Risk based approach for safety standard of coastal flood defences in Vietnam

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Abstract: This paper focuses on risk analysis and safety aspects of coastal flood defences in Vietnam. The sea dike system has been actually designed by a 20 to 25 years return period. From the current situation it seems that the dike system is not sufficient to withstand the actual sea boundary condition. As present situation the total annually economic damages of Vietnam due to floods and typhoons is about 1.0 to 1.2 % of its GDP. Accurate safety assessment of the existing coastal defence system is, therefore, of large importance. It can quantify the possible consequences after failure of the defensive system, the loss of life, economic, environmental, cultural losses and further intangibles. To determine if safe is safe enough, an investigation is carried out in this paper to determine other types of risks to which the local population is exposed, apart from the flood risk. The issues addressed in this paper may support decision-maker to find the optimal protection levels of the coastal regions and for a long term planning of rehabilitation of the coastal flood defences in Vietnam.

1. Introduction

1.1 Backgrounds

A coastal flood defence system may comprise various elements i.e sea dike sections, estuarine dike sections, dunes, sea walls, dike crossing structures and discharged structures. The system is designed to protect low-lying coastal zone from sea floods by a certain safety level which is written in the codes.

Main interests are what is the actual safety of the protected areas and if safe is safe enough. The first question is answered by quantification of probability that the protected areas are inundated or, in other word, the probability that the system failure occurs. Answer for the later issue can be given by determination of acceptable risk level for the protected regions.

The inundated (failure) probability can be quantified accurately by probabilistic design method. This approach has been increasingly proposed, applied and developed in the fields of civil engineering during the last decades (see e.g. the concepts, methods and applications in Rackwitz 1977; Ditlevsen 1979; Bakker & Vrijling 1980; Vrijling et al. 1998; van Gelder 1999; Oumeraci et al. 2001; and Voortman 2002). Fundamental advantages of probabilistic design approach are that it is based on an acceptable frequency of failure of the considered system; take into account the uncertainties of the input parameters and treat them as the random variables; describe failure of the structures by various possible failure modes; and find a true probability of failure of the whole system based on failure probability of system components. Therefore the safety level of a structured system is explicitly known.

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1.2 Motivation and study approach

Vietnam lie in a tropical monsoon climate region has a long coastline along the South China Sea that is regularly substantial suffering due to floods and typhoons. The most severe floods occur during high river discharges and during, and shortly after, typhoons. Typhoons arrive on average 4 to 6 times per year at the Viet Nam coast. The typhoons generate storm surges and waves, both attacking severely the sea dikes along the coast. The typhoons are accompanied by torrential rains causing flash floods which regularly submerge low-lying areas. These rains, when added to rivers already swollen because of the monsoon rains, create floods which endanger river dikes and threaten millions of households. The deltaic coastal area to a distance of about 20 km behind the sea dikes is threatened in particular because of the combined occurrence of storm surge from the sea and high river discharge.

As a result of the severe sea loads and the rather low safety level of the present dikes, the water defense system of Viet Nam fails regularly. Since 1953, Viet Nam 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). The most severe storms and floods induced disasters occurred in North Viet Nam in 1971, 1996 and 2005; in the South in 1997; and in the Central in 1964 and 1998. Mostly, these events were initiated by typhoons which attacked the coastal zones then, additionally, accompanied by heavy monsoon rains inland.

The relatively low safety level of the sea dikes in Vietnam was noticed in 1996 during two visits of Dutch expertise missions (DWW/RWS 1996a,b). Most designs of the sea dikes in Vietnam are based on loads with return period 20 year or even shorter periods. Compared to the Dutch standard (return periods 1000 to 10000 year) these return periods are very small. Besides this fact the Dutch mission marked that most Vietnamese dikes were designs as poor and disputable (DWW/RWS 1996a,b). As a result the true probability of failure of the Vietnamese water defense system exceeds by far the design frequency (Mai Van et al. 2006, 2007). Although designed to fail once in 20 to 25 year the sea defense system might well fail almost every year. The experiences in the past 20 years support this statement.

Besides of these above imperfections in the designs, it should be noted that the adopted return periods are not based on proper statistic risk analysis. Often adopted return period 20 years is founded on a rather arbitrary basis. However, these arbitrary considerations already show a notion of the fact that the safety level of important, valuable areas should be enlarged compared to the safety level of less important areas (Vrijling et al. 2000). This system reflects logical results, which could have been obtained by common risk analysis. Future improvements of flood safety standards might build on the existence of this system. However, these improvements should be based on proper risk analysis of the areas under consideration.

The improvement of this situation calls for the use of present available knowledge on all levels. Viet Nam 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 modelling is not up to date. Therefore the transfer of this knowledge was strongly recommended (DWW/RWS 1996b; Vrijling et al. 2000; Mai Van et al. 2006). An additional important fact is the economic situation of Vietnam, just at the beginning of developing process, limiting the resources for improvement of the water defence system. On the other hand this situation asks for a more detailed and careful analysis to ensure that the limited resources are used in the optimal way which takes into account the developing characteristics (limited initial investment, fast economic growth, and cheap labor).

In this paper probabilistic risk-based methods are presented and critical reviewed. Acceptable risk levels are modeled and the risk based approach in determination of the optimal safety levels of water defence system is developed. First application is assessment of actual safety of the existing sea dikes in Vietnam. Second application is to find the optimal safety standards for the case of coastal flood defences in Vietnam. As part of knowledge transfers, the analysis result supports well long-term planning processes in rehabilitation of the sea defences in Vietnam.

2. Flood risk, Acceptable risk and risk measures

Risk is defined as the probability of a disaster, e.g. a flood, related to the consequences (usually the multiplication of both variables). 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; Damrey typhoon 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. Most probably society will look to the total damage caused by the occurrence of a flood. This comprises a number of casualties, material and economic damage as well as the loss of or harm to immaterial values like works of art and amenity.

From literature, the acceptance of risk should be studied from three different points of view in relation to the estimation of the consequences of flooding. The first point of view is the assessment by the individual. Attempts to model this are not feasible therefore it is proposed to look to the preferences revealed in the accident statistics. The probability of losing one's life in normal daily activities such as driving a car or working in a factory appears to be one or two orders of magnitude lower than the overall probability of dying. Only a purely voluntary activity such as mountaineering entails a higher risk (Vrijling et al. 1998). Second point of view concerns the risk assessment by society on a national level related to the number of casualties due to a certain activity by using a definition 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" (Vrijling et al. 1995). 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, called the FN-curve. On the other hand acceptable level of risk can also be formulated in a way of economically cost benefit analysis. The total costs in a system are determined by the sum of the expenditure for a safer system and the expected value of the economic damage. The acceptable risk measure can be estimated by comparing the cost of protection to a characteristic value of the consequences of flooding (DMWG 2005). The optimal level of economically acceptable risk, incorporates with an optimal level of safety, corresponds to the point of minimal total costs. The total potential economic damage that will be caused by a flood can be presented, in a similar way of FN-curve, by an exceedance frequency curve for damage, a so-called FD-curve.

2.1 Individual risk

The smallest-scale component of the social acceptance of risk is the personal cost-benefit assessment by the individual. It is defined as the probability that an average unprotected person, permanently present at a certain location, is killed due to an accident resulting from a hazardous activity. A general mathematical formulation of the personal risk acceptance (IR=Pdi) for a particular activity is (CUR/TAW 1990):

$$IR = P_{di} = \frac{N_{di}}{N_{pi}} = \frac{N_{pi} P_{fi} P_{d/Fi}}{Npi} = P_{fi} P_{d/Fi} \tag{1}$$

where: Npi number of participants to activity i; Ndi number of deaths with activity i; Pfi probability of accident with activity i; $P_{d/Fi}$ probability of a death given the occurrence of an accident.

Since attempts to model this appraisal procedure quantitatively are not feasible, Vrijling et al. (1998) proposed to look at the pattern of preferences revealed in the accident statistics. Statistics show that the actual personal risk levels connected to various activities show statistical stability over the years and are approximately equal for the Western countries indicates a consistent pattern of preferences. The probability of losing one's life in normal daily activities such as driving a car or working in a factory appears to be one or two orders of magnitude lower than the overall probability of dying. Only a purely voluntary activity such as mountaineering entails a higher risk.

In the Netherlands the measure of individual risk is used to limit the risks nearby hazardous installations and transport routes. The Dutch Ministry of Housing, Spatial planning and Environment (VROM) has set $IR < 10^{-6} \left(yr^{-1} \right)$. This standard is set for more or less involuntary imposed risks related to the sitting of hazardous activities. A broader set of risk standards ranging from voluntary activities to more involuntary risks is proposed by the Dutch Technical Advisory Committee on Water Defences (TAW 1985):

$$IR = P_{fi} P_{d/Fi} < \beta_i \cdot 10^{-4} \text{ (1/year)} \tag{2}$$

In this expression the value of the policy factor βi varies with the degree of voluntariness with which an activity i is undertaken and with the benefit perceived. It ranges from 100, in the case of complete freedom of choice like mountaineering (Pfi,= 0.1 = $100*10^{-4}/10^{-1}$) to 0.01 in the case of an imposed risk without any perceived direct benefit. Vrijling (1998) proposed a βi-value of 1.0 to 0.1 for flood risk.

2.2 Societal risk

The basis of the calculation of societal risk is formed by the probability density function (pdf) of the yearly number of fatalities. From the pdf an FN curve can be derived, which shows the probability of exceedance as a function of the number of fatalities, on a double logarithmic scale.

$$1 - F_N(x) = P(N > x) = \int_x^{\infty} f_N(x) \cdot dx \tag{3}$$

where fn(x) is the probability density function (pdf) of the number of fatalities per year; FN(x) is probability distribution function of the number of fatalities per year, signifying the probability of fewer than x fatalities per year.

VROM limits the societal risk at plant level by a line that is inversely proportional to the square of the number of deaths.

$$1 - F_N(x) < \frac{10^{-3}}{x^2} \quad \text{for all } x \geq 10 \tag{4}$$

where: F_{Ndij} = the c.d.f. of the number of deaths resulting from activity i in place j in one year

In Vrijling et al. (1995) determination of the total risk assumed that the accident statistics reflect the result of a social process of risk appraisal and that a standard can also be derived from them. In addition to that the total risk is considered also risk aversion in a society by adding the desired multiple k of the standard deviation to the mathematical expectation of the total number of deaths. The following formula was proposed:

$$TR = E(N) + k \cdot \sigma(N) \tag{5}$$

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 situation is tested against the norm of βi*MF casualties by the following form:

$$E(N_{di}) + k * \sigma(N_{di}) < \beta_i * MF \tag{6}$$

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 the population of the country.

The norm states that an activity is permissible as long as it is expected to claim fewer than βi*MF casualties per year. It is tested with k=3 and MF=100 for several activities in the Netherlands.

The translation of the nationally acceptable level of risk to a risk criterion for one single installation or plant by taking into account the number of independent installations NA where an activity takes place depends on the distribution type of the number of casualties for accidents of the activity under consideration. In order to relate the new local risk criterion to the common shape of a FN-curve the following type is preferred:

$$1 - F_{N_{dij}}(x) < \frac{C_i}{x^n} \quad \text{for all } x \geq 10 \text{ with } C_i = \left[\frac{\beta_i \bullet MF}{k \bullet \sqrt{N_{A_i}}} \right]^2 \tag{7}$$

where: x is the number of casualties in a year, FN(x) is the distribution function of the number of casualties (probability of less than x casualties in a year); C_i is a constant that determines the position of the limit line; n is steepness of the limit line, a standard with a steepness of n=1 is called risk neutral. If the steepness n=2, the standard is called risk averse (Jonkman, 2007). It can also be transformed mathematically into a VROM-type of rule applicable at plant level for a single installation. For values of βi = 0.03, k = 3 and NA = 1000 the rule equates exactly to the VROM-rule.

2.3 Economical approach in determination of acceptable risk

2.3.1 FD-Curve

The FD curve displays the probability of exceedance as a function of the economic damage. The FD curve and the expected value of the economic damage can be derived from the pdf of the economic damage fD(x):

$$1 - F_D(x) = P(D > x) = \int_x^{\infty} f_D(x) \cdot dx \text{ and} \quad (8)$$

$$E(D) = \int_0^{\infty} x \cdot f_D(x) \cdot dx \quad (9)$$

where: FD(x): the probability distribution function of the economic damage; E(D): expected value of the economic damage;

2.3.2 Economic optimization of acceptable risk measure

In the method of economic optimisation the total costs of a system (Ctot) are determined by summing up the investments (IΔH) for a safer system; the expected value of the maintenance cost M and the expected economic damage D (see also van Dantzig, 1956 for a fundamental approach). The total cost of the system with dike heightening ΔH is:

$$C_{tot}(H_0, \Delta H_{P_f}) = \left[I_{0,P_{f0}} + I_{\Delta H_{P_f}}(\Delta H_{P_f}) + PV(M) + PV(P_f * D) \right] \quad (10)$$

The optimal level of safety indicated by Pf-opt corresponds to the point of minimal cost:

$$\min(C_{tot}) = \min \left[I_{0,P_{f0}} + I_{\Delta H_{P_f}}(\Delta H_{P_f}) + PV(M) + PV(P_f * D) \right] \quad (11)$$

Cost of dike heightening in this study is accounted for: Cost of enlarging dike body (heightening the dike crest level which leads to increasing the cross section area (AΔH); additional cost of outer and inner slope protection due to increase of the protected length of the outer and inner slopes (Lout), (Lin); additional cost of crest protection; and additional cost of land area use for dikes (Wlanduse).
Therefore, the increment cost IΔH is determined by:

$$I_{\Delta H} = C_1.A_{\Delta H} + C_2.L_{out} + C_3.L_{in} + C_4.W_{landuse} + C_{Crest} \quad (12)$$

Where: Ci, with i=1:4, is the unit cost of different cost components, expressed in $US Million per geometrical unit of dike elements; CCrest: the unit cost of dike crest protection, in $US Million per 1 km.
The present value of the expected maintenance and damage costs are estimated by:

$$PV(M) = E(M) * \sum_{i=0}^{i=T} \frac{1}{(1+r)^i} \text{ and} \quad (13)$$

$$PV(P_f * D) = P_f * E(D) * \sum_{i=0}^{i=T} \frac{1}{(1+r)^i} \quad (14)$$

Where: Pf is probability of failure per year; E(M) is yearly expected maintenance cost;
E(D) is expected damage in case of flood; r is real effective rate of interest, T is planning period, in years.

3. Safety assessments

Following the probabilistic design method (Vrijling, 1980), safety assessment of Namdinh sea dike system is conducted. All possible failure mechanisms of dike sections are taken into account. Testing present dike system and different scenarios of dike improvement has been made. By using level III method Monte Carlo simulation the failure probability of possible failure modes and of the whole dike system is analysed and summarized as in Figure 1 (for more details on all calculations see Mai Van et al. 2006).

Study found that failure of sea dike in Hai Hau is mainly due to wave overtopping mode. It is clear that the existing dike system is unsafe, total failure probability of the system, which take into account also length effects, is nearly P_{f_sys}=0.78 per year (1/1.3 year), even though it was design for standard of 1/20 years ($P_{f\_sys}^{design}$=0.05). From Figure 3 in order to come up with the current existing standard of 1/20 year, the dikes should be heightened up to around 6.8 meters. Findings of this study is a good agreement with results of deterministic safety assessments and what have happened at the case study area during the last few decades, see also [5].

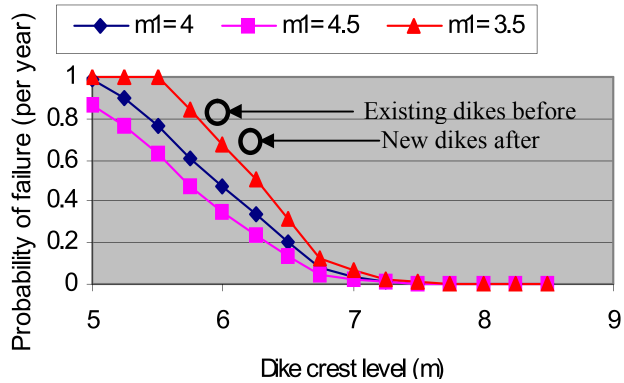


Figure 1: Reliability of the Vietnam sea dikes by different scenarios

4. Determination of acceptable riskS in Vietnam

4.1 Acceptable risk levels in Vietnam

To establish a norm for the acceptable level of risk for engineering structures in Vietnam it is proposed in this paper to base the answer on the probability of a death due to natural causes which is approximately equal to 1.3×10^{-5}/year.

The overall death rate in the Vietnam follows by the ratio of the total number of deaths in a year and the total population of the country (total yearly deaths of 526,150; total population of 85 million, based on CIA Factbook-online (2007). This gives the death rate $r=6.19 \cdot 10^{-3}$ per year. The multiplication factor for Vietnam (MFVN) can be calculated [19]:

$$MF_{VN} = \frac{1.3 \times 10^{-5} * 85 \times 10^{6}}{20} \cong 550 \tag{15}$$

This multiplication factor for Vietnam is reasonable if compared to that of Netherlands (MFNL=100) and the factor for South Africa (MFSA=750), based on calculations made by Van Gelder et al. (2004). Therefore, the norm for Vietnam situation can be selected at β*550. This norm is used for all later calculations.

4.2 Flood Risk in Vietnam

From the Department of Dike Management and Flood Control (DDMFC 2007) of Vietnam yearly fatalities and economic loss data due to floods and storms is collected. The data set is available from 1970 up to 2007.

Based on the online reports of the Asian Disaster Reduction Centre (ADRC 2006) the top 25 flood disasters of Vietnam in the 20th century are available. In which there are twenty events that were due to floods and storms. These events are considered as historical events and included in analysis. FN curve due to flooding for the whole country including historical events is presented in Figure 2. A lognormal curve with μ = 541 and sigma=1169.7 are found as the best-fit to the yearly fatality dataset.

In Figure 3, the FN curve for the flooding in Vietnam is compared to some other risks in the Netherlands. The figure shows that the risks of sea flooding in Vietnam are much higher than in the risk curves in the Netherlands. This could be due two reasons: (i) natural difference between Vietnam and the Netherlands, Vietnam has a relatively narrow low-lying coastal strip along the coast while in the Netherlands more than half of the country is below mean sea- and river level; and (ii) the fact that the Vietnamese population is more used to floods than most Western populations. Therefore the acceptance of personal risks in Vietnam might differ from the Netherlands.

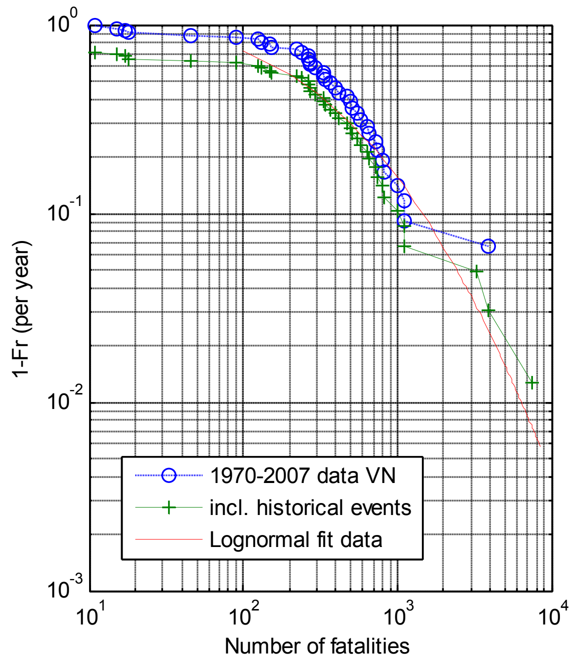


Figure 2: FN-curve due to flooding in Vietnam

In order to satisfy criteria by Eq. 9: $TR=E+k*\sigma< \beta*550$, different choices for k give different policy factors β approximately ranging from 3 to 7.5 and the norm coefficient (Ci) in Eq. 10 is found accordingly (see Table 1). This shows a significant difference with the situation in the Netherlands where β ranges from 0.01 to 1.0. This difference is by a factor of 10 to 100 when comparing the flood policy factors of Vietnam and Netherlands. As a result safety standards in Vietnam towards flood risk may be set at a design frequency of 1/1000 to 1/100 per year;

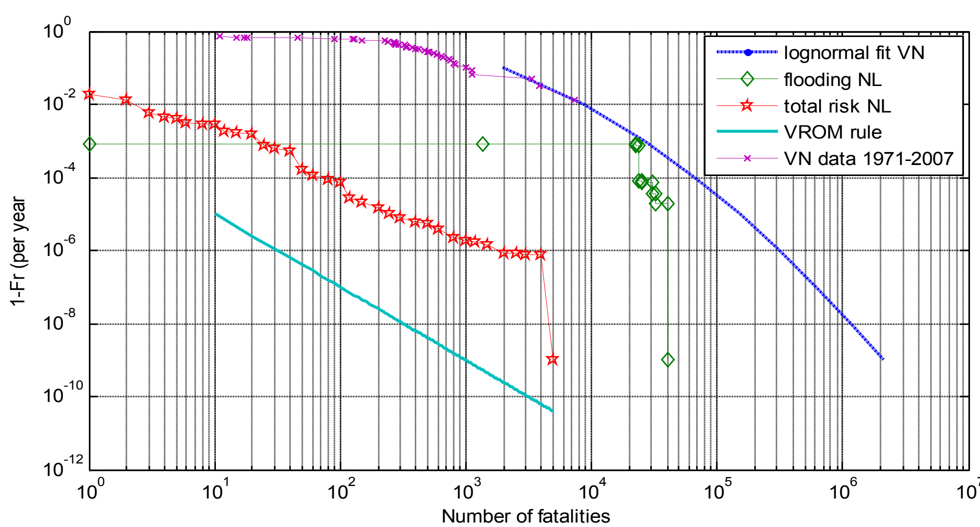


Figure 3: Flood risk in Vietnam compares to risk of various installations in Netherlands (total risk in NL excluding flood risks; FN curve for flood risk in the Netherlands is based on scenario analyses and simulations, not on actual loss of life data)

Table 1: Policy factor tested for Vietnam situation

k	TR	β	C_i
1	1710.7	3.1	0.30
2	2880.4	5.2	0.07
3	4050.1	7.4	0.03

4.3 FD-Curve of Vietnam due to floods based on data from 1970 to 2007

Based on the given economic damage data during 55 years due to floods, similar to FN-curves, the exceedance curve of damage (FD-curve) can be constructed. Damage curves with and without historical events are presented in Figure 4. A lognormal curve with E(D)= 181.3 and σ=309.5 (*10^6 US$) is found as the best fit to the economic damage dataset. Based on the p.d.f, the total potential damage due to floods could be equal to E+k*σ=181+3*309= $US 1108*$10^6$ per year. This is comparable with the reported actual flood situation during the last 10 years (total flood damages are estimated as 1.5 % of Vietnam GDP during the last 10 years, [sources: VNExpress]).

5. Economic optimization of protection level for a dike ring in Nam Dinh province, Vietnam

5.1 Description of the case study

Nam Dinh coastal zone is protected by 90 km of sea dikes. The dikes system has been constructed based on loads with return period 20 year. However, the true probability of failure of the Nam Dinh defense system is 0.78-0.95 per year (Mai Van et al. 2006 & 2007). This exceeds by far the design frequency and reflects that failure of the dike system occurs almost every year.

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 due to budget constrains, lack of information on the sea boundary conditions and suitable design methods as well as strategic and long-term solutions. 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 (DDMFC, 2007).

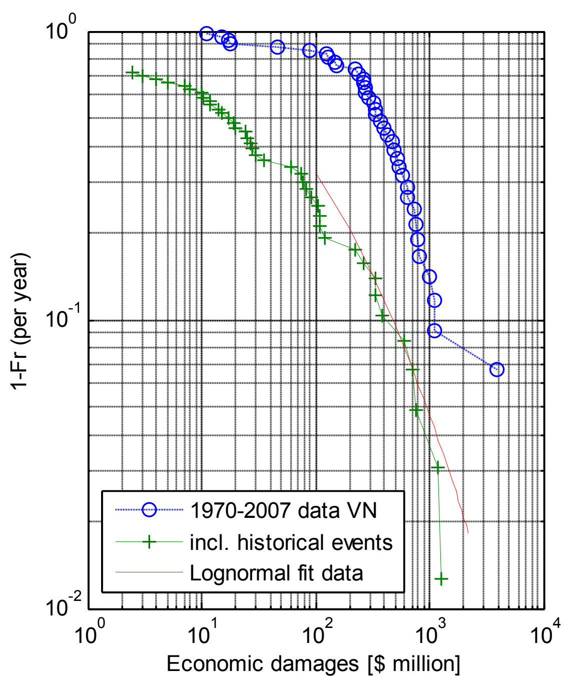


Figure 4: Flood FD-curve of Vietnam

Recently, Damrey Typhoon occurred in September 2005 in northern Vietnam caused approximately more that 8 km of sea dike breaches at different sections along coastline of Nam Dinh, which led to a total direct loss of 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 Ministry of Agricultural and Rural Development (MARD). The sea dike program is implemented for 2005-2015 period and appointed with two important tasks: (i) researches on safety standards, boundary conditions and finding optimal solutions for sea defences along the whole country; (ii) design and construction new dikes, at places where sea dikes has not been existed or were breached, and reinforcement of the existing dikes on the basic of findings in the first task. Coastlines along Hai Hau district was selected as a pilot location. Construction works took place in 2005 and had finished in 2007. However design the new dikes is still based on existing safety standards (design frequency of 1/20 year), which is known as out of date. It is necessary to check safety of the new constructed dike system at the pilot locations to see if the current rehabilitation works provides enough safety given present situation and if safe is safe enough for current Vietnam development. Findings are important input contributing to the first task of the sea dike program of Vietnam, which aims at providing design guidelines for sea defences.

5.2 Optimal protection levels of Nam Dinh sea dike system

Based on design documents and expense reports of existing Nam Dinh sea dikes given by DDMFC/MARD 2005, taking into account the actual inflammation rates of Vietnam (9 percent in 2007) the unit cost factors are determined as in Table 2. Costs of dike heightening are presented in Figure 5.

Table 2: Unit cost factors for Nam Dinh sea dikes.

Para.	Unit	$US*10^6	Descriptions
Co	Mil. $US/km	3,2172	existing dike
C_1	Mil. $US/m²/km	0,0096	dike body
C_2	Mil. $US/m/km	0,0424	outer slope
C_3	Mil. $US/m/km	0,0024	inner slope
C_4	Mil. $US/m/km	0,0206	land use

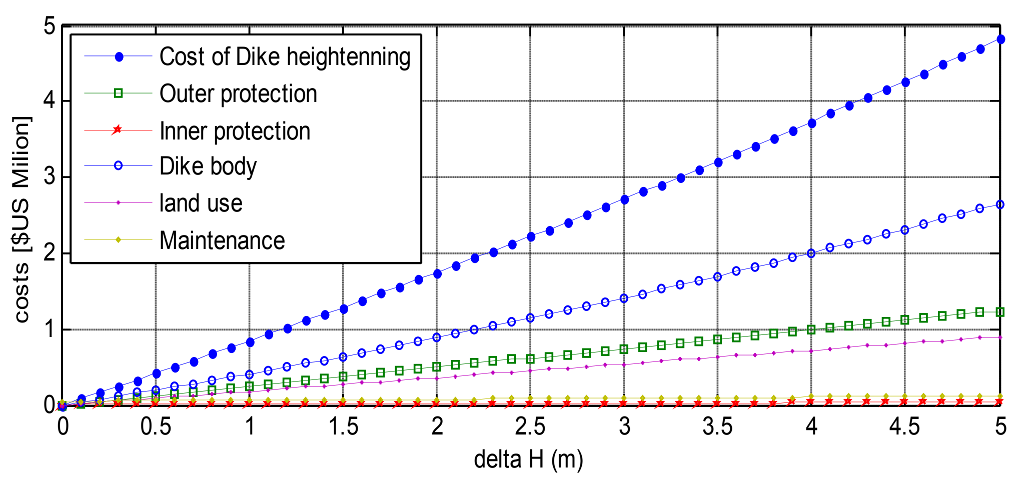
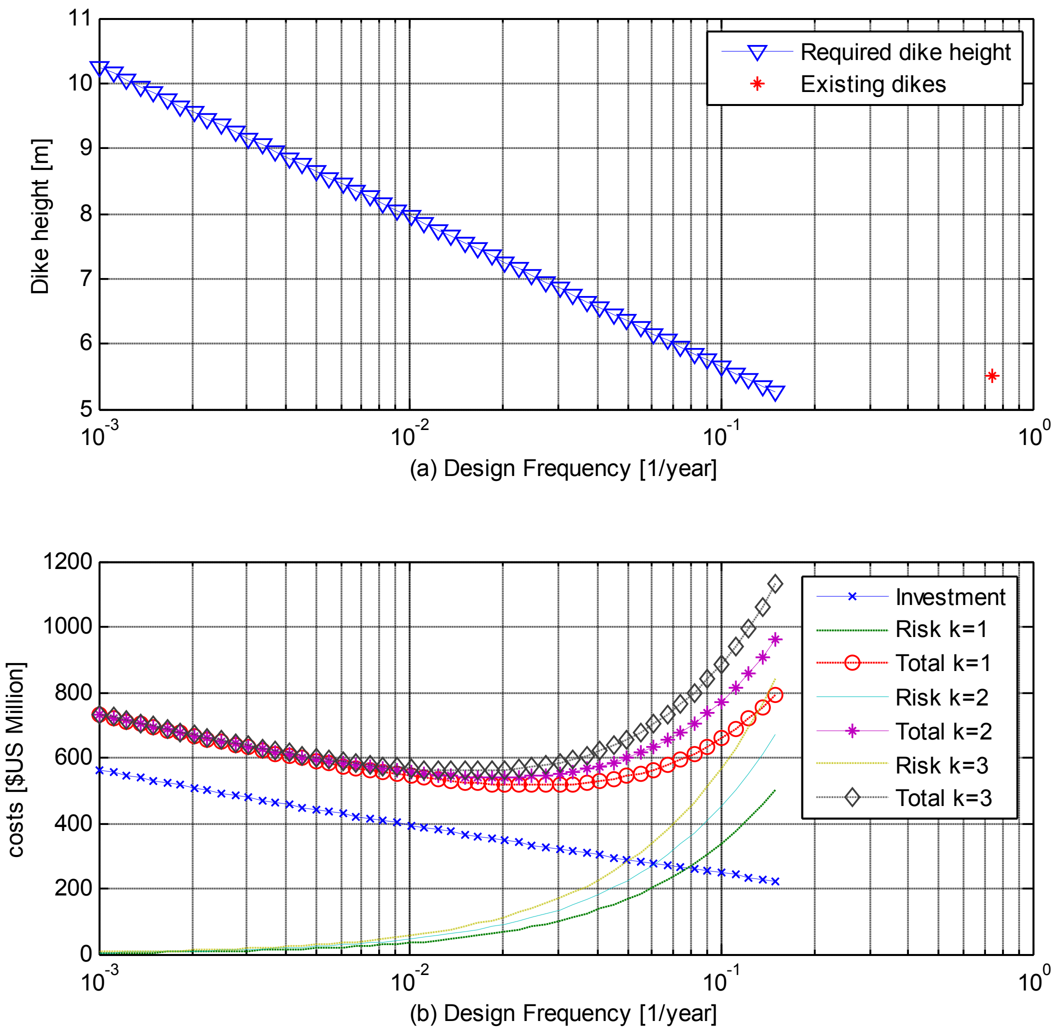


Figure 5: Expenditure costs as function of dike heightening

Application of reliability analysis for the case of Nam Dinh coastal flood defences the relationship between dike heights and design frequencies is established. Based on overtopping conditions, 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 logarithsm scale (Figure 6a). This line can be considered as a limit with safe side (lower left side of the line) and unsafe side (upper right side of the line). Inspection of the actual Nam Dinh sea dikes shows that the existing system is in the un-safe side.

Economic risk analysis for the case of Nam Dinh coastal flood defences, taking into account the actual economic growth rate (7.5%) of Vietnam and expected damage from the FD-curve (Figure 5) gives results as in Figure 6b.

Figure 6: Economic risk based optimal safety levels



The expected damages is determined based on a adjusted mean and standard deviation from FD-curve, E(D)=μ+k*σ, for Nam Dinh. By different values of k (from 1 to 3) it clearly shows in Figure 6 that the optimal level of safety is around 1/95 to 1/85 years. The design of the sea dike system should be based on a return period 50 years or more (left side of intersection between investment and risk curves). 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. Selection of the design return periods of less than 30 years leads to very high risk as well as high expenses for maintenance and repair and is therefore a bad choice in this situation. Selection of 100 years return period is recommended for the future planning of coastal protection in Nam Dinh. Invest nothing, dike height remains at 5.5 m with annual failure probability is 0.15 for single dike section and 0.78 for the whole system, may lead to an economic risk of over $US million 500, which is similar to the total direct loss of the Damrey 2005.

6. Conclusions

Based on statistical data analysis it is clear that at national scale risks by health related natural causes in Vietnam is in the same order of magnitude as in Netherlands. However risk due to flooding shows significant differences between the countries. The policy factor β of Vietnam was found in the range of 3 to 7.5 while in the Netherlands it is from 0.01 to 1.0. As a result safety standards in Vietnam towards flood risk should be based on a design frequency of 1/1000-1/100 per year;

The safety norm of β*550 is derived in this paper and suggested to apply to the Vietnamese conditions for this moment. It should be noted that the safety norms are country specific and the acceptable risk levels are not the same for different nations because attitudes of people and society towards risks are also country specific. Behavior and perception of people towards flood risks in Vietnam should be studied separately to get more insight in further establishment of the safety norms.

Application of reliability analysis with overtopping criteria for the case of the Nam Dinh coastal flood defences leads to a linear relation between the required dike height and the design frequency on logarithmic scale. This line can also be used as a limit state function with a safe- and unsafe-side. Actually, based on this limit state function it can be concluded that the existing Nam Dinh sea dikes are on the un-safe side.

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 strong enough in views of the current Vietnamese development with fast economic growth. 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.

The situation of the Nam Dinh sea defences is typical and representative for sea defences in Vietnam. Therefore, updated safety standards for coastal flood defences for the whole country need to be investigated further. The presented risk based models are thought to be powerful tools to support the decision process to set (or re-set) the safety levels of protection in relation to investments and acceptable consequences for various scales of protection in Vietnam.

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