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RISK ANALYSIS OF COASTAL FLOOD DEFENCES- A VIETNAM CASE

CV Mai[1], PHAJM van Gelder[1], JK Vrijling[1] and TC Mai[2]

1. Department of Hydraulic Engineering, Faculty of Civil Engineering and Geosciences, Delft University of Technology, the Netherlands
2. Department of Coastal Engineering & Port Development, UNESCO-IHE, Delft, the Netherlands.

ABSTRACT: This paper aims at risk analysis and the investigation of 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 conditions. Accurate safety assessment of the existing coastal defence system is 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 long-term planning and decision-making for rehabilitation of the coastal flood defences in Vietnam.

Keywords: coastal structures, sea dikes, safety assessment, probabilistic design, Damrey typhoon.

1. INTRODUCTION

1.1 Backgrounds

Vietnam lies in a tropical monsoon climate region, has a long coastline along the South China Sea, which is regularly substantial suffering from 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, which generate storm surges and waves, both attacking severely the sea dikes along the coast and are accompanied by torrential rains causing flash floods which regularly submerge low-lying areas and threaten millions of households. In particular, the deltaic coastal area, to a distance of about 20 km behind the sea dikes, is threatened because of the combined occurrence of storm surge from the sea and high river discharge.

Since 1953, Viet Nam was affected by number 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.

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 to 25 year periods and were disputable. The true probability of failure of the Vietnamese water defense system exceeds by far the design frequency (Mai *et al*., 2006, 2007). Although designed to fail once in 20 to 25 years the sea defense system might fail almost every year. The experiences in the past 20 years support this statement.

The design return periods are not based on proper statistic risk analysis often the return periods are adopted on a rather arbitrary basis 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, however, 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 by a proper risk analysis.

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 *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 acceptable risks are modeled and the risk based approach in determination of the optimal safety levels of water defence system are developed. Application is made to find the optimal safety standards for a 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. 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.

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. This is translated as the probability of losing one's life due participating in daily activities (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. Acceptable level of risk can also be formulated by economical 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.

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*=P_{di}) for a particular activity is given in CUR/TAW 141. 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.

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 $IR < 10^{-6} [year^{-1}]$. 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):

[1] $IR = P_{fi} P_{d/Fi} < \beta_i \cdot 10^{-4} [year^{-1}]$

In this expression the value of the policy factor β_i varies with the degree of voluntariness in 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 (P_{fi},= 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 β_i-value of 1.0 to 0.1 for flood risk

2.2 Societal risk

The basis for 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.

[2] $1 - F_N(x) = P(N > x) = \int_x^{\infty} f_N(x) \cdot dx$

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 less than x fatalities per year.

VROM limits the societal risk at plant level by: [3] $1 - F_{N_d}(x) < \frac{10^{-3}}{x^2} \quad for\ all\ x \geq 10$

In Vrijling *et al.* (1995) 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. Determination of the total risk was proposed by:

[4] $TR = E(N) + k \cdot \sigma(N)$

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 and tested against the norm of β_i*MF* casualties by:

[5] $E(N_{di}) + k * \sigma(N_{di}) < \beta_i * MF$

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.

The translation of the nationally acceptable level of risk to a risk criterion for one single installation or plant is proposed by Vrijling *et al.* (1998) as:

$$[6]\ 1 - F_{N_{dij}}(x) < \frac{C_i}{x^n} \qquad for\ all\ x \geq 10 \text{ with } C_i = \left[\frac{\beta_i \bullet MF}{k \bullet \sqrt{N_{A_i}}} \right]^2$$

where: N_A is number of independent installations; x is the number of casualties in a year, $F_N(x)$ 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 β_i = 0.03, k = 3 and N_A = 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 $f_D(x)$:

$$[7]\ 1 - F_D(x) = P(D > x) = \int_x^\infty f_D(x) \cdot dx \text{ and } [13]\ E(D) = \int_0^\infty x \cdot f_D(x) \cdot dx$$

where: $F_D(x)$: the cumulative distribution function of the economic damage; $E(D)$: expected value of the economic damage;

2.3.2 Economic optimization of acceptable risk level

In the method of economic optimization the total costs of a system (C_{tot}) are determined by summing up the investments ($I_{\Delta H}$) 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 expresses by Eq.8. The optimal level of safety indicated by $P_{f\text{-}opt}$ corresponds to the point of minimal cost, $\min(C_{tot})$.

$$[8]\ C_{tot}(H_0, \Delta H_{P_f}, P_f) = \left[I_{0,P_{f0}} + I_{\Delta H_{P_f}}(\Delta H_{P_f}) + PV(M) + PV(P_f * D) \right]$$

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 ($A_{\Delta H}$); additional cost of outer and inner slope protection due to increase of the protected length of the outer and inner slopes (L_{out}), (L_{in}); additional cost of crest protection; and additional cost of land area used for dikes ($W_{landuse}$). The present value of the expected maintenance and damage costs are estimated by:

$$[9]\ PV(M) = E(M) * \sum_{i=0}^{i=T} \frac{1}{(1+r)^i} \text{ and } [17]\ PV(P_f * D) = P_f * E(D) * \sum_{i=0}^{i=T} \frac{1}{(1+r)^i}$$

Where: P_f 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. DETERMINATION OF ACCEPTABLE RISKS IN VIETNAM

3.1 Acceptable risk levels in Vietnam

To establish a safety norm for engineering structures in Vietnam it is proposed to base the answer on the probability of a death due to a non-voluntary activity which is approximately equal to 1.3×10^{-5}/year. The overall death rate in Vietnam is $r=6.19 \cdot 10^{-3}$ per year (total yearly deaths of 526,150; total population of 85 million, based on CIA Factbook-online 2007). The multiplication factor for Vietnam (MF_{VN}) is:

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

This multiplication factor for Vietnam is reasonable if compared to that of Netherlands (MF_{NL}=100) and the factor for South Africa (MF_{SA}=750), based on calculations made by Van Gelder *et al.* (2004). Therefore, the norm of β*550 is proposed for the Vietnam situation.

3.2 Flood Risk in Vietnam

At 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 from 1970 to 2007. This data is merged with historical data of the top 25 flood disasters of Vietnam in the 20th century, which is available online by the Asian Disaster Reduction Centre (ADRC, 2006). FN curve due to flooding for the whole country including historical events is presented in Figure 1. A lognormal curve with μ = 541 and *sigma*=1169.7 are found as the best-fit to the yearly fatality dataset. In Figure 2, the FN curve for the flooding in Vietnam is compared to some other risks in the Netherlands. It shows that the risk of sea flooding in Vietnam is higher than in that of the Netherlands. This could be due two reasons: (i) natural topographical 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.

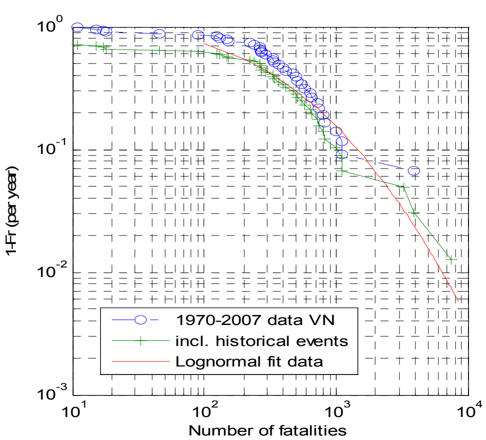

Figure 1: FN-curve due to flooding in Vietnam

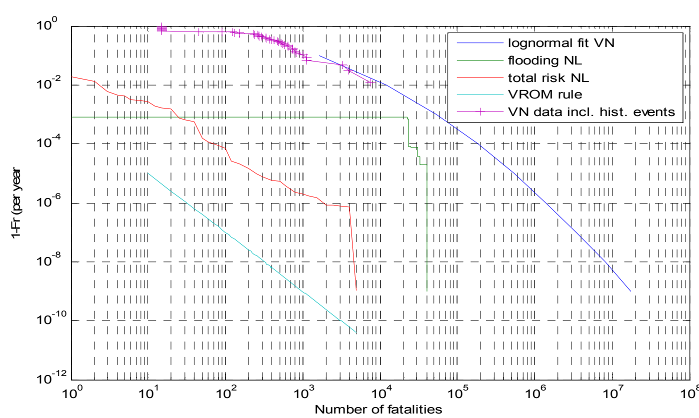

Figure 2: Flood risk in Vietnam compares to risk of various installations in Netherlands (total risk in NL excluding flood risks; FN curve for flood risk in the Netherlands is based on simulations)

In order to satisfy criteria by Eq. 5, $TR=E+k*\sigma < \beta*550$, different choices of k give different policy factor β. The correspondent norm coefficient (C_i) is also found (see Table 1). This shows a significant difference with the situation in the Netherlands where β ranges from 0.01 to

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

1.0 for flood. This difference is by a factor of 10 to 100 when comparing the flood policy factor of Vietnam. 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.

3.3 FD-Curve of Vietnam due to typhoons and floods

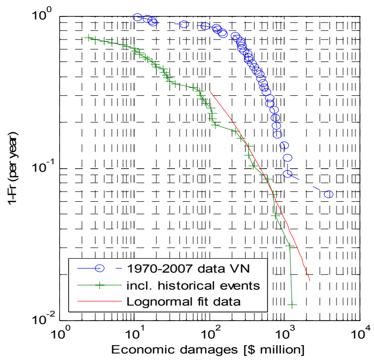

Figure 3: Flood FD-curve of Vietnam

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 3. 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 $E+k*\sigma$=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: http://www.vnexpress.net/Vietnam/Xa-hoi/2007/10/3B9FB183/).

4. ECONOMIC OPTIMIZATION OF PROTECTION LEVEL

4.1 Description of the case study: a dike ring in Nam Dinh province, Vietnam

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 *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.

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.

4.2 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 costs of dike heightening are presented in Figure 3.

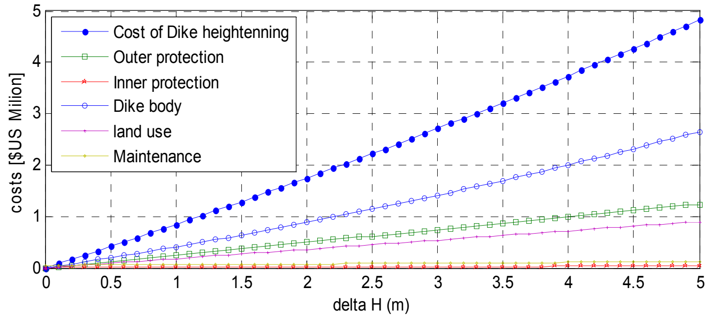

Figure 3: Expenditure costs as function of dike heightening

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 4a). 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 3) gives results as in Figure 4b. It is clear that the optimal level of safety is around 1/90 years. The design of the sea dike system should be based on a return period 50 years or more. 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.

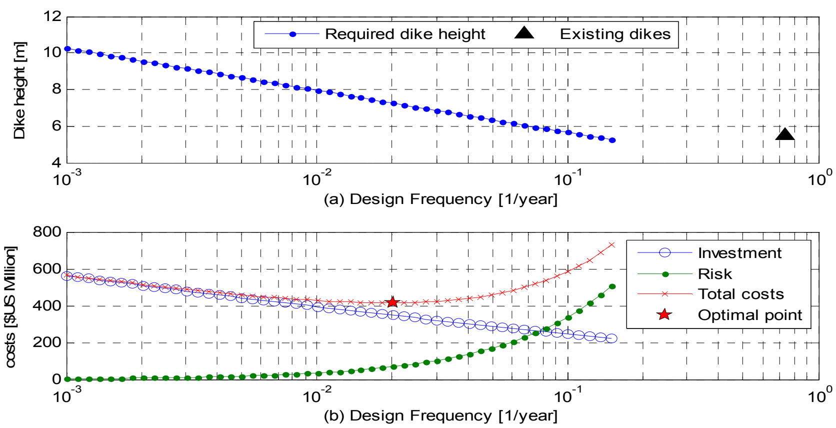

Figure 4: Economic risk based optimal safety levels

5. RECOMMENDATIONS

Based on statistical data analysis it is clear that at national scale risk relates to natural causes in Vietnam is in the same order of magnitude as in Netherlands. However risk due to flooding is significantly differences between these 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.

Economic risk analysis showed that the actual safety standard of coastal flood defences of the Vietnamese case study (1/20 years) is not safe enough in views of the current Vietnamese development with fast economic growth. An optimal choice of the acceptable risk level is recommended at 1/100 years. This is in good agreement with the upper bound of the result of societal acceptable risk of Vietnam.

The situation of the Nam Dinh sea defences is a representative for sea defences in Vietnam. Therefore, updating safety standards for coastal flood defences of the whole country is necessary. 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 flood protection in Vietnam.

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