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Risk based design of coastal flood defences - A vietnam case

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ABSTRACT: This paper presents risk based design approach and its application for a case study of coastal flood defences in Nam Dinh province, Vietnam. In accordance with present situation analysis, the coastal flood defences in Vietnam is not strong enough to withstand the actual sea boundary condition and ensure the safety for protected areas in views of present socio-economic development. In the last years annual economic damages of Vietnam due to floods and typhoons is estimated 1.0 to 1.2 % of its GDP. This loss often associates with the human life, environmental, cultural and further intangible values which are difficult to quantify. Methods are critically reviewed, developed and explored on how to deal with this problem and how to include them in a risk analysis of coastal and fluvial floods. Furthermore, investigation of accepted risks in the coastal and fluvial flood-prone areas is made to answer the question if safe is safe enough and to determine the acceptable risk levels. Application of the methods is made to define the optimal safety standard for the case study. As part of knowledge transfers, the analysis results could contribute to fundamental base for long-term planning rehabilitation of the sea defences in Vietnam.

1 INTRODUCTION

In the low-lying coastal regions where inland elevations are lower than high sea water levels, coastal flood defence systems are important to protect the low-lying hinterland from sea flood. Typically, the system contains sea dikes, dunes, estuarine river levees, dams, sluices, etc. In principle, failure of any element will lead to flooding of the polders and may cause serious consequences. In order to have a better design solution over the recent years, considerable effort has been devoted to improving the knowledge of how to design the defence system to protect the low-lying region safely. Risk based design, with acceptable risk as the basic criteria for design, appears as a useful approach by considering the balance of the potential risk due to flooding and the characteristic value of the defence system and has been widely applied in the fields of water defences (Dantzig 1956, Vrijling *et al.* 1995).

Acceptable risk is strongly related with the acceptable probability of failure and the acceptable amount of losses. There is general agreement in the literature and in regulatory circles that risk should at least be judged from two points of view in relation to inundation consequences. The first point of view concerns the risk assessment by society on a national level which relates to the number of casualties due to a certain hazardous event. Risk is defined as "*the relation between frequency and the number of people suffering from a specified level of harm in a given population from the realisation of specified hazards*". If the specified level of harm is limited to loss of life, the societal risk may be modelled by the frequency of exceedance curve of the number of deaths, FN-curve. Secondly, the acceptable level of risk can be formulated in a view of economic cost-benefit. Basically, the total costs of a system are determined by the sum of the expenditure for a safer system and the expected value of the losses. The acceptable risk level can be estimated by comparing the cost of protection to a characteristic value of the consequences of flooding.

Coastal- and fluvial floods have a large impact on not only economic value of the area, but also human life and environmental, cultural and further intangible aspects. How the public perceives the seriousness of different environmental or cultural problems is very difficult to measure.

In this paper methods are critically reviewed, developed and explored on how to deal with this problem and how to include them in a risk analysis of coastal- and fluvial floods. An investigation of accepted risks in the coastal and fluvial flood-prone areas is made to answer the question if safe is safe enough and to define the acceptable risk levels. A risk-based approach in defining optimal safety levels of water defence system is developed. Application is made to define the optimal safety standard for a case of coastal flood defences in Nam Dinh province, Vietnam.

2 COASTAL FLOOD DEFENCE IN VIETNAM

Vietnam lies in a tropical monsoon climate region that has a long coastline along the South China Sea that is regularly substantial suffering due to floods and typhoons. Typhoons arrive on average 4 to 6 times per year at the Vietnam coast. The deltaic coastal areas to a distance of about 20 km behind, which are protected by the 2000 km of sea dikes, is threatened by storm surges and high tides from the sea and high water level from the rivers. Thus, water defences are crucially important to protect the country from flooding.

The applied design safety levels of sea dikes are relatively low. This was also noticed in 1996 after the visit of Dutch expertise missions (DWW/RWS, 1996). Most designs of the sea dikes in Vietnam are based on the sea loads with return period 20 years. Besides this fact the Dutch mission marked that most Vietnamese dikes were in poor and disputable conditions (DWW/RWS, 1996). Consequently, the true probability of failure of the Vietnamese sea flood defense system exceeds by far the design frequency (Mai *et al.*, 2006, 2007). Although designed to fail once in 20 years the sea defense system might well fail almost every year. The experiences in the past years support this statement.

Since 1953, Vietnam was affected by numbers of flood disasters, each disaster responsible for the loss of hundreds of lives and considerable damage to infrastructure, crops, rice paddy, fishing boats and trawlers, houses, schools, hospitals, etc... The total material damage of the flood disasters over last 60 years exceeded \$ US 7.5 billion. Additionally, floods and storms caused the loss of more than 20,000 lives (ADRC, 2006 & DDMFC, 2007).

Currently, the design guidelines for sea dikes, named 14TCN-130-2002, are used for all sea dike design in Vietnam. In this guidelines the design water level comprises of two components of i) sea water level of 5% exceedence frequency (1/20 year return period) of occurrence of tidal levels, and ii) storm surge heights cause by the design storm which corresponds to the wind speeds at the Beauford scale 9 to 10. The storm surge heights in dike design were fixed in the code by specific values. Arbitrary selection of 5% tidal level and artificial treating storm surge level and tidal level as two independent components does not reflect well the physic of total water level due to typhoon occurrence. In addition, selection of the design storms does not properly reflect statistical sense with no associating by any frequency of occurrence. Therefore, the safety level in the design guidelines only explicitly refers to a 1/20 year return period of the tidal level; it does not statistically count for extreme events i.e. typhoons.

The improvement of this situation calls for the use of present available knowledge on all levels. Vietnam has profound practical experience in the field of flood protection, however, the theoretical knowledge in the fields of dike design, reliability and safety approach, risk analysis, policy analysis, statistics in relation to boundary conditions and mathematical modeling is not up to date. Therefore, the transfer of this knowledge was strongly recommended (DWW/RWS, 1996; Vrijling *et al.*, 2000; Mai *et al.*, 2006).

3 RISK ANALYSIS AND RISK BASED DESIGN

Risk can be defined as the probability of a disaster, e.g. a flood, related to the consequences (usually the multiplication of both variables), see CUR/TAW 1990. The idea of acceptable risk for different regions/countries may be influenced by a single spectacular accident or incident like 1953 flood disaster in the Netherlands; tsunami disaster 2004 in Asia; Katrina in New Orleans, USA 2005; Typhoon Damrey in Vietnam 2005; and large flooding in Bangladesh 2007. These unwanted events could be starting/ turning points of any new safety policy establishment for the countries.

As mentioned in section 1, the acceptance of risk in a public view should be studied from two different points of view in relation to the estimation of the consequences: societal and economic risks.

3.1 *Societal risk*

Societal risk concerns the risk assessment by society on a national level related to the number of casualties due to a certain hazardous event (Vrijling *et al.*, 1998). The societal risk can be modelled by the frequency of exceedance curve of the number of fatalities, a FN-curve. The FN curve can be described on a double logarithmic scale in the following form (Jonkman, 2007).

$$1 - F_N(x) = P(N > x) = \int_x^{\infty} f_N(x) \cdot dx \tag{1}$$

Where: $f_n(x)$the probability density function (pdf) of the number of fatalities per year; $F_N(x)$probability distribution function of the number of fatalities per year, signifying the probability of fewer than x fatalities per year.

Vrijling *et al.* (1998) notes that the societal risk should be judged on a national level by limiting the total number of casualties in a given year. The total number of casualties is tested against the norm of $\beta_i^* MF$ by the following form:

$$E(N_{di}) + k * \sigma(N_{di}) < \beta_i * MF \tag{2}$$

The multiplication factor *MF* is country-specific and based on: the value of the minimum death rate of the population, the ratio of the involuntary accident death rate (exclusive diseases) with the minimum death rate, the number of hazardous activities in a country (on average about 20 sectors) and the size of population. In Mai Van *et al.* (2008) the multiple factor was determined, *MF*=550, for the Vietnam situation. This value is reasonable while comparing to that of Netherlands (MF_{NL} = 100), and of South Africa (MF_{SA} = 750) by van Gelder *et al.* (2004). Therefore, the norm for Vietnam situation can be set at β*550 and used for all successive calculations.

3.2 *Economic approach in determination of acceptable risk*

In this approach, the total costs of a system (C_{tot}) are determined by the sum of the expenditure for a safer system ($I_{\Delta H}$) and the expected value of the maintenance cost M and the expected economic damage D (van Dantzig, 1956). The total cost of the system with dike heightening ΔH is:

$$C_{tot}(H_0, \Delta H_{P_f}, P_f) = \left[I_0 + I_{\Delta H_{P_f}} + PV(M + P_f * D) \right] \quad (3)$$

Where: P_f is probability of failure per year; M is yearly expected maintenance cost; D is expected damage in case of flood, this can be determined from FD-curve, an exceedance frequency of the economic damage; r is real effective rate of interest; T is planning period, in years.

The optimal level of safety indicated by P_{f-opt} corresponds to the point of minimal cost.

4 DESCRIPTION OF THE CASE STUDY

Nam Dinh coastal zone is protected by 70 km of sea dikes. The dikes system has been constructed on the basis of sea load with 20 year return period. However, the true probability of failure of the Nam Dinh defense system is 0.78 per year (Mai *et al*. 2007). This exceeds by far the design frequency and reflects that failure of the dike system occurs almost every year.

Typhoon Damrey occurred in September 2005 and hitted the Nam Dinh coasts caused approximately more that 8 km of sea dike breaches. Total direct loss of the effected region is over 500 million USD (DMWG 2005).

In attempt to rehabilitate the sea dike system in a long run, a huge sea dikes program has been established by the Ministry of Agriculture and Rural Development (MARD). One of the main tasks of the program is assessment of the present situation of the sea defence regarding safety aspect and establishment of new safety standards for protecting the coastal regions. Coastal flood defence system of Nam Dinh province was selected as a pilot location for implementation of the new sea dikes. In 2005 several dikes sections were constructed closure of breaches. However, these dikes is still based on existing safety standards (with adopted design frequency of 1/20 year), which is known as out of date. It is necessary to check the current safety of the new constructed dike system in Nam Dinh to see if the current rehabilitation works provide enough safety for the protected region. If not, to which level of protect the system should be designed.

5 ACCEPTABLE RISK IN VIETNAM

5.1 *Individual risk due to flood in Vietnam*

The individual risk for coastal flooding, IRflood, in Vietnam can be estimated by:

$$IR_{flood} = p_{f-flood} * p_{d/F-flood} \quad (4)$$

Where:

– $p_{f-flood}$ is actual probability of inundation.

In Vietnam the existing coastal flood defences are required to meet 1/20 year design safety standard. Therefore, the inundation probability can be taken as 0.05 per year.

– $p_{d/F-flood}$ is conditional probability which mean that probability that an individual who lives in the protected coastal region would be killed given occurrence of the sea flood.

In general the conditional probability depends on various factors namely e.g: Type of floods: predictable or unpredictable; Warning time before flood occurring; Effectiveness of evacuation; Possible shelters/ degree of exposure to flood, etc.

Regarding these above aspects in estimating the conditional probability, since there is hardly any information e.g in form of report or written paper available in Vietnam it is suggested to base the estimation on expert opinions and past experiences of coastal flooding in Vietnam. The following information has been collected by means of meetings and/or remote communication with Vietnamese experts who have much knowledge on coastal flooding in Vietnam and other subject-matter experts in the Netherlands.

The Vietnamese coast is hit (almost) every year by typhoons. Therefore the populations in coastal areas are relatively well aware and prepared. It is expected that this will lead to high evacuation percentages (93–98%). Given the relatively limited size of the flooded areas there are good opportunities to evacuate or find shelter within the area. The exposed rate in this case can be taken as 5% of the total population in the affected area.

In addition to that, in many coastal areas the more severe and deep flooding is limited to the area very near the coast (over 1 to 3 km, depths can reach 1 to 3 m). Areas further away from the coast may effected by flooding but generally with limited depth (<1m).

Jonkman (2007) has shown that the mortality due to these events is generally around 1%. This research was based on of historical information of coastal floods in the Netherlands, U.K, U.S and Bangladesh. This "1% -rule of thumb" was considered relatively high for flood events along the Vietnamese coast. A value of 0.2% is proposed in Jonkman 2009 for Vietnam based on discussions with Vietnamese experts. In previous section, based on the historical data of loss of life and total number of effected people due to storm induced flood of the coastal regions in the last century (ADRC 2006) the rate is estimated approximately of 0.3%. This means that 0.3% of the exposed population will not survive.

The conditional probability then can be determined by:

$p_{d/F-flood} = p(\text{exposure})^* p(\text{decease when exposure}) = (0.05 \div 0.1)^* 3.10^{-3} = (1.5 \div 3)^* 10^{-4}$

Substitutes $p_{f-flood}$ and $p_{d/F-flood}$ to (4) the individual risk due to flooding in Vietnam is approximately 10^{-5}. Referring this IR value to the individual risk criteria (Eq. 6–1), the policy factor for flooding in Vietnam becomes 0.1. Comparing IR_{flood} to individual risk due to traffic accident ($IR_{traffic} = 1.45 \times 10^{-4}$

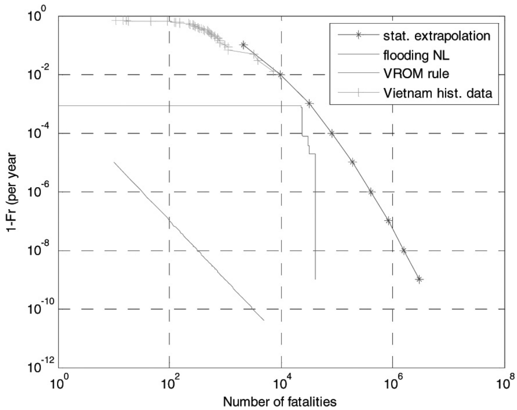

Figure 1. Vietnam flood FN-curve.

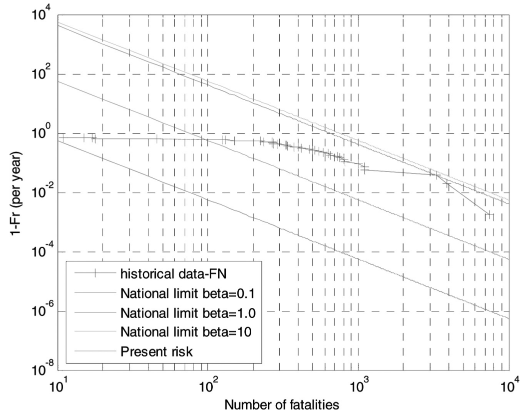

Figure 2. Societal risk criteria for vietnam.

per year, see also Mai Van et al. 2008), the risk due to flood is lower and a factor of approximately 10 is found.

5.2 *Societal risk for flooding in Vietnam*

The FN-curve due to flooding on a national scale of Vietnam are in Fig. 1 (Mai Van *et al.* 2008). It is noted that these curves were established on the basis of historical loss information in terms of economic damages and human lives due to all-cause-flood events of Vietnam in the last century. The most important and reliable source of information used in these analysis is the top 25 flood disasters of Vietnam in the 20th century, which currently available in the report of Asian Disaster Reduction Centre (ADRC, 2006).

The FN-curve has the shape which is best modeled by exponential distribution with a shape parameter $\alpha = 728$ fat/year (Fig. 1). The FD-curve has lognormal shape with $\mu = 1108$ and $sigma = 309.5$ million USD.

The societal risk at national level can be limited by:

$$1 - F_{N_d}(x) < \frac{C_N}{x^n} \quad \text{with } C_N = \left[\frac{\beta \bullet MF}{k \bullet \sqrt{N_A}}\right]^2 \tag{5}$$

k	Total risk
1	2060.8
2	3382.8
3	4704.8

Where C_N is the position constant and N_A takes into account number of independent places where a considered hazardous may take place in a country. Regarding flooding in Vietnam, number of independent places $N_A = 6$ on a national scale is supposed as similar as independent climate zones, in which each zone is characterized on the basis of similarity of natural conditions (e.g weather characteristics, topographical feature, frequency of storms and typhoons landing and flooding characteristics and frequency) and has a size approximately as large as the size of a typhoon affected area.

Inspection of the FN-curve and limit lines in Fig. 2 the following points can be drawn:

Flood risk is completely unaccepted by the national limit in accordance with the policy factor $\beta = 0.1$ (characteristic for an involuntary activity with some benefit: IR$= 10^{-5}$ per year), which is found for individual risk due to flood in Vietnam in Section 5.1. The limit line corresponds to the constant value of $C_N = 56$.

A flood event which would claim less than 100 fatalities is accepted with the limit in accordance with the policy factor taken a value of 1.0, which is similar to acceptable risk limit for traffic accidents.

With the policy factor $\beta = 10$ the limit line lies above the FN-curve. This means that flooding in Vietnam is acceptable if flood accident is viewed as similar as a voluntary activity with direct benefit. This might be true only for some specific rural areas in the low-lying Mekong river delta where floating house are popular and annual flood brings fertilizing rice fields.

Total societal risk at national scale for Vietnam in case of k=3 gives $\beta = 8.6$. The limit line in this case expresses the present risk due to flooding in Vietnam. The actual flood risks would be acceptable for a limit line that corresponds to $C_N \cong 5.10^5$.

5.3 *Potential loss of life estimation for Nam Dinh*

An important input for establishment of individual and societal acceptable risk of an activity is the number of fatalities due to the activity. In flood risk analysis the number of fatalities due to flood can be based on collecting of historical data on loss of life which associated historical flood events of the interested area. This way is not always possible as the data is not often available.

Another way for estimation of potential loss of life is based on flooding characteristics (depth, velocity, duration etc.), flooded area and the characteristics of the effected area (number of inhabitants, emergency evacuation, etc.). In Jonkman (2007) a general method has been developed for the estimation of loss of life due to flooding of low-lying areas. The estimation of loss of life due to a flood event includes the following steps:

- Estimation of the flooded area and flooding characteristics (depth, velocity, etc.)
- Estimation of the number of inhabitants in the flooded area (N_{PAR}) and the effects of evacuation and shelter % (F_E).
- Estimation of mortality in flooded area (F_D) (mortality refers to the fraction or percentage of the exposed population that does not survive the disaster).

An estimate of loss of life for an event can be given by:

$$N = F_D(1 - F_E).N_{PAR} \tag{6}$$

It is noted that the mortality fraction is generally modeled dependent on flood characteristics, such as water depth, flow velocity and rise rate.

There are two ways of mortality estimation which are often used in practice i.e. i) a general overall average mortality estimate; ii) a average depth-dependent mortality function.

The first approximation can be used if no information on local flood depths and flooded areas is available to come to a rapid first order estimate of the overall mortality and loss of life. The second approach is more suitable when information on the local flood depths and their variability throughout the affected area is available. In general the second approach is used in combination with flood (depth) maps for an area.

In this paper due to lack of information, the first approach is applied as a first estimate of potential loss of life. Based on the historical data on loss of life and total number of effected people due to storm induced flood of the coastal regions in the last century (ADRC 2006) the overall average mortality rate is determined approximately of 0.3%. For Nam Dinh coastal region there approximately 41 fatalities are estimated due to occurrence of the sea flood.

In application of the second approach we consider four different scenarios of flooding events by means of different return periods. Each scenario associates with its certain flooding water level corresponding to the return period of the event. This leads to different in expected flood depths and, as consequence, the potential loss of life also differs by scenarios. Base on scenario analysis the FN-curve for Nam Dinh is found (see Fig. 3). With present situation of flood defences, the inundation probability is in range of 0.1 to 0.15 (6–10 years return periods) and the potential loss of life due to sea flood in Nam Dinh is expected at 41 fatalities.

5.4 *Acceptable risk due to flood for Nam Dinh*

FN-curve of Nam Dinh shows that a flood event occurs with 100 year return period would claim less than 100 fatalities. More extreme event e.g. 1000 year return period would lead to a loss of hundred to thousand people.

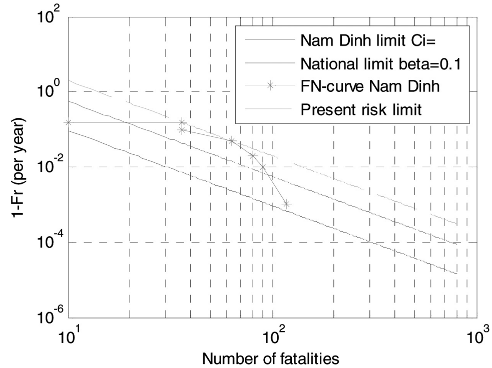

Figure 3. FN curve and limit lines for flooding in nam dinh coastal zone (simulated data, loss of life as a function of flooded depth and mortality).

Based on the probabilities and fatality numbers for the selected scenarios, the expected number of fatalities can be determined. This yields: E(N) = 9.4 fat/yr. The standard deviation equals: STD.(N) = 16.5 fat/yr. For this type of small probability, large consequence event the expected number of fatalities per year is generally relatively small. However, for this types of event the number of fatalities in one single event can be large, resulting in a large standard deviation of the number of fatalities.

In Section 5.2 the acceptable risk at a national scale for Vietnam is limited by means of Eq. 6 where the constant C_N, vertical position of the limit line, takes a value of $C_N = 56$ with the value of $\beta = 0.1$. The national limit line is represented in Figure. We can see that the societal risk for flooding in Nam Dinh coastal region exceeded and unacceptable according to the national limit for event which has exceedance frequency is smaller that pf = 0.007 (corresponding to return period of 145 years).

To obtain a risk limit for Nam Dinh coastal regions (considering as one installation), the nationally acceptable risk has to be distributed over the all installations/places in one country. For a single installation a risk limit can be applied that has the same format as Eq. 5, but the constant C_i is used instead of C_N to indicate the vertical position of the limit line for one installation, and for a certain type of activity the constant C_i must be smaller than C_N. In deriving the value of C_i, it seems reasonable to distribute the nationally acceptable risk over places according to the relative size of a place at a national scale.

In Jonkman et al. 2009 distribution of the national acceptable risk over places is done according to the relative population size of a place at a national scale. In Vietnam, approximately 70% of population (approximately 56 million people) is susceptible to flooding and live in flood-prone areas and approximately 1 million of these people live in Nam Dinh low-lying areas. The relative flood affected population size of Nam

Dinh and whole Vietnam would be approximately 1/56 times. This would imply that the value of the constant that determines the vertical height of the limit line for the dike ring (C_i) would be 1/56 times of the constant that has been derived for the national scale (C_N). This leads to $C_i = 1$ for Nam Dinh. The risk limit line for Nam Dinh by means of Eq. 6 where the constant $C_i = 1$ and the value of $\beta = 0.1$ is shown in Fig. 5. Results show that the flood risks for Nam Dinh would be unacceptable for this value of Ci. The actual flood risks would be considered acceptable for a limit line that corresponds to $C_i = 198$. It is clear that the societal risk for flooding in Nam Dinh coastal region exceeded and unacceptable according to the limit for any event that has exceedance frequency of smaller than $p_f = 1.1 \times 10^{-3}$ (corresponding to return period of 1200 years). This means flood risk is acceptable if the low lying coastal region of Nam Dinh is protected under a safety standard of less than 1/1100 per year.

6 ECONOMIC RISK BASED DESIGN

Based on design documents and expense reports of existing Nam Dinh sea dikes given by DDMFC/MARD 2005 and taken into account the actual inflation rates of Vietnam, the costs of dike heightening are estimated in Mai Van *et al.* (2008).

Sea water level and required dike height
Sea water levels along the Vietnamese coasts are measured at several stations. These water levels comprise already tidal and storm surge components and all other causes induced water level rising. Therefore, these are considered as the total sea water levels which are used for design of sea defences. For sea defences of Nam Dinh coastal region the water data from station Phu Le is used.

Based on the observed water level data at Phu Le station, water level along the Nam Dinh Coast is best fitted modeling by a mixed Gamma and Exponential distributions. In the frequency domain of interest for the design purpose of the sea flood defences (0.1 to 10^{-5}) the tail of exceedance frequency curve is best modeled by exponential distribution:

$$h = -28.8 * \ln\left(P_{fr}\right) + 339.99 \quad \text{with a domain}: P_{fr} \leq 10^{-1} \tag{7}$$

Where: h (cm) is the sea water level in cm; P_{fr} (per year) is annual exceedance frequency of corresponding sea water level h.

The required crest level of the sea dike is generally followed by:

$$Z_d = DWL + R_c \tag{8}$$

Where: *DWL* is called design water level, this is the all-cause-induced maximum sea water and depends on the specified design condition with regarding the design frequency of design return period. In this case, *DWL* can be determined from the water level exceedance frequency curve Eq. 8.

R_c is the required crest freeboard height, which can be determined from wave overtopping condition of 10 litter/m/s.

The required dike heights are calculated with different design conditions which associate with different design frequencies. A linear relation is found between the required dike height and the design frequency in logarithms scale (Fig. 4).

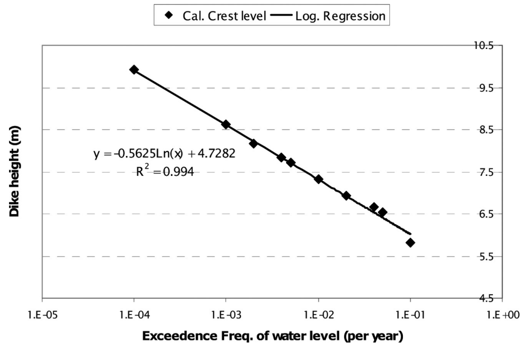

Figure 4. The required dike height in relation to exceedance frequency of sea water level.

Economic optimal safety for Nam Dinh sea dikes
Two situations are considered in economic risk analysis of Nam Dinh coastal flood defences.

Situation 1: current situation: Considering the actual economic wealth presents in the region and taking into account the actual effective economic growth rate of the region: $r' = r - i = 3.0\%$.

Situation 2: fast economic growth situation: Considering the actual economic wealth presents in the region plus the future wealth incensement as the result of fast development. The effective economic growth rate of the region is assumed at 6.5%.

Economic risk analysis is implemented for the whole coastal regions of Nam Dinh with these two above situations and by considering difference cases. Case 1: Nam Dinh sea defence system as a whole dike ring, with total length of the sea defences is 70 km; Case 2: considered coastal region of Nam Dinh consists of three independent protected areas which are administratively divided by three districts and protected by its own independent dike ring with its certain length: Giao Thuy system, Hai Hau system and Nghia Hung system.

Determination of potential economic risk:
The expected damages is determined based on a adjusted mean and standard deviation from FD-curve, $E(D) = \mu + k^*\sigma$, for Nam Dinh. Where the adjusted expected total economic loss/damage for Nam Dinh is: $D_{average} = 1108/(4 \div 6$ storm events per year $= 184 \div 277$ million USD/year.

Based on statistics of economic losses due to sea flood in the last recent years happened at the Nam Dinh coastal regions, especially the loss due to Damrey typhoon which occurred in 2005, the direct economic

Table 1. Economic loss due to coastal flood in Nam Dinh.

District	economic loss in million USD Situation 1	Situation 2	Length km
Giao Thuy	67.3	107.0	27.0
Hai Hau	61.1	97.8	27.0
Nghia Hung	42.8	73.4	16.0
Nam Dinh (total)	171.2	278.2	70.0

Table 2. Optimal safety for nam dinh coastal regions.

	Dike ring	Optimal safety Situation 1	Situation 2
Case 2	Giao Thuy district	1/45	1/95
	Hai Hau district	1/35	1/55
	Nghia Hung district	1/50	1/90
Case 1	Nam Dinh	1/50	1/100

loss for coastal districts of Nam Dinh is estimated. Considered a fast economic growth situation in the future, the potential economic loss for the considered regions can be determined. Loss estimates for both situations are in Table 1 (see also Hillen 2008 and Mai Van *et al.* 2008).

Summary result: Summary of the analysis results are in Table 2 and Figs 5a and b;

Sensitivity analysis

The value of potential loss which has been used in the above analysis are considered as an average estimated mean value of the direct economic loss. These often associate with uncertainty due to uncertain in the social, economic situations, future development of the considered area as well as the uncertainty of the sea boundary condition. If these uncertainties are taking into account somehow, the expected loss would be differed. It is suggested determining by:

$$\mathrm{E(D)} = \mu + \mathbf{k}^{*}\sigma \qquad (10)$$

Where: μ is the estimated loss from Table 2; σ is standard deviation, is determined from the FD-curve; and k is a multiple factor.

By different values of k (from 1 to 3) it clearly shows that the optimal level of safety is in range of 1/95 to 1/45 years for situation 1 (see Fig. 5a) and from 1/90 to 1/100 for situation 2 (see Fig. 5b).

Sensitivity analysis can also be done for a wider range of economic risk due to flood. Figure 6 presents contour lines of the total costs, as sum of investment cost in the defence system and the economic risk of the system, in relation to economic risk and exceedance frequency of the corresponding flood events. Contour line Zero expresses a set of the optimal solution while the total cost of the system is minimum. For Nam Dinh case the potential economic loss would be in range of less than 500 million USD, the optimal safety

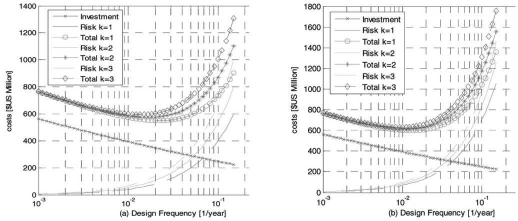

Figure 5. Optimal safety with k values of 1, 2 and 3.

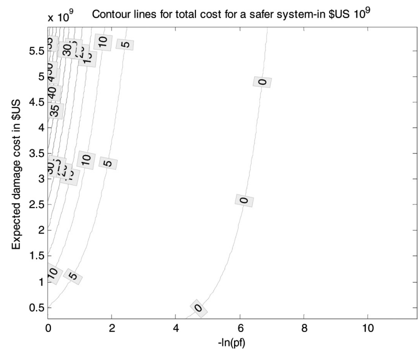

Figure 6. Contour lines of total costs of the system.

can be chosen from 1/50 to 1/100 as the *ln(Pf),* in the horizontal axis, takes value in range of 4.0 to 4.5

7 DISCUSSIONS

Economic risk analysis while considering the Nam Dinh coastal flood defences as a whole dike ring shows that the safety standard of 1/50 years or more should be applied for the present economic situation (Situation 1). While taking into account the fast economic growth and accumulated wealth in the future the safety standard of 1/100 or more should be chosen.

Regarding the present situation of Nam Dinh coastal regions, a supplementary design for a return period 100 years might turn out to be an even better choice since double safety level is archived with relatively small increment of investment cost. In addition, this return period is inline well with analysis result from the fast economic development situation (Situation 2).

When using economic risk based curves in decision making it should be note that the chosen solutions should never be on the right side of the interaction point between the risk and investment curves. Because, from the economic investment point of view, the solution is not worth as the risk is higher than the cost of the system. In this considered example for Nam Dinh case, selection of the design return periods of less than 30 years leads to very high risk and is therefore a bad choice in this situation. Selection from 50 to 100 years return period is, therefore, recommended for the future planning of coastal protection in Nam Dinh. Invest nothing, dike height remains at 5.5 m with annual failure probability of the Nam Dinh dike system is 0.78, may lead to an economic risk of over $ US million 500, which is similar to the total direct loss due to the typhoon Damrey in 2005.

8 CONCLUSIONS

Societal risk analysis for flooding on a national scale for Vietnam based on historical flood information shows that Vietnam should apply a safety standard of 1/100÷1/1000 to protect the country from flooding.

Potential loss of life due to flood is preliminary estimated in this study based on the actual information. The coastal flood defence in Nam Dinh should be upgraded to ensure that the inundation probability is less than 1/145 per year, in order to satisfy the individual and societal acceptable risk.

Economic risk analysis showed that the actual safety standards in design of coastal flood defences of the Vietnamese case study (1/20 years) are not safe enough in views of the current Vietnamese development. An optimal choice of the acceptable risk level was found at a return period of 100 years. This is in good agreement with the upper bound of the societal acceptable risk level of Vietnam.

Sensitivity analysis in estimation of expected damages shows that by different k values ranging from 1 to 3 it does not give significant influence on the optimal point. These risk curves have a converged tendency when return period increases.

REFERENCES

ADRC-Asian Disaster Reduction Centre 2006. Top 25th natural disasters of Vietnam in 20th Century.

CUR/TAW 1990. Probabilistic design of flood defences. Report 141, Gouda, Netherlands.

DDMFC-Department of Dikes Management and Flood Control of Vietnam. 2007. Flood damage reports.

Disaster Management Working Group (DMWG) 2005-Joint Assessment of Disaster and needs 2005. Rapid Needs Assessment of typhoon Damrey.

DWW/RWS, Ministry of transport, public works and water management, Rijkswaterstaat 1996a. Sea dikes northern part of Viet Nam (Red River Delta). Review report, The Netherlands, May 1996.

DWW/RWS, Ministry of transport, public works and water management, Rijkswaterstaat 1996b. Flood control in Viet Nam, Red River Delta Area, mission report, The Netherlands, October 1996.

Jonkman, S.N., 2007. Loss of Life estimation in flood risk assessment: Theory and applications. Phd-thesis, TUDelft, 2007, ISBN: 978-90-9021950-9.

Jonkman, S.N., 2009. Mission report. Technical assistants for Vietnam sea dikes research program. TUDelft, March 2009.

Mai Van, C., van Gelder, P.H.A.J.M. and Vrijling, J. K. 2006. Safety of coastal defences and flood risk analysis. Safety and Reliability for Managing Risk, ISBN 13: 978-0-415-41620-7, Taylor & Francis/Balkema, Leiden, The Netherlands, Vol. 2, pp: 1355–1366.

Mai Van, C., Van Gelder, P.H.A.J.M. & Vrijling, J.K. 2007. Failure Mechanisms of Sea dikes: inventory and sensitivity analysis. In: Proceedings of the Coastal Structures 2007- COPRI of ASCE, CORILA Venezia.

Mai Van, C., van Gelder, P.H.A.J.M., Vrijling J.K. & Mai, TC (2008). Risk analysis of coastal flood defences – A Vietnam case. Proceedings of the 4th international symposium on flood defence; managing flood risk, reliability & vulnerability (Pp. 93-1-93-8). Toronto: Institute for catastrophic loss reduction.

TAW-Technical Advisory Committee on Water Defences 1985. Some considerations of an acceptable level of risk in the Netherlands.

Van Dantzig, V.D. 1956. Economic decision problems for flood prevention. Econometrica 24.

Van Gelder, P.H.A.J.M. and Ouwerkerk, S.J. 2004. Risk acceptance and perception. In: New model in survival analaysis related to AIDS, final report, SANPAD project 2004.

Vrijling, J.K., van Hengel, W. and Houben, R. J. 1995. A framework for risk evaluation, Journal of Hazardous Materials. Vol. 43, Issue 3, pp. 245–261.

Vrijling, J.K., van Hengel, W. and Houben, R. J. 1998. Acceptable risk as a basic for design. Journal of Reliability Engineering and System Safety, pp. 141–150. Elsevier.

Vrijling,J.K. and Hauer, M. 2000. Probabilistic design and risk analysis of water defences in relations to Vietnamese condition. Mission report, Delft University of Technology.