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Abstract: This paper aims at investigation of sea dikes failures and its mechanism due to foreshore erosion and scour in front of coastal dikes. The case of Namdinh sea dikes in Vietnam is introduced and selected for analysis. Some methods to estimate scour dimensions will be reviewed and applied for the Namdinh case in determination of suitable dimensions for dike's toe and bed protection. Namdinh coastal zone is a low-lying area which has been protected by sea dikes. In the region typhoons arrive on average four to six times each year at the coastline and the typhoons generate storm surges and waves, both attacking severely the sea dikes along the coast. As the result the sea dike system frequently suffer from damages and failures. One of the main reason for failures of the sea dikes is due to collapse of the dike's toe structures, which often causes by foreshore erosion and scour holes in front of the toe. Due to failures of the dikes and foreshore erosion coastal defensive lines of Namdinh usually has to be retreated 200m inland every 10 years. In order to mitigate the problem the dikes must be well protected. Studies on the erosion and scour induced failures of sea dikes and suggestion of proper toe/foot protection for the dikes, in this case, are important and need further research.

Key words: Foreshore erosion, scour, sea dike, failure, coastal, sea defence, stability, NamDinh, Vietnam

I. INTRODUCTION

A. *General background of sea dike failures*

In the low-lying coastal regions sea dikes are usually the most important coastal structures along their coastlines. The main function of sea dikes is to protect low-lying coastal areas which are highly vulnerable to coastal flooding. In general the design of these coastal structures is often based on actual boundary conditions deterministically.

The design hydraulic boundary condition of such structures is normally based on the averaged water depth front with a certain design waves under an design extreme condition of the actual cross shore profile. However, coastal dikes are usually under impacts of many coastal processes and natural phenomena which happens randomly both in time, space, their intensity and amplitude, thus the boundary situation can change subsequently compare to the design situation.

Due to the action of sea boundaries and their changes the failure of sea dikes may presented in variety of mechanisms. Some of the most possible failure mechanisms are: overtopping, instability of slope protected element, sliding of outer and/or inner slope, piping, erosion of outer and/or inner slopes, dike's toe instability, etc.. The relation between the failure mechanisms in a dike section and the unwanted consequence flooding can be schematised with a fault-tree (see Figure 1.).

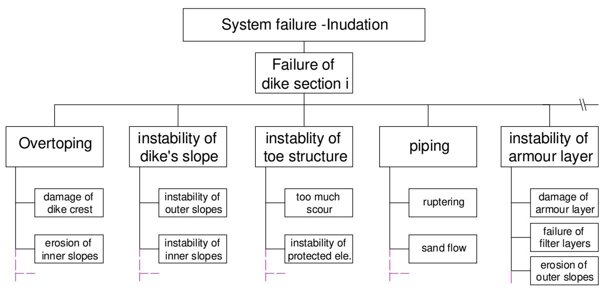


Figure 1. Example of consecutive failure mechanisms of a dike and consequence

On the other hand these failures of sea dikes can be presented in relation to their functional elements (see Figure 2.).

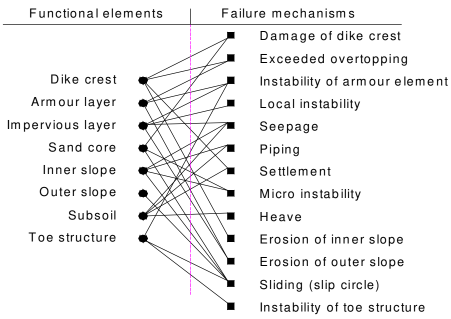


Figure 2. Functional element in relation to failure mechanism of a sea dikes

In sea dike design, it is therefore important to take in to account the future changes of boundary condition during dike design process to bring closer proper outcomes. In order to reduces the bad effects of foreshore erosion and scour, studies on the erosion and scour induced failures of sea dikes are necessary. Prediction of scour pattern (scour depth and width) and suggestion of proper toe/foot protection for the dikes, in this case is also necessary.

B. Erosion and scour induced dike's failures

Foreshore erosion and scour may cause direct and indirect effects to the safety of sea dikes and revetments. It can be explained that, firstly when the foreshore erosion takes place, the bathymetry of the sea bed in front of the dikes changes as well. This leads to the changes of hydraulic boundary condition of design situation comparing to current situation. Consequently, the loads on the dikes change (usually increases). Secondly foreshore erosion occurs near the toe of the dikes. It concentrates and forms scour holes there. When the scour depth reached at certain depth (near the level of toe foundation) the toe structure can not be stable under action of waves and currents. The failures happen to the upper structures when the toe is collapsed as consecutive consequences. Regarding to effect of erosion and scour of sea bed near the toe of a dike, four possible failure mechanisms are schematized in Figure 3. They are separated in two groups: Direct and indirect failures

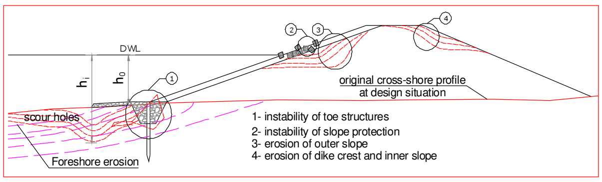
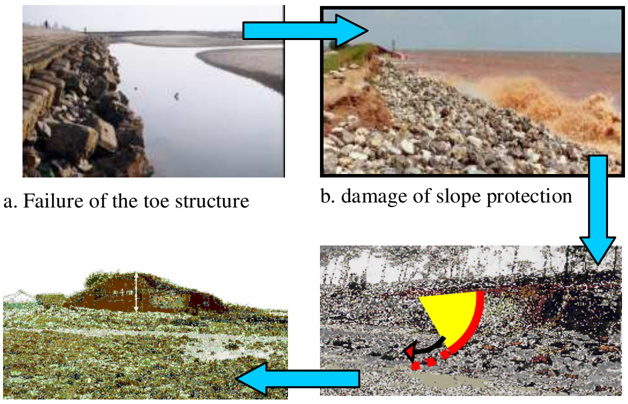


Figure 3. Schematisation of possibe erosion and scour induced dike failure modes

Direct failure: the failures which are caused by direct effect of occurring foreshore erosion and scour. Many cases in practice, due to occurring of local scour holes in front of the dikes, sand is taken away around the toe of the dikes. This sand is important for supporting the toe to remain stable. In the case heavy erosion and local scour take placed the toe structures is exposure to the sea water. The sand support is no longer available when the scour depth is exceeded depth of toe protection. This initially results in instability of toe structures by either sliding or overturning modes. Subsequently, the lower part of outer slopes of the dikes may not be stable. Overall slope stability of outer part of the dikes may be in danger also. These consecutive failure mechanisms may leads to collapse of the dikes. The series pictures in Figure 4. can be a practical expression.

Figures 4. shows the heavy damage of the dikes at Hai Chinh section 1996. First scour occurred at the toe of the dikes (Fig. 4.a) cause toe instability, after that riprap revetments was collapsed at lower and upper parts (Fig. 4.b) . After a design storm, the situation was getting more seriously. Then the dike body and revetment were collapsed after some days. The remained dike body was washed out under impact of waves and currents. Referring to the situation it is possible to say that the final failure occurred under sliding mode of outer slope



a. Failure of the toe structure
b. damage of slope protection
d. Dike breach
c. slope instability

Figure 4. Failures presented at NamDinh sea dikes [Namdinh 1996]

Regarding to erosion induced direct failure, in this study, instability of toe structures is investigated. Instability of the toe is considered with two different failure modes: sliding and overturning.

Indirect failure: Near-shore bathymetry has important influence in hydraulic loads on a coastal structures. In a eroded coastal region very often the sea bed levels in front of dike structures are lowering due to foreshore erosion process. This leads to increase in the water depth in front of the dikes. As the consequence, for a certain design climate condition, the near-shore waves is larger than that at the original bathymetry (at design situation). Subsequently, the others hydraulic loads (e.g wave run-up and wave overtopping...) increase as well. It therefore may cause the dikes failures. This is , in this study, defined as indirect failures. In principle when loads on the dikes are larger than the design loads, various failure modes may present and need to examined. In this case the following modes is mentioned: instability of protective armour layers at outer slopes; erosion of outer slope; erosion and damage dike crest and inner slopes.

Sensitivity analysis on rock stability of outer slope protection base on Pilarczyk 2nd formula for rock armour show that due to 50% water depth increase, the depth limited wave height increase by factor 1.5. As the result the new requirement of rock diameter increase by factor 1.4 or the safety factor decrease by factor 0.7 (see Figure 16.). Other sensitive impact analysis will be discussed with Namdinh case study at the below section.

Due to exceeded wave run-up and wave overtopping the following failures could be occurred:

- Erosion of dike crest.

- Erosion of inner slope
- Damage of crown wall, outer slope protection and upper part of revetment due to the overtopped seawater return flow.
- Washing material of filter layer, where the dike body was not well protected by cover layers.

Figure 5. shows the impression of failures at sea dikes in Hai Phong 2005 due to action of waves, wave run-up and wave overtopping. The damages of the dike in that picture included failures of crest wall and upper parts of revetments.

a. damage of armour layer and erosion upper part of outer slope

b. Damages of crest-wall and erosion of inner slopes

Figure 5. Failures of Hai Phong sea dikes 2005

Discussion

In coastal structure design in general and sea dike design in particular it is necessary to know in advance all kind of possible failure modes of such structures and their causes. Obviously, foreshore erosion and scour contribute a considerable effect to the failure by either direct or indirect ways. It is possible to analyze these effects by analytical method or setting up physical and/or numerical models. In term of foreshore erosion and scour induced failures of sea dikes, these consecutive failure mechanisms can be modelled conceptually as in Figure 6.

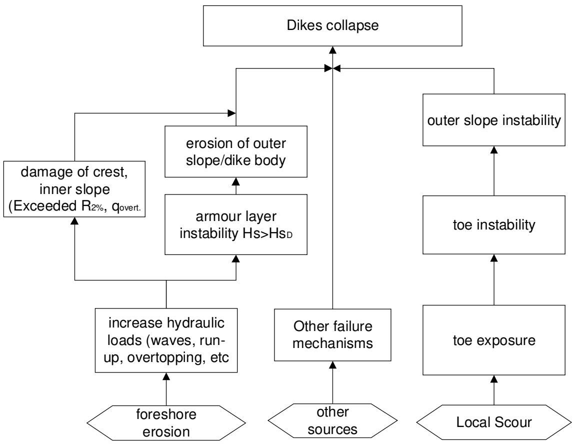


Figure 6. Consecutive failure mechanisms due to foreshore erosion and scour at a sea dikes

II. SEA DIKES FUNCTION FOR FLOOD DEFENCES IN AN ERODED COAST- A NAM DINH CASE

A. General situation of Namdinh coastal defences

The NamDinh Province constitutes part of the Red River Delta in Vietnam. The total length of Namdinh coastline is about 90 km suffering from severe erosion and serious damages of coastal defences. Along the coastline sea dikes and revetments have been the prevalent defensive system protecting the coastal areas from seawater flood and waves attacks. This system was established and has been developed continuously since thousand years ago. It suffered from many times of heavy damage, failure and breaches by attacks of severe storms, which often accompanied surges and high tidal level. This can be considered as the representative for coastal problems in Vietnam.

The failure of the sea dikes and revetments occurs frequently due to actions of severe typhoons, strong waves in combination of high tides while their design parameters were not sufficient. Moreover due to the action of waves and currents the foreshore erosion has occurred seriously which also leads to the collapse of the dikes and their revetments.

In response the central and local authorities have undertaken some efforts in order to restrain the possible adverse consequences and as future defensive measures, some sections of new sea dikes had been built. However, such efforts still remain limited to reactive and temporary measures.

The dike system is characteristically positioned as shown in Figure 7. with two defensive lines and separated section by section with sub-crossing dikes. When a breach takes place at the main dikes, the sub-crossing dikes can limit flooding areas and the second dikes will be a new first line of the system. The distance between two defensive lines is about 200 meters.

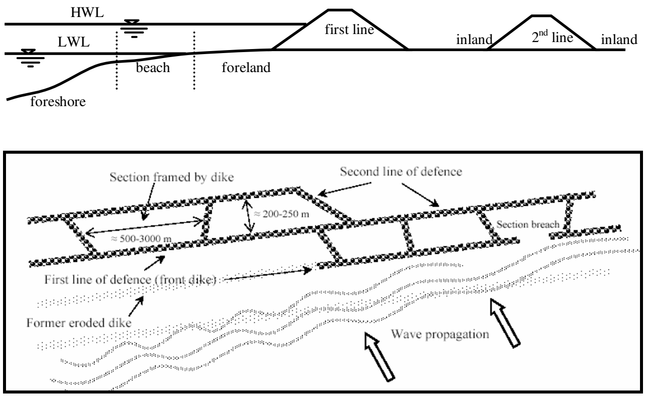


Figure 7. Schematisation of Namdinh sea dike system.

Due to budget constrains, lack of information on the sea boundary conditions and suitable design methodology as well as strategic and long-term solutions, the dike system was usually designed and constructed in poor conditions. As the consequence, the system could be destroyed once in every 10 years. Therefore the cost of dike maintenance is finally very expensive. Statistically, for maintenance of Namdinh sea dikes system it is represented nearly 95 percent of the total coastal defence budget of Vietnam. Figure 8. show the fast retreat of coastline as well the sea defence lines at Hai Trieu village, Hai Hau district in Namdinh province.

a. HaiTrieu Village in 1995

b. Abandoned HaiTrieu in 2001

Figure 8. Fast coastline retreat at HaiTrieu Village, Hai Hau, Namdinh

B. From historical development to future prediction

Historical development of coastal protection in Namdinh is available since 1890. In period from 1890 to 1972 it should be noted that there were no observation and measured records. These reports included only the major events of dike's breaches and reconstruction. More extensive information on development of the dike system is available since 1972. The observation on cross-shore profiles of Namdinh dikes were made at several locations therefore the situation can be analysed in more detail. From 1972 to 1990 the profile measurement took placed once in every 4 to 5 years. Since 1990 on the measurements of cross-shore profiles were performed at least once every year.

According to the historical information, during period of 65 years from 1890 to 1971, due to dike weakening because of erosion process and dike breaches after severe typhoon, the dikes system was shifted inland about 850 meters. There were six 6 times dike breaches and then reconstructions.

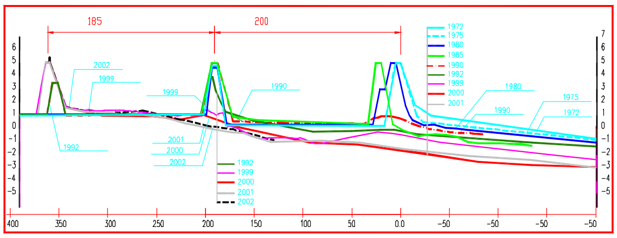


Figure 9. Overlap cross shore profiles from 1972 to 2003

During period of 30 years from 1972 to 2003, there was 6 times of dikes breach and 3 times of reconstruction of the dikes which shifting inland. The retreat of coastline during this period was around 400m inland. The dike breach and retreat of coastline for the time being because of the mentioned reasons. These processes can be summarized as following:

Since 1972 the sea dike system in Namdinh had 2 defensive lines (see Figure...). The first line was in good condition with crest level of +5.0 CD, and outer slope of 1 over 3 and inner slope of 1 over 2. Composition of dikes cross section was sandy clay body and moderated clay for outer armour layer. The toe of the dike was protected by extending under part of the outer slope with a flatter slope of 1 over 10. Foreland and beach in front of the dike was at level from -0.5 to +1.0 and around 150 m wide. The second line stood at 200m landward of the first line. The dimension of cross section was smaller than that of the first line. The crest level was at +4.5 m CD, outer slope is one over 2 and inner slope is one over 1.5. The profile of cross section is shown on Figure 9. *line label 1972.*

Three years later, in 1975, the erosion of near shore zone started. The foreland and beach along the dikes was lowered approximately 40 cm annually. The erosion depth was even more near the toe of the dikes, about 65 cm a year. Due to this erosion the toe was in danger of instability. The erosion of the lower part of outer slope was started. The first line of defensive system was in threatened. The profile (line label 1975, Figure 9.) was deeper offset in comparison to 1972's.

During period of next 5 years, from 1975 to 1980, the erosion became more heavily. Continuous erosion occurred near water line due to the actions of waves dike body's material was taken away and washed out. In front of the toe the sand was also taken away forming scour holes. The cross section of the dikes was getting smaller and thinner. Instantly, the first line was upgraded by the local people by widening the cross section at inner side. There was no recognisance of occurring of foreshore erosion and scour. The cross section then looked like *line label 1980* in Figure 9. .

In 1984 the erosion of near shore zone was still going on and the scour holes were getting deeper. The toe of the dikes was collapsed first after that sliding mode occurred as the failure of the outer slope. At the end of storm season in 1984 the first line was breached over the length of 1500 meters.

During quiet period of the sea in 1985 the breached gap was closed by new first dike section temporarily. At the same time the second line was upgraded for intention of becoming the first line later. The temporary first dike (closured section) was constructed at position of the old dikes in order to reduce the risk at the second line and kept dry area in front of that for being construction site. After upgrading, the second line became new first lines. Establishment of the new second line was started.

From 1985 to 1990 the closured section, which was constructed temporary in 1985, was eroded and had been getting weaker. At the end of storm season in 1990 this dike cross section remained only a small area with the shape of triangular (*see line label 1990,* Figure 9.). The remain material was spread out by interaction of waves and currents forming a foreshore of the new dike system.

The foreshore around the first dike toe of the new dike system was at averaged level of about +0.50. The averaged erosion rate of was about 0.30 m per year. By the end of November 1992 due to a severe storm occurred the cross shore erosion increased and scour holes appeared at approximately 0.8 meters in front of the toe and caused collapse of toe. As the consequence lower parts outer slope of the dike was damaged as well. Maintenance works were started with the outer parts of the dikes by filling rock at the dike toe and reinforcement outer slope wit riprap revetments. This maintenance work could withstand dikes until November 1995. After a typhoon with wind strength of 10 Beaufort the whole dike section mainly collapsed. The remained part had a triangle shape. It was not considered as a dike any more. At that moment the position of first dikes had to move again inland to the second dikes which stood 200 meters behind.

During the period from 1996 to 2000, busy re-reinforcement and reconstruction works of third new dikes system were going on. The upgrading works were finished temporary in 2000. New first line of dikes had crest level of +5.5m. The outer slope was one over four which was protected by rock revetments. The toe of the dikes was at level of +0.5 m with one or two lines of cylindrical concrete block. In front of the dikes the protection of scour holes was provided (see also FAO/UNDP 525 project report, Design documents for upgrading Namdinh sea dikes).

After 3 storm seasons from 2001 to 2004 the defensive system functions well in a good condition. However the observation showed that erosion process was still going on. Foreshore was narrowing and deepening year after year as the consequences.

Recently, in 2005, the Damrey typhoon, which occurred from 25th to 28th September 2005, attacked coastal areas in Northern Vietnam caused many serious damages of the coastal defence system and heavy lost for coastal regions. The wave run up was as high as 3-4 meters, high storm surge in combination with high tide led to too much overtopping of sea water at sea dikes in almost all affected regions. It broke certain sea dike sections in Thinh Long town, Hai Hau district in Nam Dinh province despite great local efforts for protection. In total, 25 kilometers of Vietnam sea dikes were broken and nearly totally destroyed. In Nam Dinh a stretch of 800m sea dikes was completely washed out.

Discussion

Based on analyses of historical development of Namdinh sea dikes the main reasons for dike failures and breaches can propose as follows:

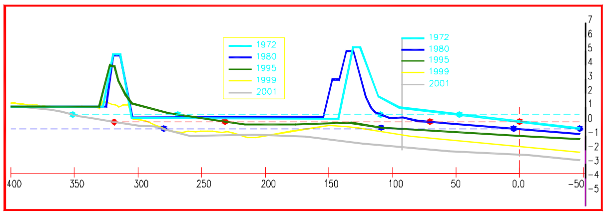
Heavy foreshore erosion led to lowering the sand beach and foreland, formed scour holes in front of the dikes. As the consequences the toe of the dikes could not be stable. The failures of the toe resulted in series of consecutive damages of upper components of the dikes.

Increase in water depth in front of the dikes, as consequence of foreshore erosion, caused higher waves height (compared to the design wave height at the design situation) attacking directly on dike outer slope. On the other hand, the outer slope of most old dikes was not protected. That could lead to many damages of the outer slope.

During storm, high water level often accompanied with a surge and wave run-up caused too much overtopped water. This led to many damages of the dike components such as inner slope, outer slope and dike crest

Future prediction

The retreat of coastline during the period of 30 years is shown in Figures 4.3. In this Figure, the retreats of foreland levels of -0.50, 0.0, +0.50 meters (+MSL) are indicated. The based point is the position of foreland level 0.0 in the year 1972.



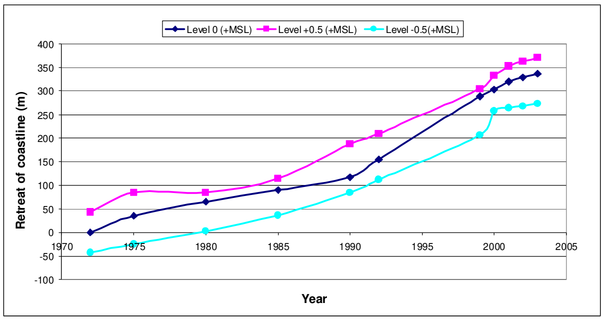


Figure 10. Retreat of coastal defences from 1972 to 2003

Based on the above analysis, if no proper measures for upgrade and protection of the dikes are undertaken, the situation will go on by similar trend of the last period. After every 10 years the retreat of coastline will be around 150 meters inland, see also Figure 10. According to the current trend, the location of the dikes will shift 200 meters landward after every 10 years.

C. Morphological changes and beach erosion of along Namdinh coast

This section concentrates on studying of sea boundary from deep ocean to near shore zone, includes waves and sediment transport processes along the coast. Advanced mathematic models - SWAN[1], and UNIBEST[2] - were used to simulate these problems. The models are setup and calibrated based on available collected data and historical map. The outputs of this section allowed, firstly, for establishment of hydraulic-sea boundaries which directly impact on the sea defensive system, and secondly, predicted statement of trend and rate of coastline changes. The wave result from SWAN model was derived and used as input data for morphological model UNIBEST. For calculation of long-shore sediment transports different sandy transport formulae were used (Bijker formula, Van Rijn formula and CERC formula). The coastline was divided into 8 sections with 9 cross section, relatively (see Figure 15.a). Simulation of coastline changes at HaiHau district by using UNIBEST-CL model was developed. The results of 24 years model are presented in Figure 15.c&d.

According to the model output, the net sediment transport direction is from north to south along the coastline. Obviously, the whole project areas are subject to erosion. The maximum erosion rate is at Hai Ly, about 22.4 meters/year (Van Rijn formula) and 21.5 meters/year (Bijker formula) which is situated in the northern part of the project, and then the erosion rate decreases southward. In order to calibrate the coastline model the simulation results are compared with the available collected data, which were deduced from the erosion map in period 1972 - 1996 (see Figure 15 b.). The comparison is shown in the Figure 15c with a acceptable fit. This result gives quite good agreement with the future prediction in the previous section.

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[1] Simulating Waves Nearshore model, developed by Delft University of Technology, Rijkswaterstaat

[2] Uniform Beach Sediment Transport model, developed by WL| Delft Hydraulics

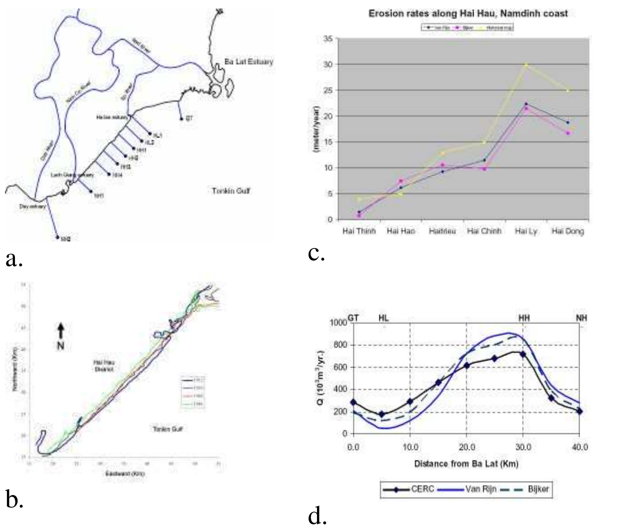


Figure 11. Longshore sediment transport and beach erosion simulation a long Namdinh coast

$$\frac{S}{H_o} = 0.42 m^{0.85} \left(\frac{Lo}{Ho}\right)^{0.2} \left(\frac{h_w}{H_o}\right)^{0.25} \left(\frac{H_o}{d}\right)^{1/3}$$

Where S is the scour depth at the seawall; Ho, Lo is wave characteristics in deep water, h_w is depth of the toe of structure and d is the sand grain size, see the schematized Figure 13.

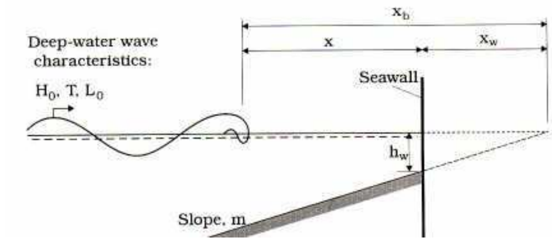


Figure 13.

D. Investigation of foreshore erosion and scour induced failures of Namdinh sea dikes

From the earlier section it could be stated that most of the failures of Namdinh sea dikes are caused by under estimation of boundary condition. The possible failure modes of Namdinh sea dikes are various. For more detail on failure description of all possible failure mechanisms, see also in Mai et al, 2004. In this paper only failure modes which were direct or indirect influent by erosion and scour are examined.

The following representative cross section of Namdinh sea dikes is introduced for the assessment:

Dike crest level: +5.5 CD; Outer and inner slope : 1/4 and 1/2; Outer slope is protected by rip-rap rock with thickness of 0.40. Inner slope is exposure (non protected).

Dike body: sand core cover by 50 cm thickness clay layer.

Toe of revetment: Toe crest level: -0.5; One line of cylindrical concrete block, diameter of 100 cm and length of 150 cm, rock filled inside. Protected depth is 1.5 meters.

1) Failure of toe foot protection

a) Scour depth prediction

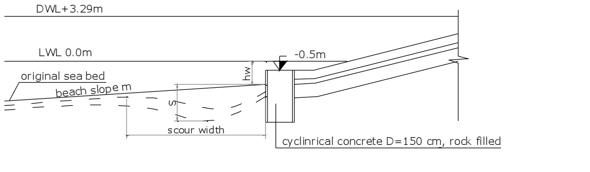


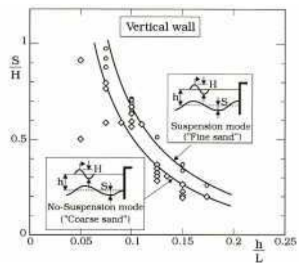
Figure 12. Schematisation of toe foot structure of NamDinh sea dikes

Scour due to waves actions is predicted at situation of occurring lowest water level. In this situation, the gentle outer dike slope is neglected; the vertical cylindrical concrete can be considered as a vertical wall. Schematisation of problem is shown in Figure 12. Maximum scour depth S can be determined by the three difference methods below.

- McDonugal Method

The scour depth in front of vertical seawall on a beach slope of m is:

- Method of Xie, 1981 (for vertical sea wall)



According to Xie 1981, the maximum scour depth is given by the curves in Figure 14. In which H, L: local wave characteristics; h : local water depth;

Figure 14.

- Method of Sumer and Fredsoe(2001) (developed for armour breakwater)

This method given by series of graph on Figure 15. . However it is applied for slope angle in the range of 30^o to 90^0. It suggests that when applied for the gentler slope of 30^0, the curve of $\alpha=90^0$ should be applied scour depth then should be reduced by a certain appropriate factor.

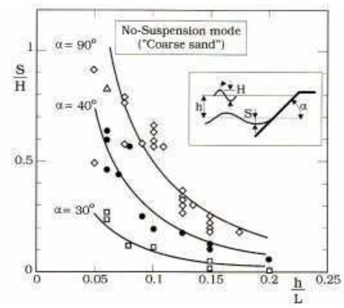


Figure 15.

$$\frac{S}{H} = \frac{f(\alpha)}{\left[\sinh\left(\frac{2\pi h}{L}\right)\right]^{1.35}}$$ in which $f(\alpha) = 0.3 - 1.77 e^{-\frac{\alpha}{15}}$

Applied the above methods for Namdinh sea dikes with the input parameter in TABLE I. and the results are in TABLE II.

TABLE I. INPUT PARAMETER

Parameter	unit	value

low water level	m	0.0 CD
Toe level	m	-0.5
Design wave height (in deep water)	m	2.0
Wave period	s	8.5
Sea bed level	m	-1.6
depth limited wave height	m	0.55*Depth
Shallow wave length	m	$T^*(gh)^{1/2}$
calculated depth D	m	1.6
grain size	m	0.00025
sea bed slope	%	1

TABLE II. MAXIMUM SCOUR DEPTH

Method	**Unit**	**Value**
McDonugal	m	1.2
Xie 1981	m	0.9
Sumer and Fredsoe(2001	m	1.3

- Discussion

By applying various methods the different results of scour depth were given. The method of *McDougal* deals with deep water characteristic of waves while *Xie*'s, and *Sumer&Fredsoe* prefer local wave characteristic. In equation of McDougal, the grain size of sand near the toe was included. This may give more appreciate mechanism of scour.

For initial design the maximum protective depth for toe structure should be selected by the largest value of maximum scour depths by applying these various methods then multiplies safety factor. For the case of Namdinh revetment, the initial depth for toe protection should be equal to: $1.2\ S_{max}=1.2*1.3=1.6m$ from the calculated bed level of *-1.6m CD*. Therefore the protected level should be at *-1.6-1.6=-3.2m CD.*

b) Stability of the toe structures

Due to occurrence of scour hole the toe structure may lost its stability by the two modes: Sliding instability; and overturning stability. Problem is schematized for two situation: Before and after occurrence of scour hole (see Figure...). The safety factor of two interested failure modes is calculated follows the critical state conditions.

- Sliding criteria:

$$SF = \frac{n_q E_2 + n_g G_W f}{n_q E_1}$$

- Overturning criteria (around point A)

$$SF = \frac{n_q E_2 r_2 + n_g G_W r_G}{n_q E_1 r_1}$$

in which:

E_1 - Total active pressure component

E_2 - Total passive pressure component

G_W - Gravity force of the cylindrical concrete block in water

f- friction coefficient of rock with foundation at assumed sliding plane.

$n_q;n_g$- multiple loading factor

SF : Safety factor

r_i : moment radius of related force

More detail of stability analysis can be found in Tran, T.T. & Mai, C.V 2005. The analysis result is summarized in TABLE III. It can be concluded that due to occurrence of local scour holes, with maximum scour depth of around 1 meter, the toe of Namdinh sea dikes is totally collapsed. The overall safety factor is very low at 0.32.

TABLE III. SAFETY OF TOE STRUCTURE AT PRE&POST SCOUR

failure modes of toe structure	***safety factor***	
	before scour	***after scour***
Sliding	2.25	0.67
Overturning	2.63	0.32

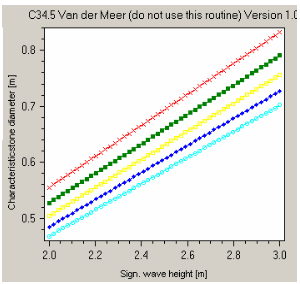
2) Indirect failure modes at Namdinh dikes due to erosion and scour

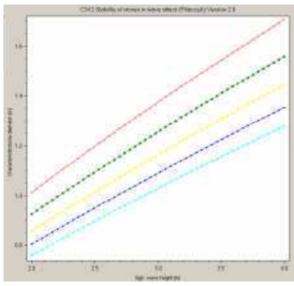
As the result from scour calculation, the water depth in front of the dikes increase possibly 1.2 meters due to scour hole in comparison to the original situation. This means that the wave height acting on the dikes may increase also, $\Delta Hs = 0.55*1.2= 0.66$ meter (according to depth limited wave height).

Regarding to safety criteria of slope protection, wave run-up and wave overtopping, wave height is a dominant parameter in the equation. With the given increase of wave height, ΔHs, the reduced factor of safety of the above criteria can be estimated by sensitivity analysis (see summary result in Figure 16. and TABLE IV.

TABLE IV. EXCEEDED SAFETY CRITERIONS DUE TO SCOUR

Criteria	***original design value Hs=2.0m***	***present require value Hs=2.7m***	***reduced factor of safety***
wave run up (Van der Meer)	2.35	3.36	0.70
wave overtopping (Van der Meer)	8.5	17	0.5
Stability of rock armour layer (Pilarczyk)	0.8	1.1	0.72
Stability of rock armour layer (Van der Meer)	0.5	0.68	0.73





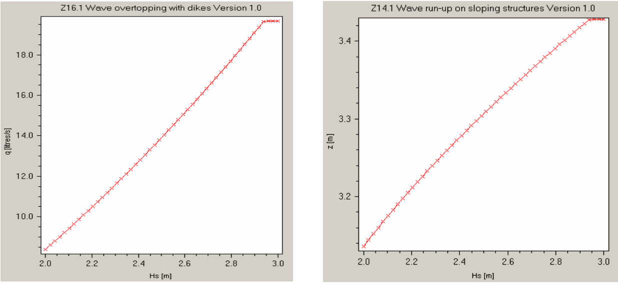


Figure 16. Sensitivity analysis of wave height related criterion

Obviously the result shows that due toe increase of 1.2 meters water depth (approximately 50% original depth) in front of the dikes, the actual safety of the dikes is decrease by factor of 0.7 in term of wave run up and stability of amour layer, and wave overtopping reduce safety factor by 0.5. This can be explained for the actual low safety level of Namdinh dikes (extensive analysis see also Mai, C.V. 2004) and what happens there during last ten years.

III. What information do we need for a rehabilitation of sea dike in Vietnam

A. *General needed information*

Year 2005 can be treated as a historical year in respect to disastrous impact of typhoons on sea defences in Vietnam. Totally 8 typhoons has hit Vietnamese coast in this year resulting in human casualties and large economic damage. Typhoons No.2 and No.7 (Damrey) were of exceptional strength and belong to the heaviest typhoons in the last 3 decades.

Typhoon No.2, on 31 July, hit mainly the coastal area of Haiphong resulting in a number of kilometers of damaged sea dikes, especially on the island Cat Hai, where 8 km dikes were broken and/or heavily damaged and need total rehabilitation.

Typhoon N0.7, on 27 September, hit three provinces, Thai Binh, Nam Dinh and Thanh Hoa. The damage was enormous; 25 kilometers of dikes were broken and nearly totally destroyed. In Nam Dinh a stretch of 800m sea dikes was completely washed out.

However, it is to hoop that year 2005 will also be a turning point in national approach to sea defences in Vietnam, similar as the year 1953 was a turning point for the Netherlands in formulating the new policy and safety standards for protection the country against flooding.

The rehabilitation of these damaged or broken dikes will take a number of years and will be implemented under guidance of Department of Dike Management and Flood Control (DDMFC). It is evident that the old dikes were to weak and usually designed based on outdated design criteria, including rather poor hydraulic boundary conditions (waves, storm surges, design water levels).

To overcome the existing problems of the old dike design and come up with more proper outcomes, it is necessary to establish relationships and/or models for hydraulic boundary conditions in front of the dike as input for the design. The following issues are needed to be examination:

- **frequency distribution of water extreme levels** (historical storms/typhoons) based on data from the existing monitoring stations. However, the number of stations is too limited to cover the whole coast. The results can only be used for areas neighbouring the stations. However, these results can be also used for verification of results obtained through other methods (typhoon simulation and storm surge estimation in combination with astronomic tide)

- **simulation of historical typhoons up to end 2005** using typhoon simulation models (Vietnamese one and one provided by Delft Hydraulics in 2002). This simulation can be extended for other possible wind fields to simulate conditions exceeding historical storms to obtain some sensitivity information when extrapolating the frequency curves beyond the observed range.

- **frequency analyse of storm surges** subtracted from the measured water levels and typhoons simulations for various location along the Vietnamese coast, and estimating the value of the representative annual tidal high water (average from astronomic high water spring). Combination of the storm surges and tidal high water provides the water level per location. For location of existing measuring stations the estimated water levels can be compared with the water levels from direct observations.

- **deep water wave prediction**; comparison of standard prediction methods with waves induced by typhoons. Preparation of recommendations concerning the method which should be used, and possibly, preparing diagrams for wave prediction.

- **transformation of waves from deep water to shallow water, up to the toe of the structure;** this very crucial component for design because it defines the wave height (H) and period (T) as to be used in design of structural elements of the dike. The wave height depends on the water depth in front of the structure. Therefore the eventual erosive tendency of the foreshore should be taken into account (the wave height may increase in time). For shallow foreshore the depth limited wave height (H) can be applied: H=a h, where h is the local depth and 'a' is a coefficient, which should be determined from local measurements (usually between 0.4 and 0.6).

- **morphological development of erosion areas.** As mention above, the morphological changes may influence the wave prediction. Especially for Nam Dinh it is known that it is erosion coast. The foreshore is gradually eroded and at certain moment the deep water and high waves are approaching the dikes leading often to their destruction. The morphological maps and cross profiles should be analysed in combination with some morphological models to establish the tendency and speed of erosion. Yearly monitoring/survey at critical sections, especially after the typhoons, should be incorporated in standard management activities.

B. *Information needed in term of erosion and scour*

The outcome of last issue could bring relatively sufficient information in dike design process to reduce probability of erosion and scour induced sea dike failures which is focused in this paper. In this term the following specific information is proposed to have in hands before implementing a sea dike design:

1- Long-term erosion rate and trend: First the large scale longterm simulation of morphological processes should be implemented. The expected outcomes should be the nearshore erosion rate and direction, the trend of coastline changes and finally the information on predicted equilibrium coastline shapes. This information need for a layout design in large scale of a dike system. Two questions need to be answered are: Can we still protect a low-lying area behind an eroded coastline by a sea dike system stand alone or it need to combine with other measures? Where would be the position of defensive lines and in which alignment?

For these study the hydro-morphodynamic models will be good tools. Mathematical models are available for this purpose for example MIKE21, DELFT-3D, UNIBEST, etc.

2- Short-term morphological change: The seabed level changes may influence the wave prediction. The short-term morphological change is not usually taken into account during the design and evaluation of sea defences because its effect is difficult to predict. At present, it is capable to use cross-shore transport models for this purpose. A conceptual equilibrium cross-shore profile can be predicted by either physical or numerical models. Based on that a conceptual optimal cross shore shape of coastal dikes can be suggested. Available UNIBEST-CT model could be an useful tools for scale of a coastline section.

3- Dimensions of maximum local scour and toe foot protection: Scour is natural phenomena caused by the action of waves, currents and their interaction. Scour occurs naturally as a part of morphological changes of coastal areas and as the result of artificial coastal structures such as sea dikes. Once the coastal structures are presented, the natural situation of waves and currents will be disturbed. Due to the action of waves, currents and their interaction with structures the scour is often being developed near the toe of these structures. In sea dike and coastal structure design, it is necessary to predict the scour patterns in order to provide a proper bed, toe foot protection.

Actually the determination of geometrical dimensions (protected depth and width; required size of protected elements) is based upon on the scour prediction and stability of element under attack of currents and wave-induced currents. There have been already several researches on development of scour near coastal and marine structures (e.g. McDougal et al 1994, Fewler 1992, Xie 1981, Fredsoe & Sumer 2001, Hoffmans 1992, etc.). Some empirical formulae were derived which can be used in a conceptual design stage. For more important stage of design, multi-dimensional physical and mathematical models should be applied.

IV. Concluding remarks and further studies

This paper starts with some background information of sea dikes design, general design boundary condition of the dikes and their possible failure mechanisms, which need to account for during a design process. Dike failures, which may cause by foreshore erosion and scour are discussed and formulated conceptually in a consecutive mechanism. Subsequently a case study of a typical coastal protection of Vietnam is introduced. Investigation on the effect of scour and erosion problems to the NamDinh dike failures is figured out. The necessary information for more proper rehabilitation of sea dikes in Vietnam is presented. However, due to limited time and lack of data and information the study is just in a general state. Every indicated point may need some further studies. Nevertheless, this study allows giving the following remarks for the sea dike design and management:

Selection of design boundary condition should not only be taken at the present design situation but also count for the future changes (during serviced-life time). Because sea dikes are usually under impacts of the coastal processes and randomly natural phenomena in which their impact parameters varies both in time, space, intensity and amplitude, thus the boundary conditions of the dikes can change subsequently compare to the design situation.

Morphological changes will influence the wave prediction and change of hydraulic boundary condition. Especially for an eroded coast of Nam Dinh, the foreshore is gradually eroded and at certain moment the deep water and high waves are approaching the dikes leading often to their destruction. The morphological maps and cross profiles should be analysed in combination with some long-term, short-term morphological models to establish the tendency and speed of erosion. Based on that an optimal layout design of whole defensive system and optimal shape of the dikes can be archived.

Foreshore erosion and scour cause direct and indirect effects to the safety of sea dikes and revetment. Failures of the dikes due to these problems are obviously indicated in the case study of sea dikes in Vietnam. Given result shows that when possible scour holes occurs the safety of the dikes decrease considerably. Since the maximum scour depth of 1.2 meters (approximately 50% original depth) presents in front of the dikes, the actual safety of the dikes is decrease by factor of 0.7 in term of wave run up and stability of amour layer, and wave overtopping reduce safety factor by 0.5. The overall safety factor of the toe structure is very low at 0.32. A conceptual model of consecutive failure mechanisms in Figure 6. described these effects to the failure of sea dikes.

Using dikes in combination with other coastal defensive measure should be considered for the heavy eroded coastal region such as Namdinh. The studies and/or pilot projects on the effectiveness of the combined measures should be carried out before decision is made for the whole system.

Bed protection at the toe of sea dikes is another important aspect. When scour occurs continuously, it leads to forming of scour holes in front of the structures and may cause consecutive damages and failures of structural components. In this sense, bed protection provides functions of keeping sand in places to avoid forming scour holes and increase stability of the toe structures. It is necessary to predict the scour patterns in order to have a proper bed, toe foot protection.

To avoid consecutive failure mechanisms at existing sea dike system, a good and management strategies must be carried out. Monitoring program must be set up to ensure that all the initial damages of the dikes are aware and be repaired in time. The observation from small to a system scale is needed during any whether conditions. Based on the observation the maintenance can be provided in proper way annually. Measurement of cross-shore profiles before and after severe condition is advised in order to see the trend of profile development.

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