnamese coastline, but they represent conditions prevalent along a large part of the coast. Three quarters of the coast consists of either sand dunes or delta planes, and the calculations used in this study should be applicable to similar parts of the Vietnamese coastline.

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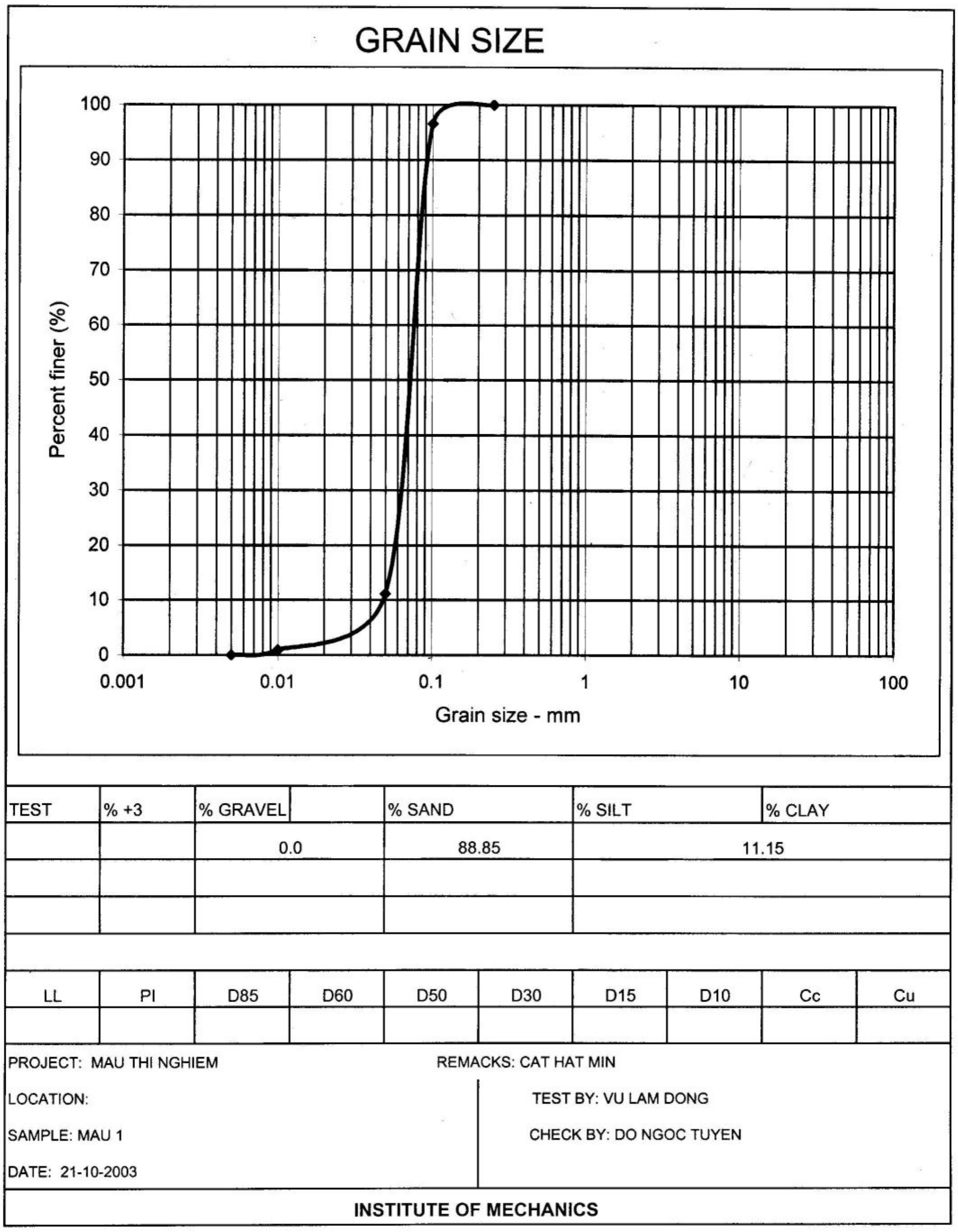
Manh, D. V. Center for Marine Environment, Survey, Research, Consultation, Hanoi, Vietnam (2003): Typhoon data and maps.

Nghia N. K. at Center for Estuary and Coastal Engineering, Hanoi, Vietnam (2003):
Maps and cross sections
.

Appendix I – Grain Size Distribution, Hai Hau Beach



TEST	% +3	% GRAVEL		% SAND	% SILT	% CLAY
		0.0		88.85	11.15	

LL	PI	D85	D60	D50	D30	D15	D10	Cc	Cu

PROJECT: MAU THI NGHIEM
REMACKS: CAT HAT MIN
LOCATION:
TEST BY: VU LAM DONG
SAMPLE: MAU 1
CHECK BY: DO NGOC TUYEN
DATE: 21-10-2003

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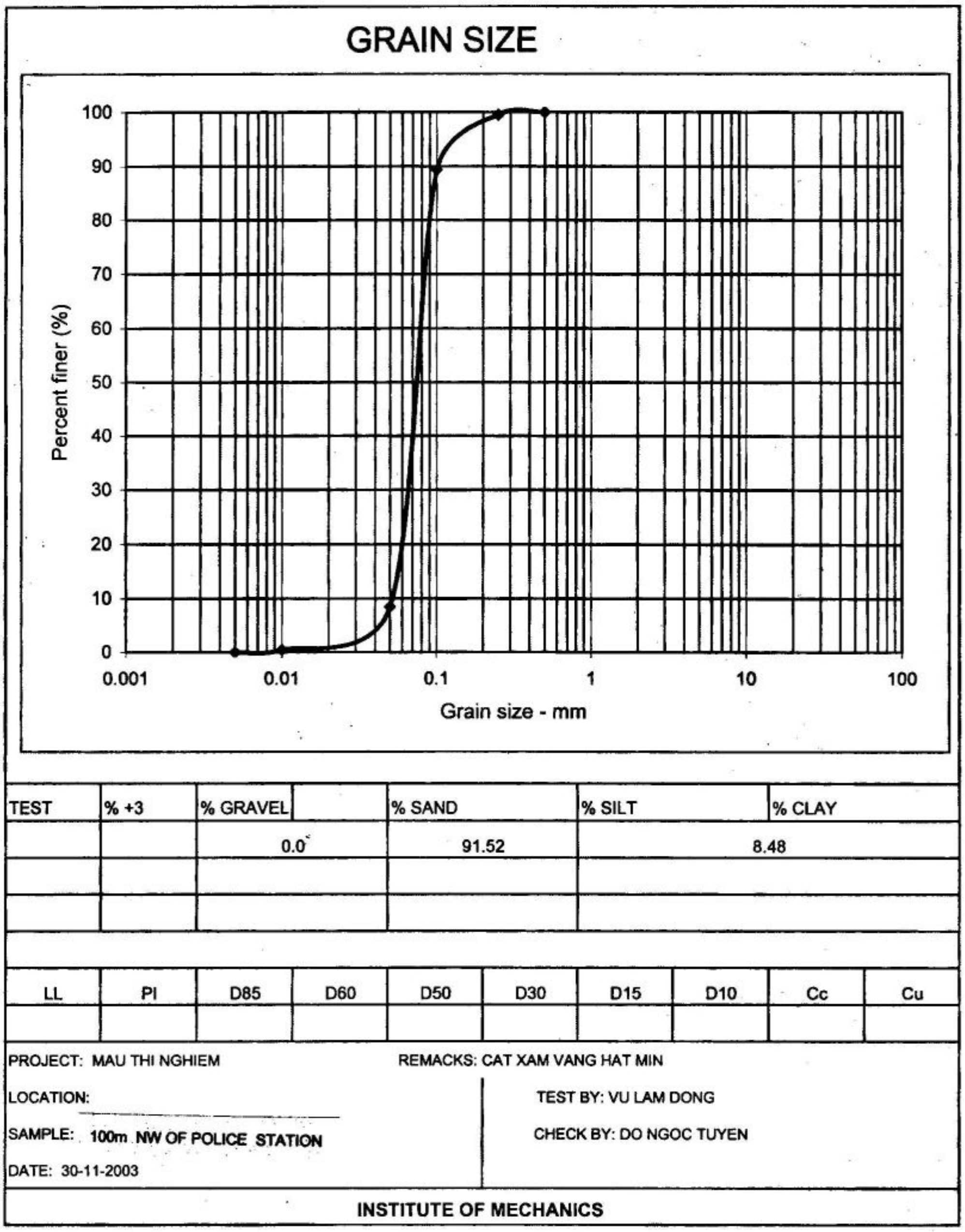
Figure I.1 *Grain size distribution at Hai Hau Beach.*

Appendix II – Grain Size Distribution, Ly Hoa Beach



TEST	% +3	% GRAVEL		% SAND	% SILT	% CLAY
		0.0		91.52	8.48	

LL	PI	D85	D60	D50	D30	D15	D10	Cc	Cu

PROJECT: MAU THI NGHIEM
REMACKS: CAT XAM VANG HAT MIN
LOCATION:
TEST BY: VU LAM DONG
SAMPLE: 100m NW OF POLICE STATION
CHECK BY: DO NGOC TUYEN
DATE: 30-11-2003

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Figure II.1 *Grain size distribution at Ly Hoa Beach.*

Appendix III – Storm Tracks 1960-1998

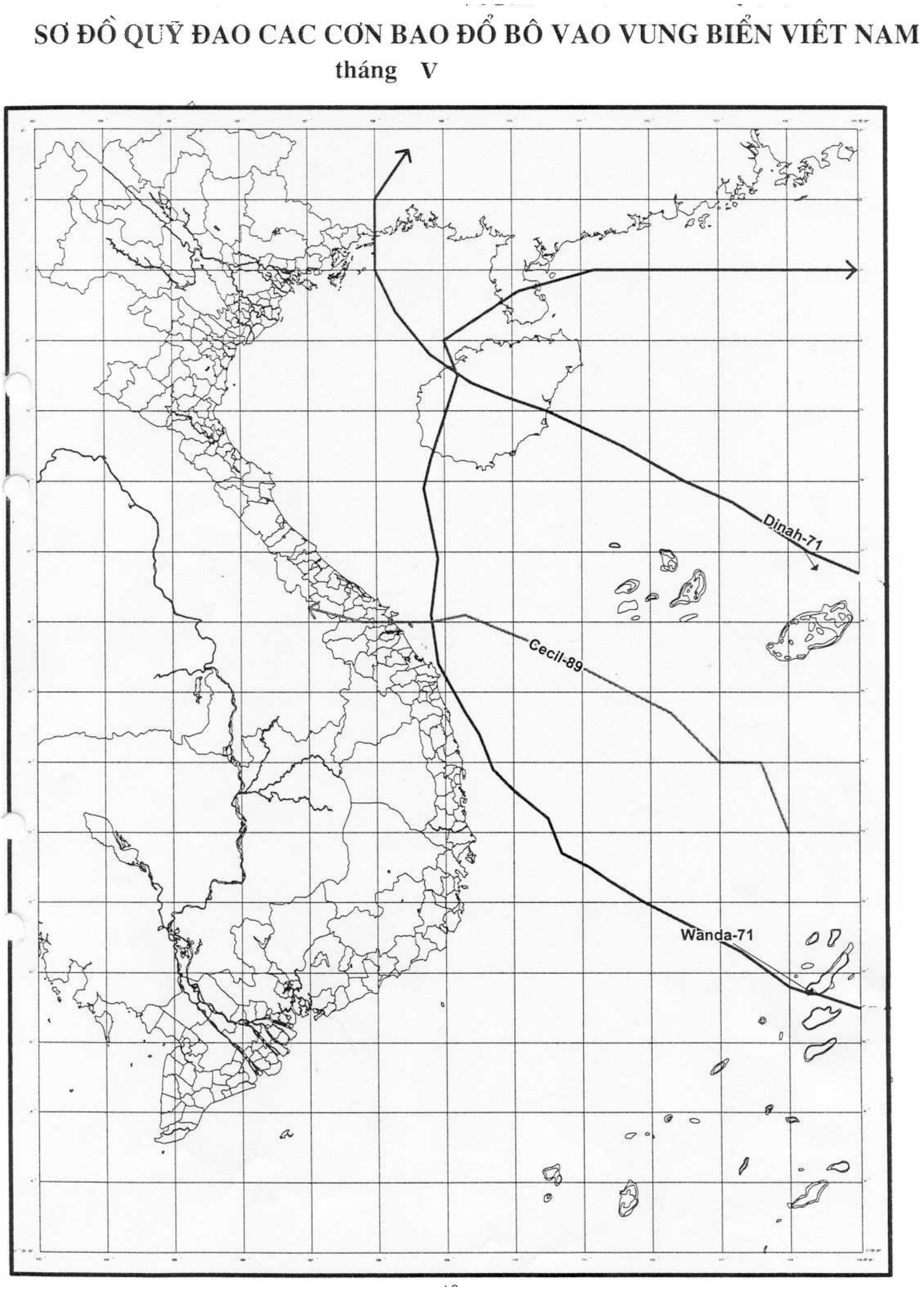

Figure III.1 *Storm tracks for May (Hung 2003).*

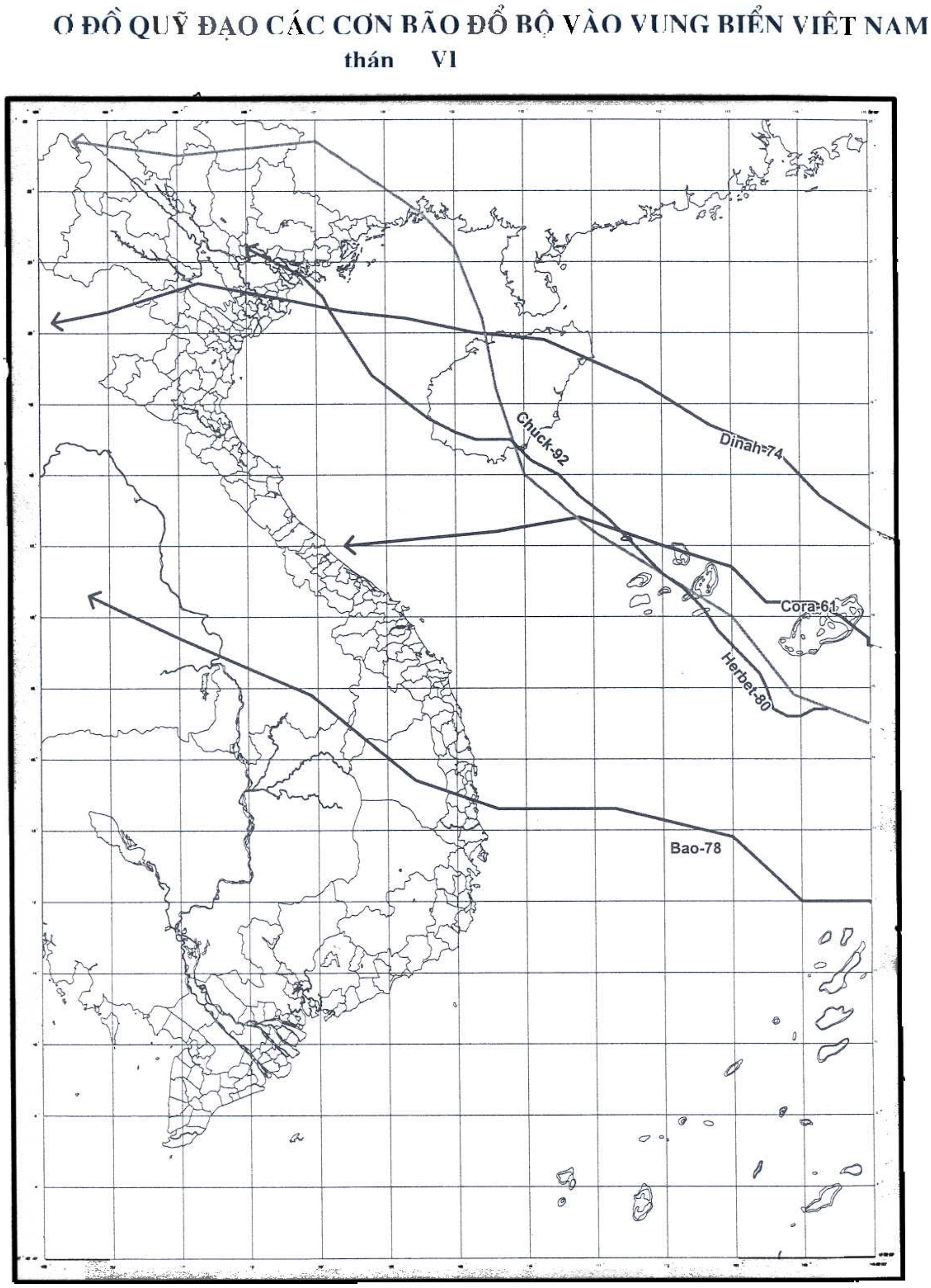
Ơ ĐỒ QUỸ ĐẠO CÁC CƠN BÃO ĐỔ BỘ VÀO VUNG BIỂN VIÊT NAM
thán VI

Figure III.2 *Storm tracks for June (Hung 2003).*

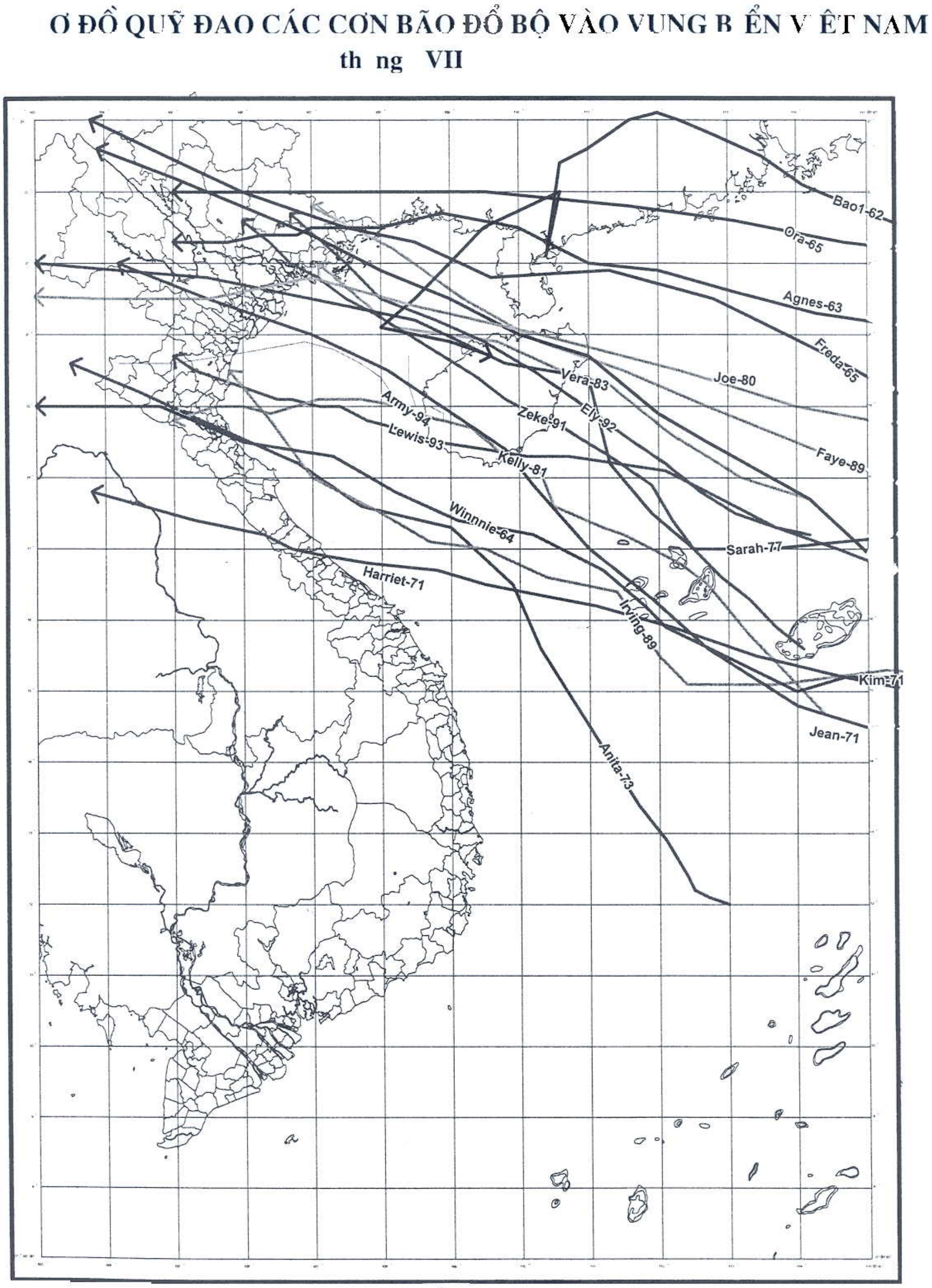

Figure III.3 *Storm tracks for July (Hung 2003).*

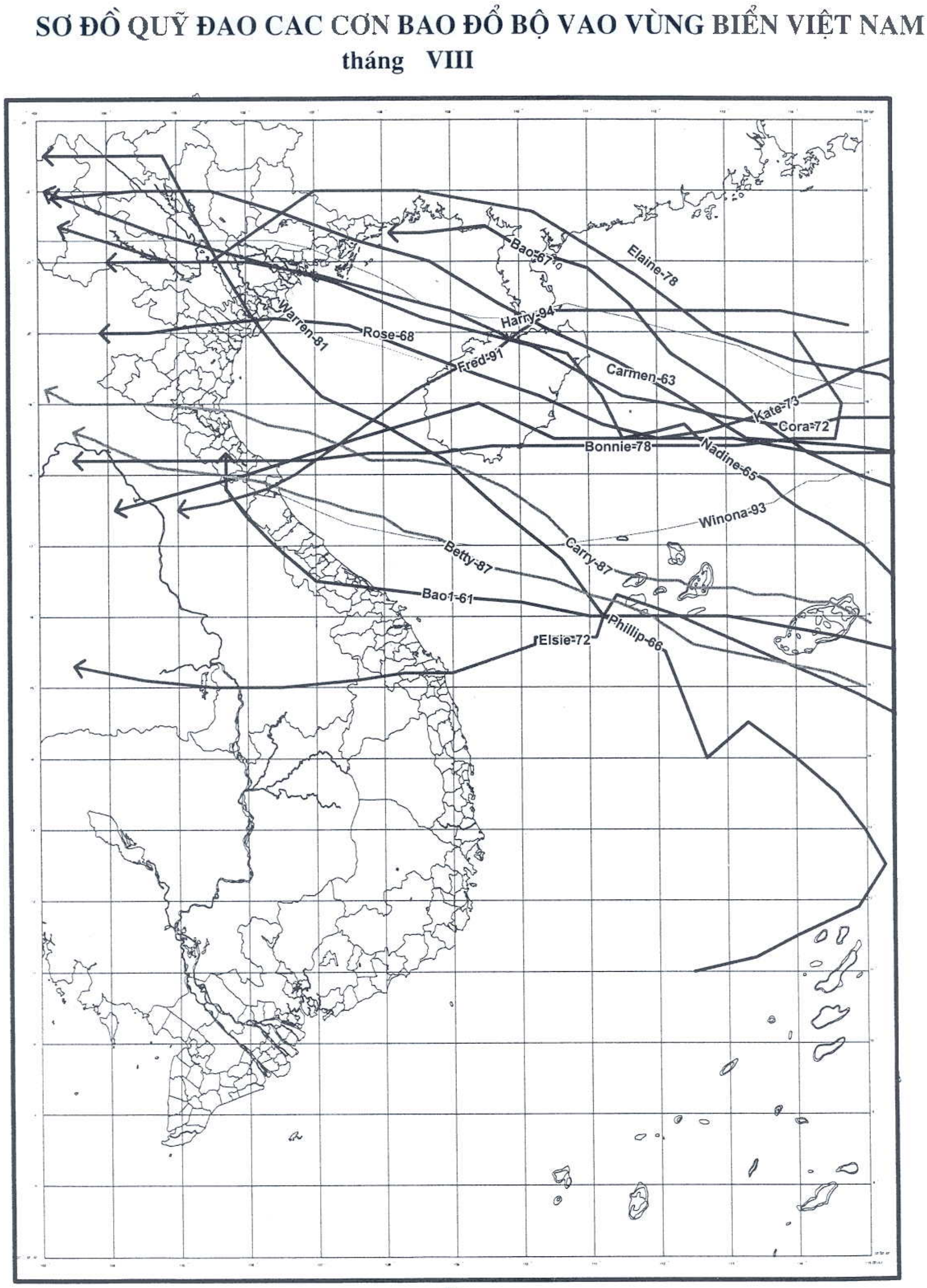

Figure III.4 *Storm tracks for August (Hung 2003)*

Ơ ĐỒ QUỸ ĐAO CÁC CƠN BÃO ĐỔ BÔ VÀO VUNG BIỂN VIỆT NAM
tháng IX

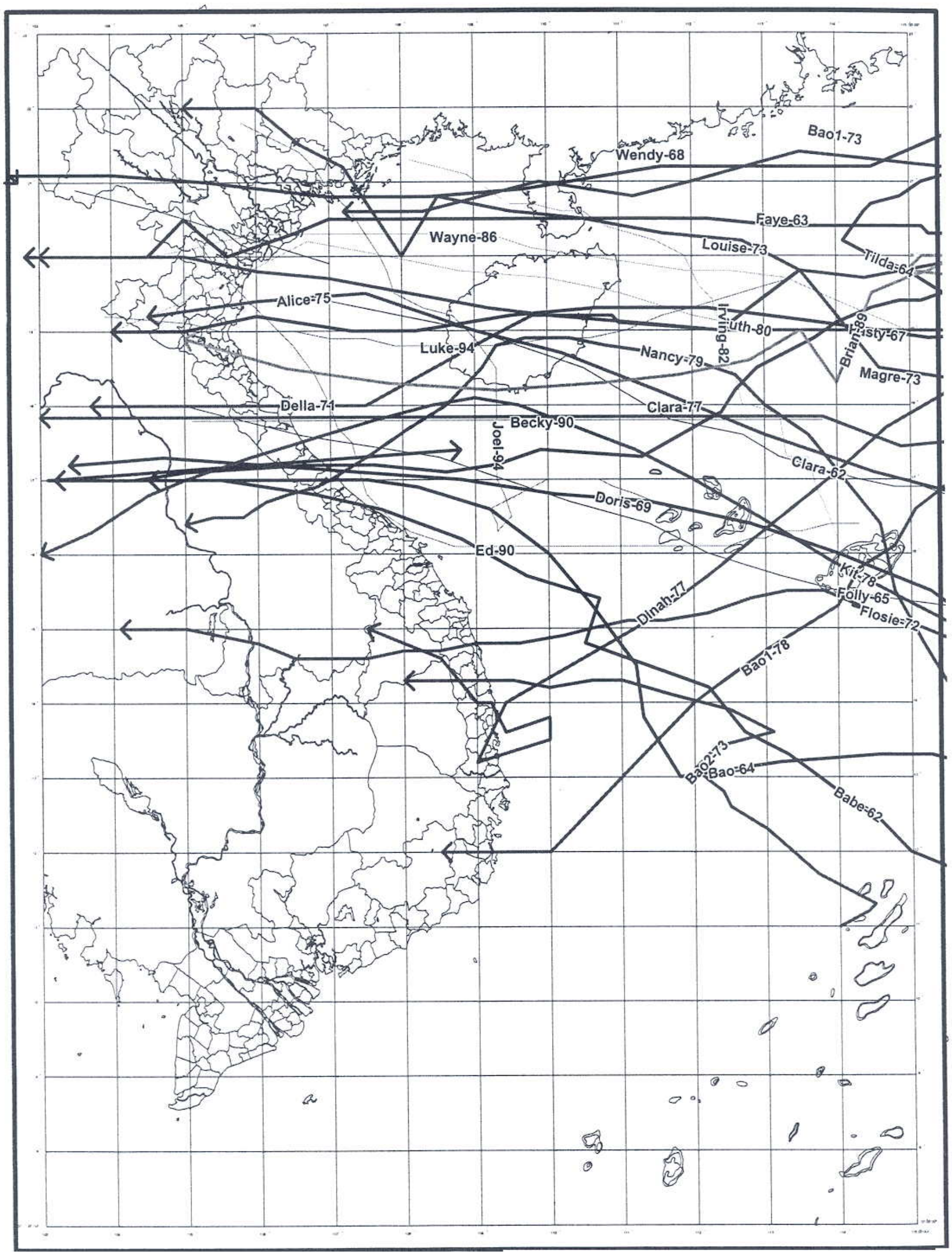

Figure III.5 *Storm tracks for September (Hung 2003)*

SƠ ĐỒ QUỸ ĐAO CÁC CƠN BÃO ĐÔ BỘ VAO VÙNG BIỂN VIÊT NAM
tháng X

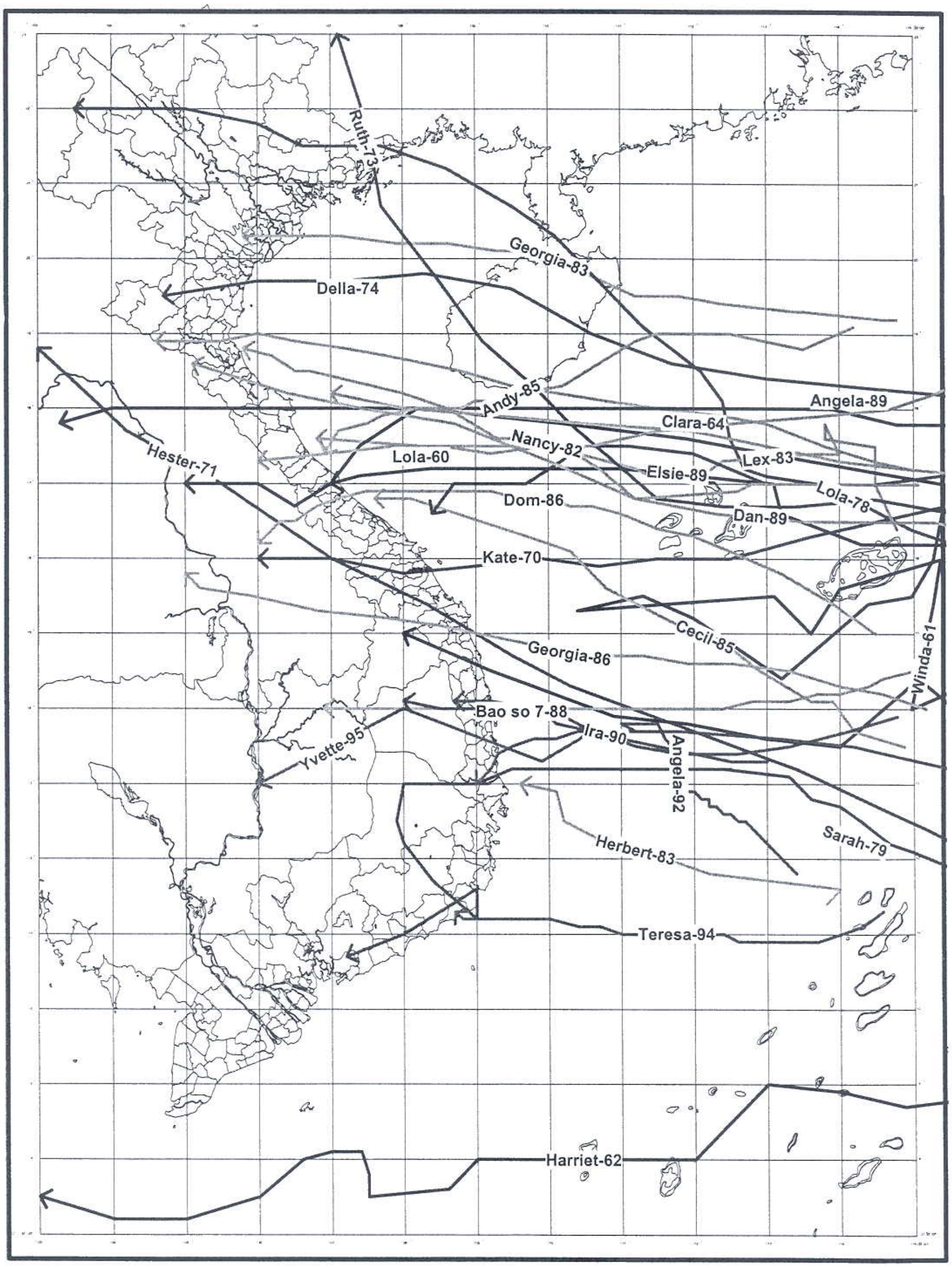

Figure III.6 *Storm tracks for October (Hung 2003)*

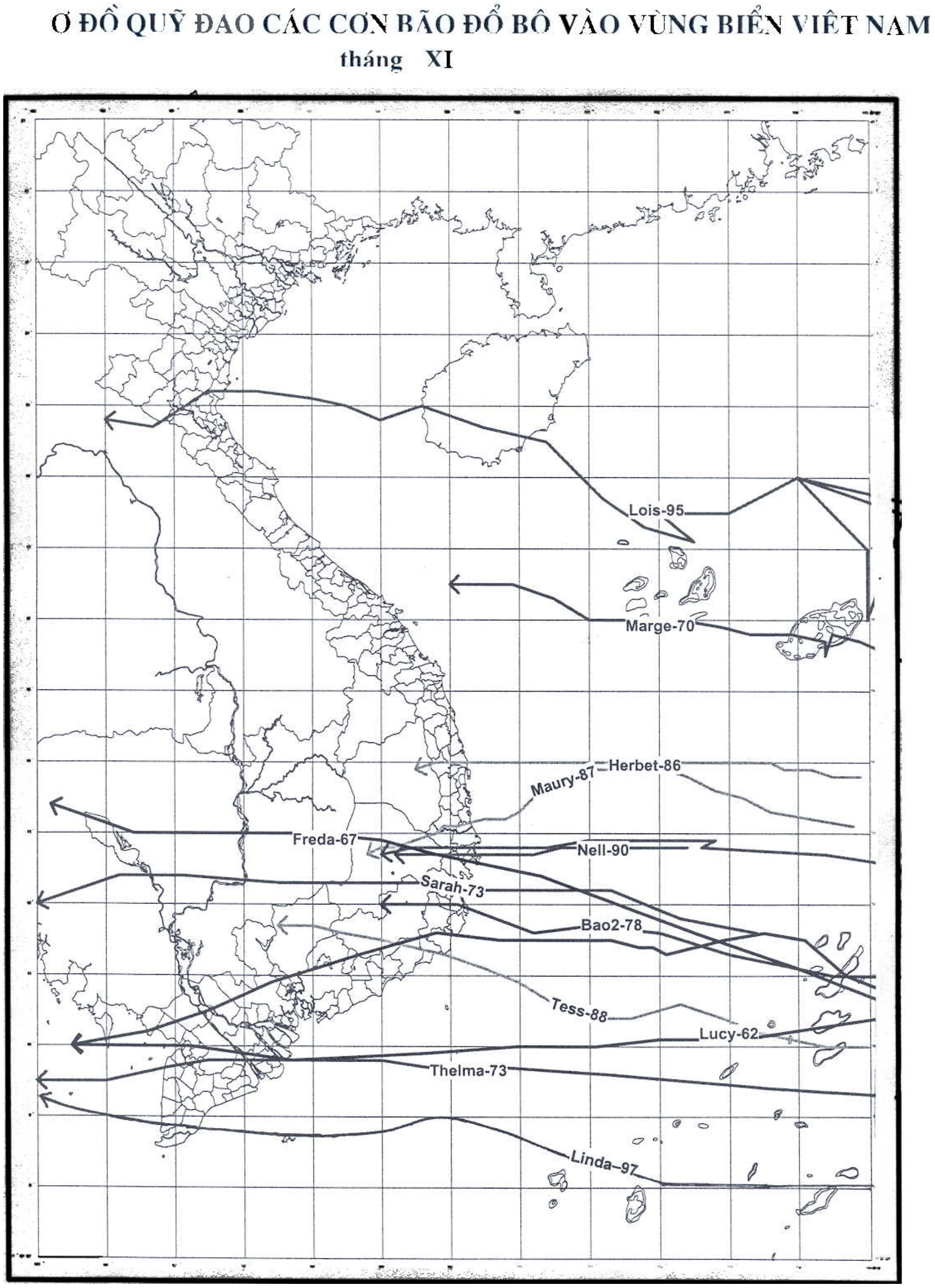

Figure III.7 *Storm tracks for November (Hung 2003)*

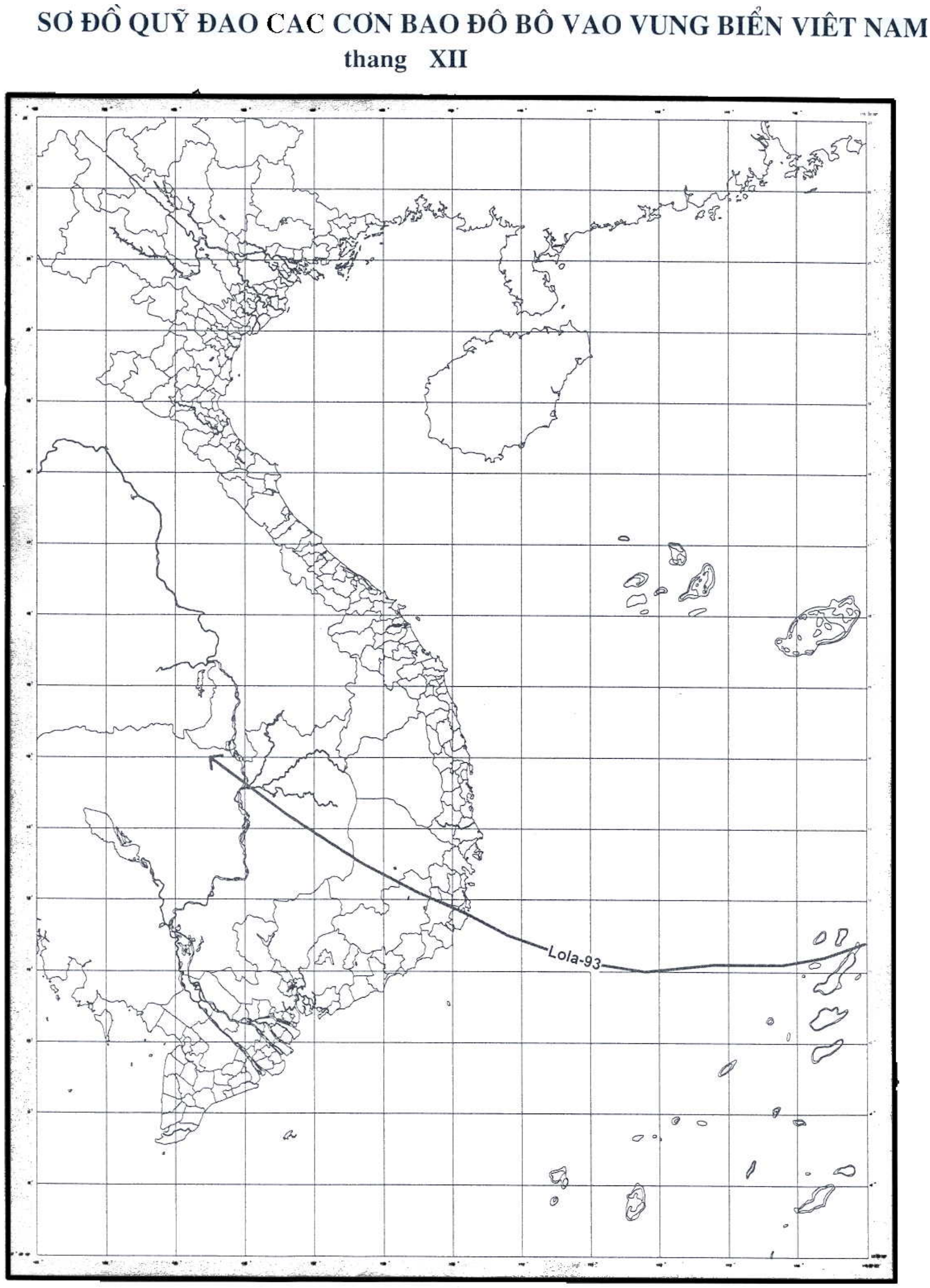

Figure III.8 *Storm tracks for December (Hung 2003)*

Appendix IV – Position of Measuring Stations for Storm Surge

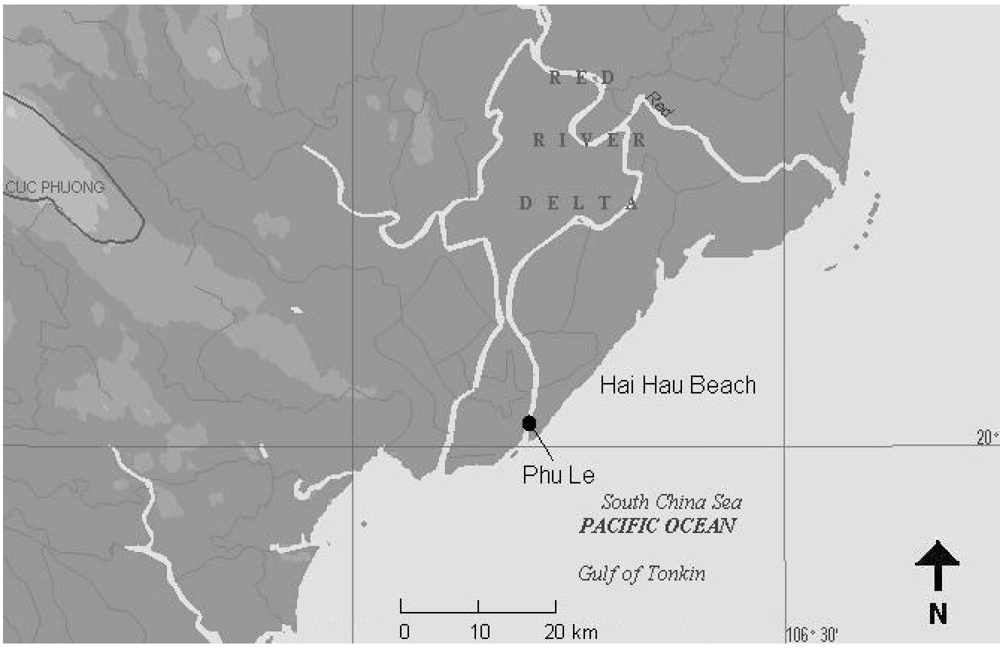

Figure IV.1 *Measuring station for storm surge at Hai Hau Beach: Phu Le (after Encarta 2000).*

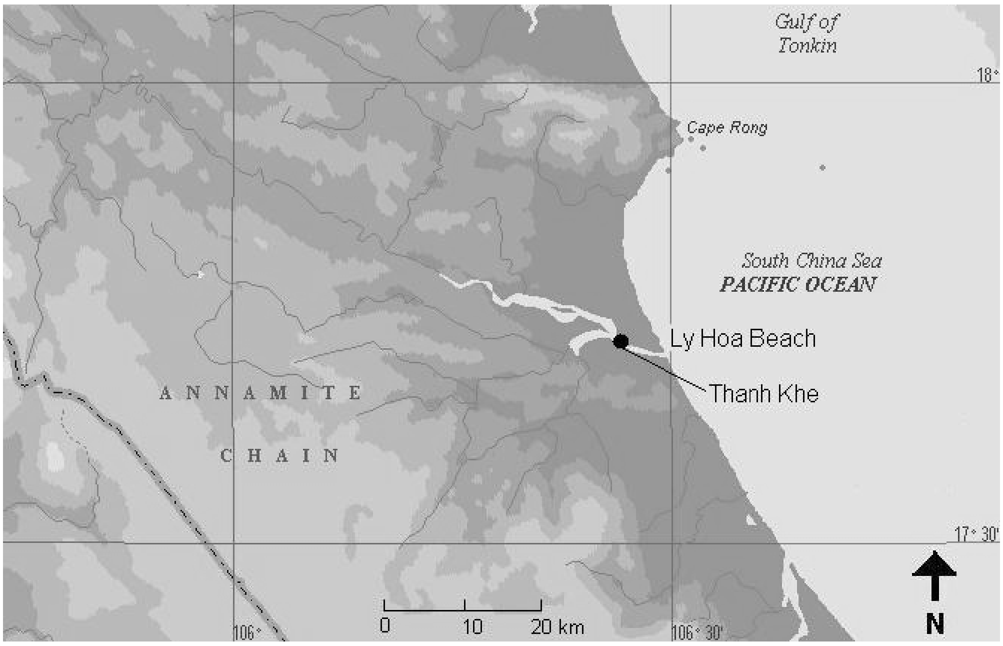

Figure IV.2 *Measuring station for storm surge at Ly Hoa Beach: Thanh Khe (after Encarta 2000).*

Appendix V – Typhoon Properties and Calculated Waves

Table V.1 *Wave heights calculated from typhoons.*

Name	ΔP	P_{min}	V_{max}	V_{fm}	R	R'	Y	x	E	f_p	T	L_0	H_s	H
Carla -62	45	965	41	6,6	42 596	33 361	0,97	301 299	8,4	0,071	14,1	310	11,6	7,25
Babe -62	40	970	38	5,5	40 003	32 747	0,97	289 063	6,6	0,074	13,5	283	10,3	6,75
Carmen -63	40	970	38	6,0	40 003	32 747	1,00	292 867	6,7	0,074	13,5	285	10,4	6,8
Faye -63	40	970	38	3,0	40 003	32 747	0,87	242 069	5,6	0,079	12,7	251	9,4	6,45
Winnie -64	40	970	38	5,6	40 003	32 747	0,98	290 371	6,7	0,074	13,5	283	10,3	6,75
Clara -64	36	974	35	6,8	37 966	32 236	1,08	285 050	5,5	0,077	13,0	264	9,4	6,4
Tilda -64	37	973	35	4,7	38 522	32 378	0,98	277 353	5,6	0,077	13,0	264	9,5	6,45
Rose -68	38	972	36	5,1	39 077	32 518	0,98	283 188	6,0	0,076	13,2	271	9,8	6,55
Dorit -69	38	972	36	6,9	39 077	32 518	1,06	289 673	6,1	0,075	13,3	275	9,9	6,6
Bao 2 -70	37	973	35	6,4	38 522	32 378	1,05	288 670	5,9	0,076	13,2	271	9,7	6,5
Jean -71	35	975	34	7,2	37 596	32 141	1,10	280 078	5,2	0,078	12,8	258	9,1	6,25
Della -71	35	975	34	8,3	37 596	32 141	1,15	262 037	4,9	0,080	12,6	246	8,8	6,15
Harriet -71	40	970	38	3,6	40 003	32 747	0,89	258 076	5,9	0,077	13,0	262	9,7	6,55
Cora -72	35	975	34	10,3	37 596	32 141	1,24	195 333	3,6	0,088	11,4	203	7,6	5,7
Elaine -72	40	970	38	5,8	40 003	32 747	0,99	292 004	6,7	0,074	13,5	284	10,4	6,8
Kate -73	35	975	34	5,2	37 596	32 141	1,02	279 409	5,2	0,078	12,8	257	9,1	6,25
Alice -75	37	973	35	7,9	38 522	32 378	1,11	277 271	5,6	0,077	13,0	264	9,5	6,45
Sarah -77	35	975	34	7,9	37 596	32 141	1,13	270 545	5,0	0,079	12,7	252	9,0	6,25
Elaine -78	35	975	34	7,7	37 596	32 141	1,13	272 908	5,1	0,079	12,7	253	9,0	6,2
Joe -80	47	963	43	7,2	43 522	33 571	0,97	303 604	9,0	0,070	14,3	319	12,0	7,38
Warren -81	40	970	38	3,7	40 003	32 747	0,90	259 731	6,0	0,077	13,0	263	9,8	6,6
Kelly -81	38	972	36	4,3	39 077	32 518	0,95	272 159	5,8	0,077	13,0	264	9,6	6,5
Nancy -82	37	973	35	4,2	38 522	32 378	0,95	269 421	5,5	0,078	12,9	259	9,3	6,35
Vera -83	40	970	38	7,3	40 003	32 747	1,05	291 969	6,7	0,074	13,5	284	10,4	6,8
Cary -87	37	973	35	5,8	38 522	32 378	1,02	287 187	5,8	0,076	13,1	270	9,6	6,45
Betty -87	55	955	49	4,7	47 041	34 331	0,77	271 173	10,5	0,069	14,4	324	13,0	7,8
Dot -89	35	975	34	4,5	37 596	32 141	0,99	271 450	5,0	0,079	12,7	252	9,0	6,25
Brian -89	35	975	34	7,3	37 596	32 141	1,11	278 621	5,2	0,078	12,8	257	9,1	6,25
Dan -89	50	960	45	6,2	44 633	33 817	0,89	299 355	9,9	0,069	14,5	327	12,6	7,6
Angela -89	50	960	45	4,6	44 633	33 817	0,82	274 532	9,1	0,071	14,1	309	12,0	7,45
Cecil -89	35	975	34	2,6	37 596	32 141	0,90	230 524	4,3	0,083	12,0	226	8,3	6
Becky -90	43	967	40	6,3	41 485	33 103	0,97	297 735	7,7	0,072	13,9	300	11,1	7,05
Ed -90	35	975	34	3,4	37 596	32 141	0,94	251 415	4,7	0,081	12,4	240	8,6	6,1
Fred -91	35	975	34	4,7	37 596	32 141	1,00	274 862	5,1	0,078	12,8	254	9,0	6,2

Table V.2 *List of abbreviations*

$\triangle P$	$\triangle P$ at landfall (mb)
P_{min}	$\triangle P = 1010 - P_{min}$ (mb)
V_{max}	Maximum sustained wind speed (m/s)
V_{fm}	Forward motion of the typhoon (m/s)
R	Radius of the eye (m)
R'	Spatial scale parameter (m)
Y	Scaling factor (m/s)
x	Equivalent hurricane fetch (m)
E	Total energy (m)
f_p	Wave frequency (Hz)
T	Spectral wave period (s)
L_0	Length of significant wave (m)
H_s	Significant wave height (m)
H	Reduced significant wave height due to bottom friction (m)

Appendix VI – Cross Sections Hai Hau Beach

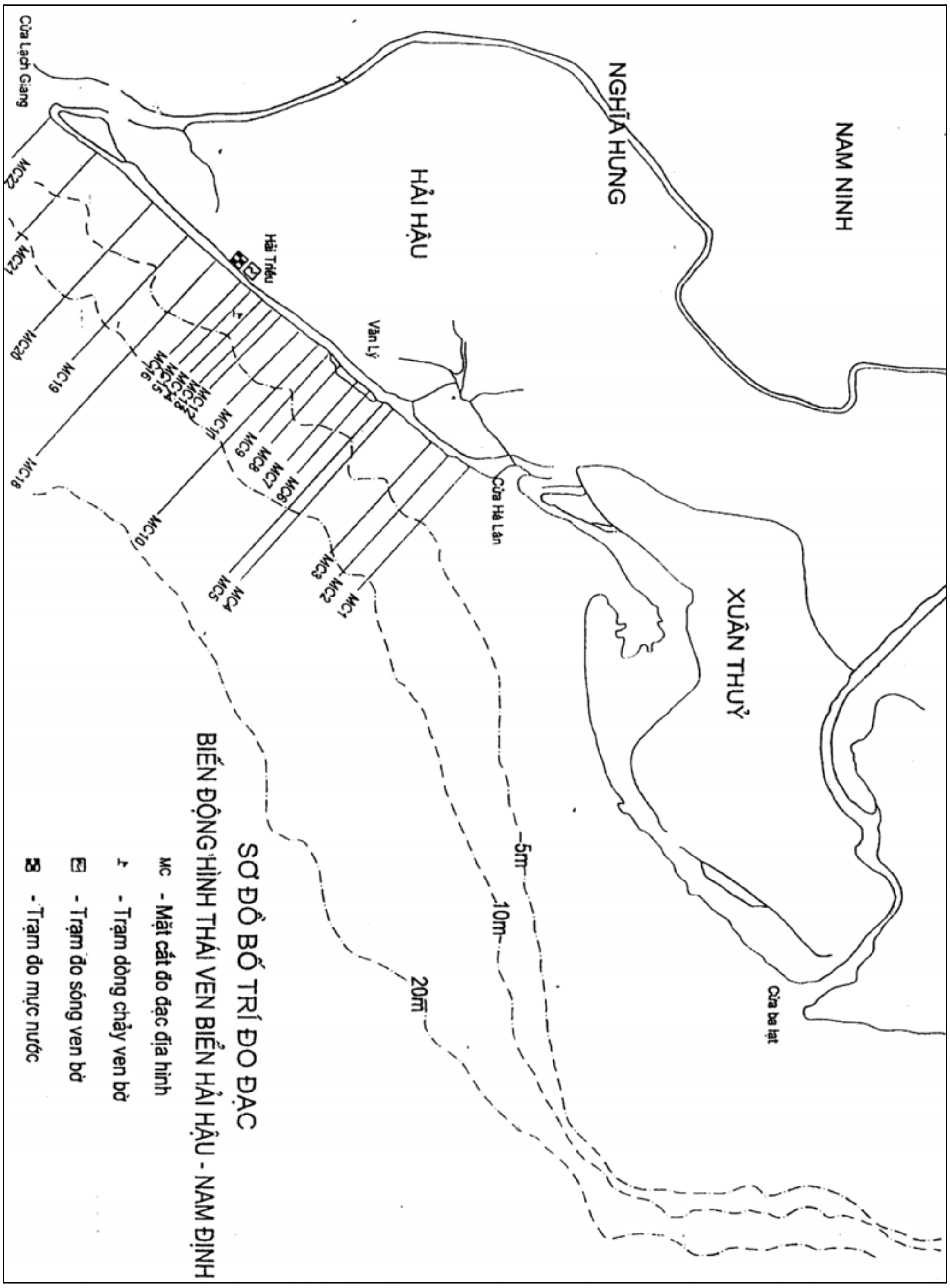

Figure VI.1 *Location map for cross sections along Hai Hau Beach (Häglund & Svensson 2002).*

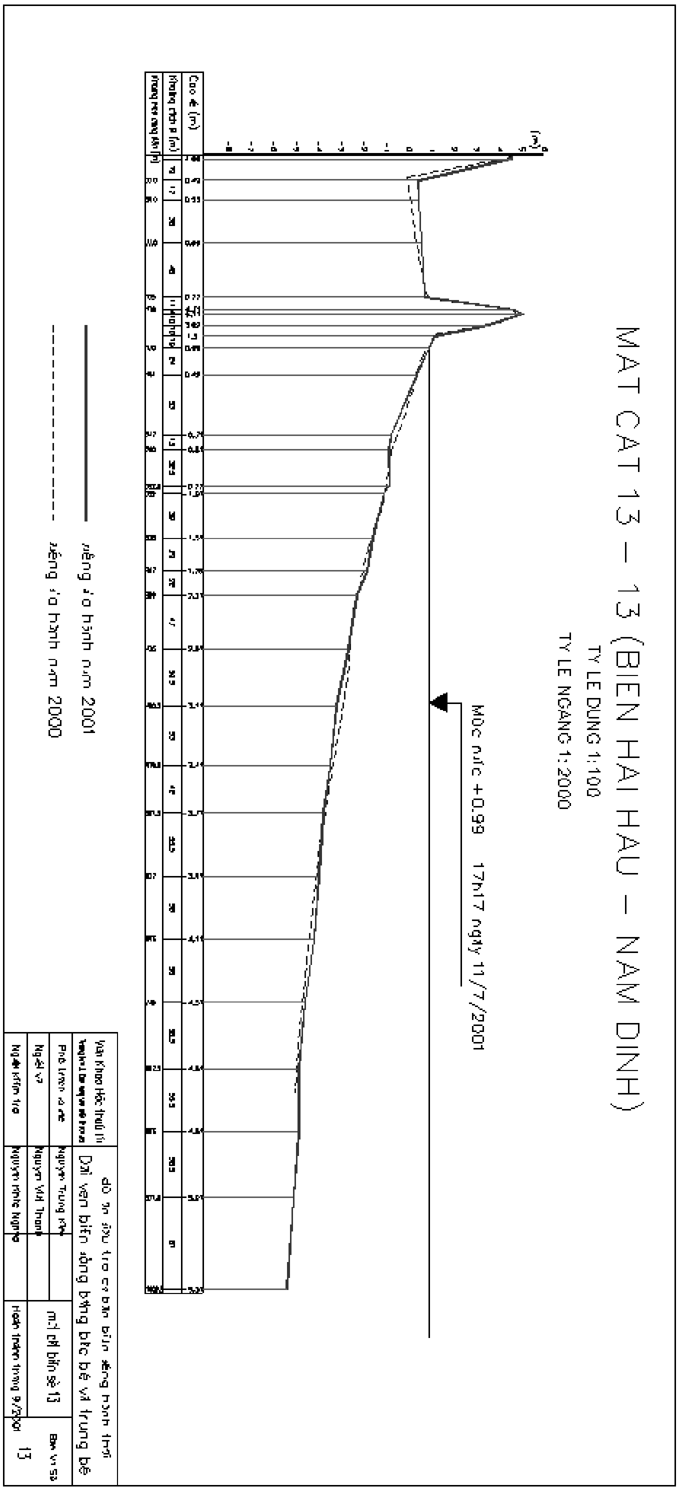

Figure VI.2 *Cross Section MC13 at Hai Hau Beach*

Appendix VII – Storm Surge and Calculated Runup

Table VII.1 *List of abbreviations.*

surge+tide	Level above MSL
surge	Level above MSL
tan β	Average beach slope
R_{max}	Maximum runup height (m)
tot height	Runup height above MSL
overtopping	- = no overtopping, + = overtopping

Table VII.2 *Runup height and wave overtopping at Hai Hau Beach for high tide.*

	1st section					2nd section			
Name	**surge+tide**	**tan β**	**R_{max}**	**tot height**	**overtopping**	**tan β**	**R_{max}**	**tot height**	**overtopping**
Babe -62	2,20	0,0097	2,40	4,6	0,5	0,0102	2,50	4,7	-0,2
Carmen -63	2,11	0,0102	2,51	4,6	0,5	0,0102	2,51	4,6	-0,1
Faye -63	2,42	0,0106	2,32	4,7	0,4	0,0106	2,32	4,7	-0,2
Winnie -64	2,44	0,0106	2,59	5,0	0,1	0,0106	2,59	5,0	-0,5
Clara -64	2,29	0,0104	2,33	4,6	0,5	0,0104	2,33	4,6	-0,1
Tilda -64	2,13	0,0102	2,31	4,4	0,7	0,0102	2,31	4,4	0,1
Rose -68	2,77	0,0111	2,54	5,3	-0,2	0,0111	2,54	5,3	-0,8
Jean -71	3,16	0,0117	2,48	5,6	-0,5	0,0117	2,48	5,6	-1,1
Della -71	2,10	0,0101	2,14	4,2	0,9	0,0101	2,14	4,2	0,3
Harriet -71	2,24	0,0103	2,37	4,6	0,5	0,0103	2,37	4,6	-0,1
Cora -72	1,99	0,0099	1,79	3,8	1,3	0,0099	1,79	3,8	0,7
Kate -73	2,06	0,0101	2,21	4,3	0,8	0,0101	2,21	4,3	0,2
Alice -75	2,67	0,0109	2,44	5,1	0,0	0,0109	2,44	5,1	-0,6
Sarah -77	2,18	0,0102	2,20	4,4	0,7	0,0102	2,20	4,4	0,1
Joe -80	2,44	0,0107	2,99	5,4	-0,3	0,0107	2,99	5,4	-0,9
Warren -81	2,44	0,0106	2,42	4,9	0,2	0,0106	2,42	4,9	-0,4
Kelly -81	2,67	0,0109	2,46	5,1	0,0	0,0109	2,46	5,1	-0,6
Nancy -82	2,35	0,0105	2,32	4,7	0,4	0,0105	2,32	4,7	-0,2
Vera -83	2,25	0,0104	2,54	4,8	0,3	0,0104	2,54	4,8	-0,3
Cary -87	2,92	0,0113	2,55	5,5	-0,4	0,0113	2,55	5,5	-1,0
Betty -87	2,60	0,0110	3,21	5,8	-0,7	0,0110	3,21	5,8	-1,3
Dot -89	2,24	0,0103	2,21	4,5	0,7	0,0103	2,21	4,5	0,0
Brian -89	2,23	0,0103	2,25	4,5	0,6	0,0103	2,25	4,5	0,0
Dan -89	3,02	0,0116	3,31	6,3	-1,2	0,0116	3,31	6,3	-1,8
Angela -89	2,04	0,0102	2,84	4,9	0,2	0,0102	2,84	4,9	-0,4
Cecil -89	2,02	0,0100	1,97	4,0	1,1	0,0100	1,97	4,0	0,5
Becky -90	2,73	0,0111	2,85	5,6	-0,5	0,0111	2,85	5,6	-1,1
Ed -90	2,12	0,0101	2,09	4,2	0,9	0,0101	2,09	4,2	0,3
Fred -91	2,19	0,0102	2,22	4,4	0,7	0,0102	2,22	4,4	0,1

Table VII.3 *Runup height and wave overtopping at Hai Hau Beach for mean tide.*

		1st section				2nd section			
Name	**surge**	**tan β**	**R_{max}**	**tot height**	**overtopping**	**tan β**	**Rmax**	**tot height**	**overtopping**
Babe -62	0,63	0,0077	2,01	2,6	2,5	0,0081	2,08	2,7	1,8
Carmen -63	0,54	0,0081	2,11	2,6	2,5	0,0081	2,11	2,6	1,9
Faye -63	0,85	0,0081	1,89	2,7	2,4	0,0081	1,89	2,7	1,8
Winnie -64	0,87	0,0081	2,10	3,0	2,1	0,0081	2,10	3,0	1,5
Clara -64	0,72	0,0081	1,92	2,6	2,5	0,0081	1,92	2,6	1,9
Tilda -64	0,56	0,0081	1,93	2,5	2,6	0,0081	1,93	2,5	2,0
Rose -68	1,20	0,0092	2,20	3,4	1,7	0,0092	2,20	3,4	1,1
Jean -71	1,59	0,0096	2,13	3,7	1,4	0,0096	2,13	3,7	0,8
Della -71	0,53	0,0081	1,80	2,3	2,8	0,0081	1,80	2,3	2,2
Harriet -71	0,67	0,0081	1,96	2,6	2,5	0,0081	1,96	2,6	1,9
Cora -72	0,42	0,0080	1,51	1,9	3,2	0,0080	1,51	1,9	2,6
Kate -73	0,49	0,0081	1,86	2,4	2,8	0,0081	1,86	2,4	2,1
Alice -75	1,10	0,0081	1,93	3,0	2,1	0,0081	1,93	3,0	1,5
Sarah -77	0,61	0,0081	1,83	2,4	2,7	0,0081	1,83	2,4	2,1
Joe -80	0,87	0,0082	2,43	3,3	1,8	0,0082	2,43	3,3	1,2
Warren -81	0,87	0,0081	1,97	2,8	2,3	0,0081	1,97	2,8	1,7
Kelly -81	1,10	0,0081	1,95	3,1	2,1	0,0081	1,95	3,1	1,4
Nancy -82	0,78	0,0081	1,90	2,7	2,4	0,0081	1,90	2,7	1,8
Vera -83	0,68	0,0081	2,11	2,8	2,3	0,0081	2,11	2,8	1,7
Cary -87	1,35	0,0093	2,20	3,6	1,6	0,0093	2,20	3,6	0,9
Betty -87	1,03	0,0082	2,57	3,6	1,5	0,0082	2,57	3,6	0,9
Dot -89	0,67	0,0081	1,83	2,5	2,6	0,0081	1,83	2,5	2,0
Brian -89	0,66	0,0081	1,86	2,5	2,6	0,0081	1,86	2,5	2,0
Dan -89	1,45	0,0096	2,85	4,3	0,8	0,0096	2,85	4,3	0,2
Angela -89	0,47	0,0082	2,40	2,9	2,2	0,0082	2,40	2,9	1,6
Cecil -89	0,45	0,0080	1,67	2,1	3,0	0,0080	1,67	2,1	2,4
Becky -90	1,16	0,0082	2,25	3,4	1,7	0,0082	2,25	3,4	1,1
Ed -90	0,55	0,0080	1,75	2,3	2,8	0,0080	1,75	2,3	2,2
Fred -91	0,62	0,0081	1,85	2,5	2,6	0,0081	1,85	2,5	2,0

Table VII.4 *Runup height and wave overtopping at Ly Hoa Beach for high tide.*

		1st section				2nd section			
Name	**surge+tide**	**tan β**	**R_{max}**	**tot height**	**overtopping**	**tan β**	**R_{max}**	**tot height**	**overtopping**
Babe -62	1,94	0,0158	3,50	5,7	0,5	0,0180	3,86	6,1	-2,8
Carmen -63	1,41	0,0149	3,36	5,5	0,8	0,0173	3,78	5,9	-2,6
Faye -63	1,31	0,0146	2,98	5,4	0,8	0,0171	3,36	5,8	-2,5
Winnie -64	1,30	0,0147	3,31	5,8	0,5	0,0171	3,73	6,2	-2,9
Clara -64	1,90	0,0156	3,20	5,5	0,8	0,0178	3,54	5,8	-2,5
Tilda -64	2,12	0,0160	3,28	5,4	0,8	0,0181	3,60	5,7	-2,4
Rose -68	1,23	0,0145	3,13	5,9	0,3	0,0170	3,53	6,3	-3,0
Jean -71	1,42	0,0148	2,97	6,1	0,1	0,0172	3,34	6,5	-3,2
Della -71	1,84	0,0154	2,96	5,1	1,2	0,0177	3,29	5,4	-2,1
Harriet -71	1,70	0,0153	3,20	5,4	0,8	0,0176	3,56	5,8	-2,5
Cora -72	1,32	0,0144	2,38	4,4	1,9	0,0169	2,70	4,7	-1,4
Kate -73	1,22	0,0145	2,92	5,0	1,3	0,0170	3,31	5,4	-2,1
Alice -75	1,52	0,0150	3,10	5,8	0,5	0,0174	3,48	6,1	-2,8
Sarah -77	1,24	0,0145	2,87	5,0	1,2	0,0170	3,25	5,4	-2,1
Joe -80	1,76	0,0157	4,00	6,4	-0,2	0,0179	4,43	6,9	-3,6
Warren -81	1,28	0,0146	3,10	5,5	0,7	0,0171	3,50	5,9	-2,6
Kelly -81	1,39	0,0148	3,09	5,8	0,5	0,0172	3,48	6,2	-2,9
Nancy -82	1,37	0,0147	3,01	5,4	0,9	0,0172	3,39	5,7	-2,4
Vera -83	1,26	0,0146	3,31	5,6	0,7	0,0171	3,74	6,0	-2,7
Cary -87	1,69	0,0153	3,22	6,1	0,1	0,0176	3,58	6,5	-3,2
Betty -87	2,07	0,0163	4,35	7,0	-0,7	0,0183	4,76	7,4	-4,1
Becky -90	2,88	0,0179	4,11	6,8	-0,6	0,0193	4,37	7,1	-3,8
Ed -90	1,50	0,0148	2,81	4,9	1,3	0,0173	3,16	5,3	-2,0
Fred -91	1,79	0,0154	3,04	5,2	1,0	0,0177	3,38	5,6	-2,3

Table VII.5 *Runup height and wave overtopping at Ly Hoa Beach for mean tide.*

1st section						2nd section			
Name	**surge**	**tan β**	**R_{max}**	**tot height**	**overtopping**	**tan β**	**Rmax**	**tot height**	**overtopping**
Babe -62	0,91	0,0142	3,22	3,9	2,4	0,0168	3,66	4,3	-1,0
Carmen -63	0,38	0,0130	3,03	3,6	2,7	0,0158	3,53	4,1	-0,8
Faye -63	0,28	0,0129	2,70	3,6	2,7	0,0157	3,15	4,0	-0,7
Winnie -64	0,27	0,0130	3,01	3,9	2,4	0,0158	3,51	4,4	-1,1
Clara -64	0,87	0,0140	2,95	3,7	2,6	0,0167	3,36	4,1	-0,8
Tilda -64	1,09	0,0144	3,01	3,6	2,7	0,0169	3,41	4,0	-0,7
Rose -68	0,20	0,0129	2,85	4,1	2,2	0,0158	3,33	4,5	-1,2
Jean -71	0,39	0,0129	2,67	4,3	2,0	0,0157	3,12	4,7	-1,4
Della -71	0,81	0,0139	2,73	3,3	3,0	0,0165	3,12	3,7	-0,4
Harriet -71	0,67	0,0138	2,95	3,6	2,6	0,0164	3,38	4,1	-0,8
Cora -72	0,29	0,0127	2,16	2,6	3,7	0,0156	2,53	3,0	0,3
Kate -73	0,19	0,0129	2,67	3,2	3,1	0,0157	3,11	3,6	-0,3
Alice -75	0,49	0,0129	2,77	3,9	2,4	0,0158	3,23	4,3	-1,0
Sarah -77	0,21	0,0128	2,62	3,2	3,0	0,0157	3,06	3,7	-0,4
Joe -80	0,73	0,0141	3,69	4,6	1,7	0,0167	4,21	5,1	-1,8
Warren -81	0,25	0,0129	2,82	3,7	2,6	0,0157	3,28	4,2	-0,9
Kelly -81	0,36	0,0129	2,79	3,9	2,4	0,0157	3,25	4,4	-1,1
Nancy -82	0,34	0,0129	2,72	3,5	2,7	0,0157	3,17	4,0	-0,7
Vera -83	0,23	0,0130	3,02	3,7	2,5	0,0158	3,52	4,2	-0,9
Cary -87	0,66	0,0138	2,97	4,3	1,9	0,0164	3,40	4,8	-1,5
Betty -87	1,04	0,0146	4,00	5,0	1,2	0,0171	4,51	5,5	-2,2
Becky -90	1,85	0,0159	3,75	4,9	1,3	0,0180	4,14	5,3	-2,0
Ed -90	0,47	0,0128	2,51	3,1	3,2	0,0157	2,93	3,5	-0,2
Fred -91	0,76	0,0138	2,80	3,4	2,8	0,0165	3,20	3,8	-0,5

Appendix VIII – Cross Sections Ly Hoa Beach

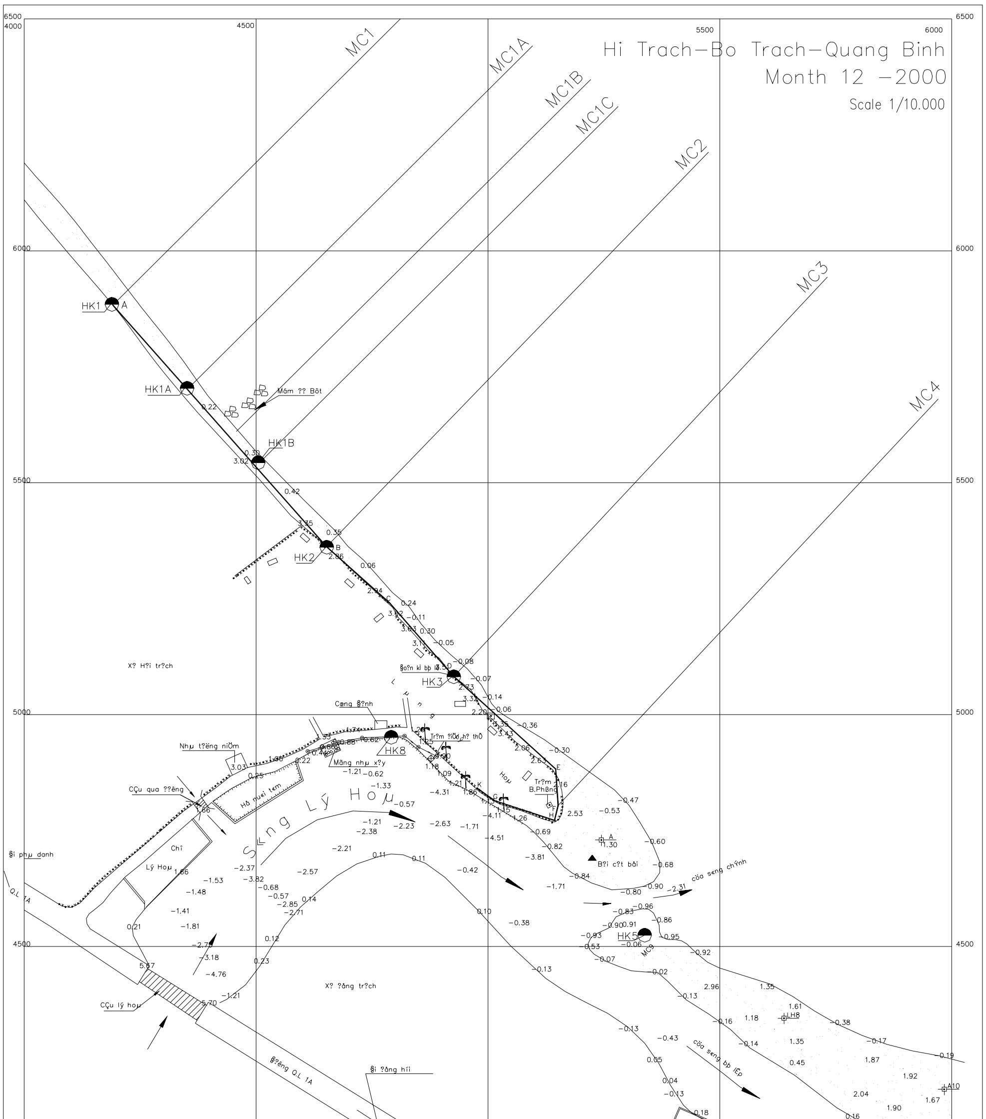

Figure VIII.1 *Location map for cross sections along Ly Hoa Beach (Nghia 2003).*

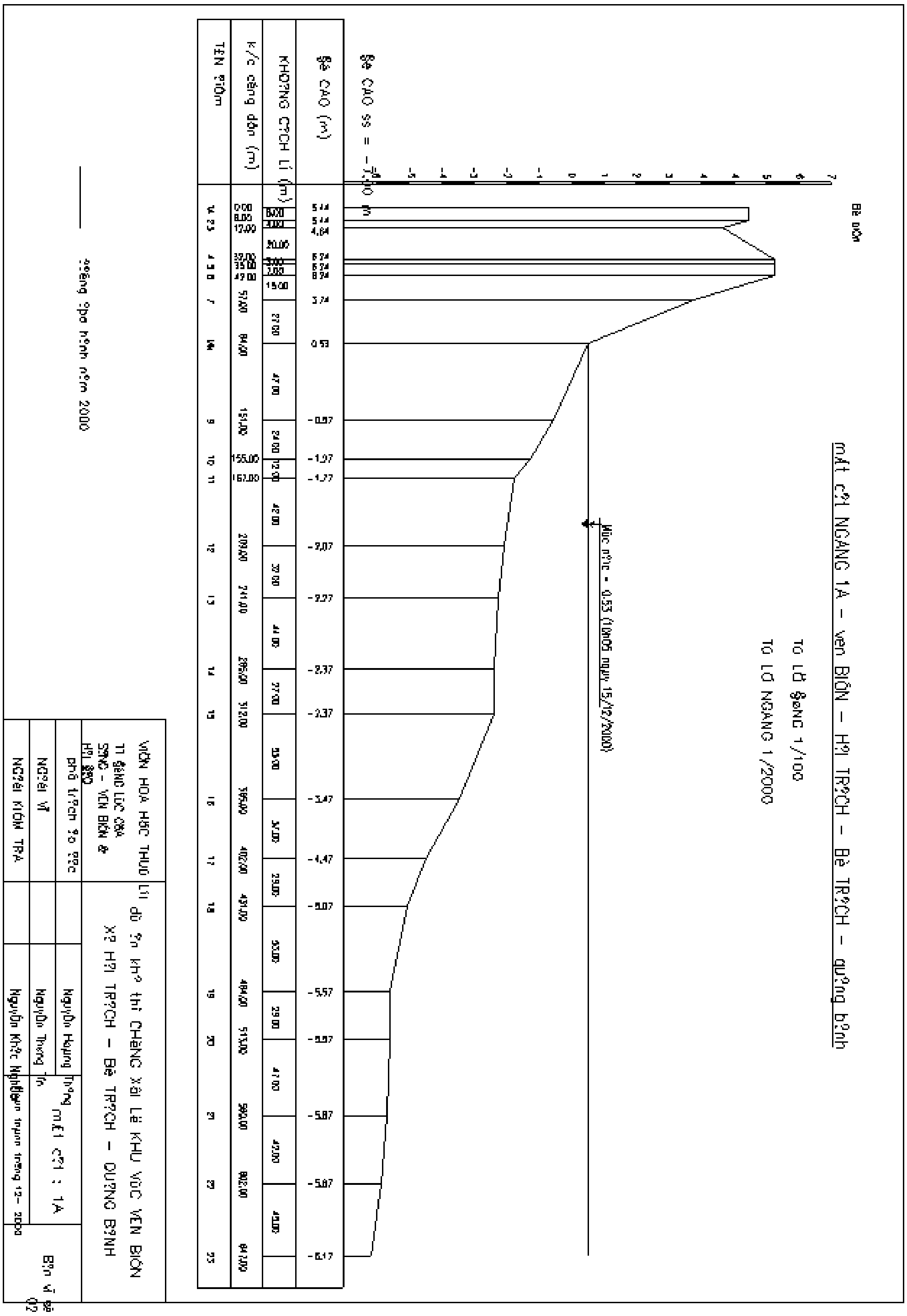

Figure VIII.2 *Cross Section MC1A at Ly Hoa Beach (Nghia 2003).*

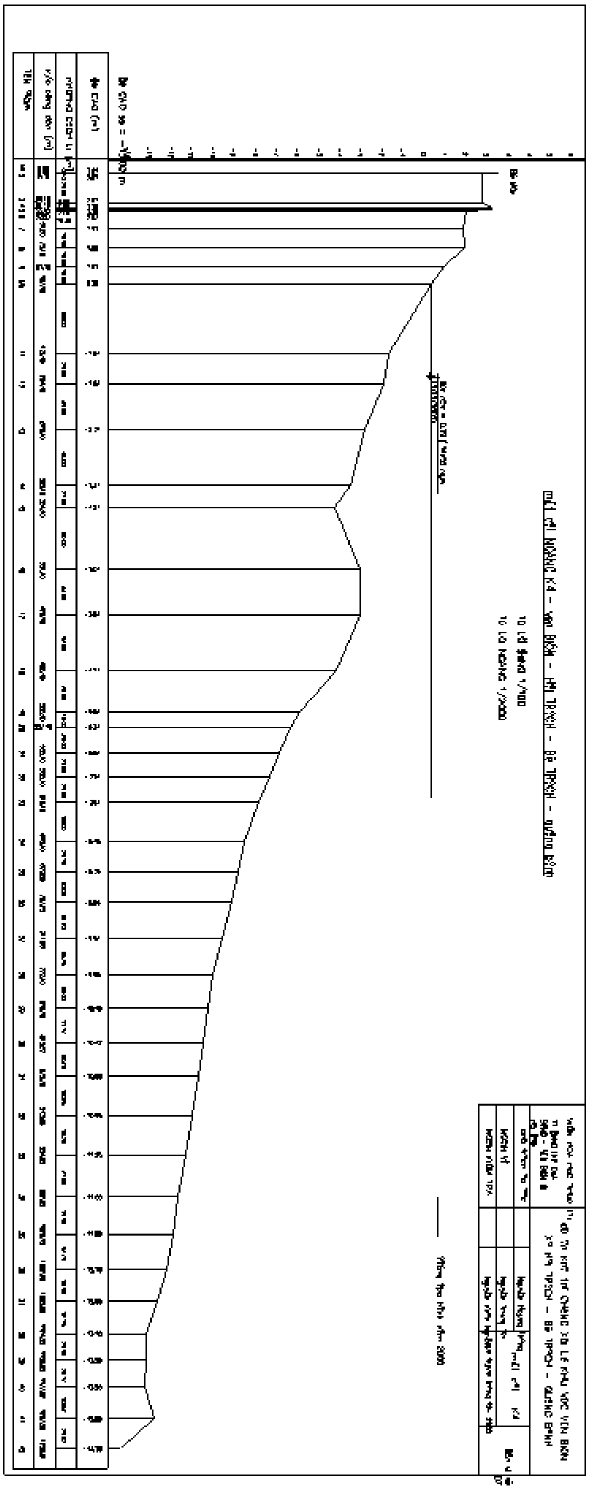

Figure VIII.3 *Cross Section MC3 at Ly Hoa Beach (Nghia 2003)*