

Risk based approach for long-term plan of coastal flood defences: A Vietnam case

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Abstracts: This paper aims at investigation of safety aspects of coastal flood defence system and determination of safety standard for a long-term plan of the system on basic of acceptable levels of risk. Acceptable risk is strongly related with the acceptable probability of failure and the acceptable amount of damage. In general agreement has been made in the literature and in regulatory circles that risk should at least be judged from two points of view. The first point of view is that of the individual, who decides to undertake an activity weighing the risks against the direct and indirect personal benefits. The first point of view leads to the personally acceptable level of risk or the acceptable individual risk, defined in as “the frequency at which an individual may be accepted to sustain a given level of harm from the realisation of specified hazards”. The specified level of harm is narrowed down to the loss of life in many practical cases. The second point of view is that of the society, considering the question whether an activity is acceptable in terms of the risk involved for the total population. This risk analysis framework is applied for a case of coastal flood defences in Vietnam, a country which has its coastlines of about 3000 kilometers, with deltaic coastal areas to a distance of about 20 km from the coastlines is mainly protected by the sea dikes. As from practical situation it seems that the actual dike system is not sufficient to withstand the sea loads. An accurate assessment of actual safety of the Vietnamese coastal defences and investigation of accepted risks for the deltaic areas, in which, due to possible failure of flood defences, loss of life, economic, environmental, cultural losses and further intangibles can occur is necessary to determine the question if safe is safe enough. Subsequently, long-term planning decisions for rehabilitation of the coastal flood defences on basic of acceptable levels of risk are therefore very important. Effort will be made in this paper to give a proper answer to these above issues given an actual Vietnamese condition.

Keywords: Safety assessment, risk analysis, sea dikes, acceptable risk.

1 INTRODUCTION

In civil engineering design one often knows of conventional design method which is considered as deterministic approach. The basic of the deterministic approach are the so-called design values for the loads and the strength parameters. Loads for instance are the design water level and the design significant wave height. Using design rules according to codes and standards it is possible to determine the dimensional geometrical parameters of the civil engineering structures i.e buildings, bridges, tunnels, dams, dikes and storm surge barriers. These design rules are, in general, based on limit states of the structure's elements.

In deterministic approach it is assumed that the structure is safe when the margin between the design value of the load and the characteristic value of the strength is large enough for all limit states of all elements. Therefore the safety level of a structured system is not explicitly known [1,2].

Probabilistic design approach with reliability- and risk- based design concepts have been increasingly proposed and applied in the fields of civil engineering and water defences during the last few years (see e.g. the concept, method and application in [1,2,3,4]). A fundamental difference with the deterministic approach is that the probabilistic design methods are based on an acceptable frequency or probability of failure of the considered structure.

The probabilistic approach allows designers: (i) take into account the uncertainties of the input parameters and treat them as the random variables; (ii) describe failure of the structure in various possible failure modes which based on the physical processes of these failure mechanisms; and (iii) find a probability of failure of the whole system taking account of each individual element (cross-section and/or structure); For instance, with a flood defence system, the accepted probability of flooding is not the same for every polder or floodplain. It depends on the nature of the protected area, the expected loss in case of failure and the safety standards of the country. For this reason accepted risk is a better measure than an accepted failure probability because risk is a function of the probability and the consequences of flooding. The failure probability and the probability of the consequences form the probability part of the risk. When the risk is calculated the design can be evaluated. For this criteria must be available such as a maximum acceptable probability of a number of casualties or the demand of minimizing the total costs including the risk. For determining the acceptable risk it needs to refer to a frame of reference. This frame of reference can be the national safety level aggregating all the activities in the country. After the evaluation of the risk one can decide to adjust the design or to accept it with the remaining risk.

The modern probabilistic approach aims to give protection when the risks are felt to be high. Risk is defined as the probability of a disaster, e.g. a flood, related to the consequences. 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. These unwanted events could be starting/ turning points of any new safety policy establishment for the countries.

Actually, for Vietnamese situation of flood defences and coastal protection, the safety levels were set by design frequencies from national code, which varies by locations and importance of the elements. It is known as a fixed values and indicated in National Design Standards (i.e. for provincial sea dike is 1/20 years, river dike 1/25 years) [5]. These safety levels were selected more than 30 years ago. Due to significant changes of social, economic situations during the last 30 years it is necessary to update these design safety levels and safety regulations for the whole country.

In this paper methods of probabilistic design and risk-based approach are presented and critical reviewed. Development is made with an application to the sea dikes system in Vietnam. Actual safety of the existing sea dikes is investigated. The question if “safe is safe enough” is answered with references to the acceptable risk level, which determined by different risk measures. Safety standards for coastal flood defences by a case study in Vietnam is proposed to support the decision making process in long term plan.

2 PROBABILISTIC DESIGN METHOD AND ITS APPLICATION IN SAFETY ASSESSMENT OF COASTAL FLOOD DEFENCE SYSTEM

A coastal flood defence system may comprise different components, including sea dike sections, estuarine dike sections, dunes, sea walls and dike crossing structures i.e discharged structures or pumping station. The system is designed to protect low-lying coastal zone from sea flooding by a certain safety level which written in the codes. Main interest is, however, what is the actual safety of the protected areas. This question can be answered by quantification of probability that the protected areas are inundated or, in other word, the probability that the system failure occurs.

In order to determine the system failure probability following steps are often required:

- Description of the system in logical fault trees from detail to overview levels with its components and component's possible failure modes.
- Calculation of failure probability of each mode, each components
- Combination of failure probability to determine the overall system failure probability.

In principle the failure and breach of any system element leads to flooding of the polder. The probability of flooding results from the probabilities of failure of all system elements by various failure modes. The relation between the failure mechanisms in a dike section and the unwanted consequence flooding can be described by fault-trees as in Figure 1 [5].

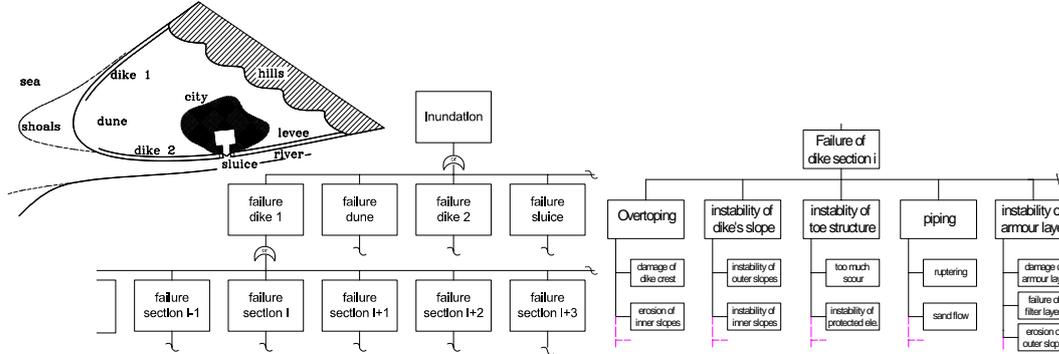


Figure 1: Description of flood defence system by fault trees by different levels

Quantification of the probability of system failure starts with the definition of reliability functions for all potential failure modes of all system elements. As from literatures, the general form of limit state equation for a failure mode is [4]:

$$g(z,X)= R(z,X) - S(z,X) \quad (1)$$

where R is the resistance of the component, S is the load acting on the component, z is a vector of design variables describing among others the structural geometry of the component and X is a vector of load of random variables.

If the joint probability density function $f_{R,S}(R, S)$ of R and S is known, the probability of failure can be calculated by means of integration:

$$P_f = P\{Z < 0\} = \iint_{Z < 0} f_{R,S}(R, S) dR dS \quad (2)$$

Because $Z < 0$ if $R < S$ the following applies:

$$P_f = \int_{-\infty}^{\infty} \int_{-\infty}^S f_{R,S}(R, S) dR dS \quad (3)$$

This integral can seldom be determined analytically. The solution is therefore usually calculated with numerical methods. The two well-known of these which usually be used, are numerical integration and solutions based on the Monte Carlo method.

The overall failure probability of a system component is then given by combination of failure probability of all considered failure modes depending on the composition of the sub-fault tree, which describes the system element.

The overall system failure probability is determined in a similar way as soon as the failure probability of all system elements is found by following the fault tree which describe the system and taking into account the correlation between components. Numerical integration and Monte Carlo simulation are available to determine an exact system failure probability. In this paper the later method is used to estimate the overall system failure probability

Discussions: If the geometry of every component is known and the joint probability distribution of load and strength variables is quantified, the probability of failure of system components and of the whole system can be found. This can be applied for technical management purpose to determination of safety levels of an existing system and to find out where the weakest point of the system takes place.

3 RISK BASED SAFETY STANDARDS FOR WATER DEFENCE SYSTEM

The estimation of the flood risk constitutes a central element in the modern approach. 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. Even the loss of trust in the water defense system is a serious, but difficult to quantify the effect.

However, for practical reasons, the notion of risk in a societal context is often reduced to total number of casualties 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". 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 [6]. Obviously, if dike improvement is relatively expensive a higher probability of flooding will be accepted. On the other hand if the consequence of flooding is relatively substantial one will aim for a smaller probability. Moreover, the environmental consequences of flooding and the potential effects on nature and cultural heritage should also play an increasing role in assessing the required scale of flood protection.

From literatures, 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 [7]. 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. The determination of the socially acceptable level of risk assumes also that the accident statistics reflect the result of a social process of risk appraisal and that a standard can be derived from them. In addition to that the formula is accounted for risk aversion in a society [Risk aversion paper]. Relatively frequent small accidents are more easily accepted than one single rare accident with large consequences like a flood, although the expected number of casualties is equal for both cases. The standard deviation of the number of casualties reflects this difference.

The problem of the acceptable level of risk can be also 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. 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, called FD-curve [8].

3.1 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 can be found from [7]:

$$IR = P_{di} = \frac{N_{di}}{N_{pi}} = \frac{N_{pi} P_{fi} P_{d/Fi}}{N_{pi}} = P_{fi} P_{d/Fi} \quad (4)$$

Where: N_{pi} number of participants to activity i ; N_{di} number of deaths with activity i ; P_{fi} 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 [7]. 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 the following standard for populated areas.

$$IR < 10^{-6} \left(yr^{-1} \right) \quad (5)$$

This standard is set for more or less involuntary imposed risks related to the siting 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 [3]:

$$IR = P_{\beta_i} P_{d/F_i} < \beta_i \cdot 10^{-4} \text{ (1/year)} \quad (6)$$

In this expression the value of the policy factor β_i 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 ($P_{\beta_i} = 0.1 = 100 \cdot 10^{-4} / 10^{-1}$) to 0.01 in the case of an imposed risk without any perceived direct benefit, see Table 1. For the safety of dikes a β_i -value of 1.0 to 0.1 is thought to be applicable [7].

Table 1: The value of the policy factor β_i as a function of voluntariness and benefit

β_i	Voluntariness	Direct benefit	Example
100	Completely voluntary	Direct benefit	Mountaineering
10	Voluntary	Direct benefit	Motor biking
1.0	Neutral	Direct benefit	Car driving
0.1	Involuntary	Some benefit	Factory/ Flood
0.01	Involuntary	No benefit	Fuel station/ Flood

3.2 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 [8].

$$1 - F_N(x) = P(N > x) = \int_x^{\infty} f_N(x) \cdot dx \quad (7)$$

Where: $f_i(x)$ 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.

One of the oldest simple measure of societal risk is the Potential Loss of Life (PLL), which is defined as the expected value of the number of deaths per year:

$$E(N) = \int_0^{\infty} x \cdot f_{N_{dij}}(x) \cdot dx \quad (8)$$

where : $f_{N_{dij}}$ = the p.d.f. of the number of deaths resulting from activity i in place j in one year. The subscript dij will be omitted further on.

VROM limits the societal risk at plant level by a line that is inversely proportional to the square of the number of deaths. This absolute requirement that formed the basis for the regulation and the siting of hazardous installations or new developments in the Netherlands during the last decade reads:

$$1 - F_N(x) < \frac{10^{-3}}{x^2} \quad \text{for all } x \geq 10 \quad (9)$$

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

The British Health and Safety Executive (HSE) has defined a risk integral as a measure for societal risk [9]. However a limiting value is not yet attached to this new concept.

$$RI = \int_0^{\infty} x \cdot (1 - F_N(x)) \cdot dx \quad (10)$$

In [10] it is mathematically proven that the RI can be expressed in two characteristics of the pdf of the number of fatalities, the expected value $E(N)$ and the standard deviation $\sigma(N)$:

$$RI = \frac{1}{2} [E^2(N) + \sigma^2(N)] \quad (11)$$

A disadvantage of the risk integral RI might be that the units are [death²/year] and some difficulty will be met in formulating an easy to understand limiting value.

In [6] 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:

$$TR = E(N) + k \cdot \sigma(N) \quad (12)$$

It is notes in [8] 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 $\beta_i \cdot MF$ casualties by the following form:

$$E(N_{di}) + k \cdot \sigma(N_{di}) < \beta_i \cdot MF \quad (13)$$

Note that the multiple 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 $\beta_i \cdot MF$ 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 N_A 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:

$$1 - F_{N_{dij}}(x) < \frac{C_i}{x^n} \quad \text{for all } x \geq 10 \quad (14)$$

$$C_i = \left[\frac{\beta_i \cdot MF}{k \cdot \sqrt{N_{A_i}}} \right]^2 \quad (15)$$

Where: 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 [9].

It can also be transformed mathematically into a VROM-type of rule applicable at plant level for a single installation. For values of $\beta_i = 0.03$, $k = 3$ and $NA = 1000$ the rule equates exactly to the VROM-rule, which appears to be a specific case in a more general framework.

3.3 Economical approach for determination of risk measures

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 ($f_D(x)$)

$$1 - F_D(x) = P(D > x) = \int_x^{\infty} f_D(x) \cdot dx \quad (16)$$

$$E(D) = \int_0^{\infty} x \cdot f_D(x) \cdot dx \quad (17)$$

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

Economic optimisation of acceptable risk measure

Another way to formulate the acceptable level of risk is using an economic decision problem [11]. In the method of economic optimisation the total costs in a system (Q_{tot}) are determined by summing up the investments (I) for a safer system and the expected value of the economic damage. The optimal level of safety indicated by Pf-opt corresponds to the point of minimal cost:

$$\min(Q) = \min [I(P_f) + PV(P_f * S)] \quad (18)$$

The present value of the expected damage PV may be estimated conforming equation (-):

$$PV(P_f * S) = P_f * S * \sum_{i=0}^{i=n} \frac{1}{(1+r)^i} \quad (19)$$

where Q refers to the total cost, P_f is probability of failure per year; S is damage in case of failure; r is real rate of interest, n is number of years of planning period.

4 CASE STUDY: COASTAL DEFENCES IN VIETNAM

4.1 Case study description

Vietnam is affected regularly by substantial suffering due to sea and river floods. The most severe floods occur during high river discharges and during, and shortly after, typhoons from the South China Sea. Since 1996, Vietnam was affected by several flood disasters, each of those 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, on averaged, exceeded USD 1 billion in these years, which was accompanied by the loss of almost over 1000 lives [12].

A selected case study in this paper is a new sea dike system of in Hai Hau district, Namdinh province, Vietnam. Total length of the Haihau sea defence system includes around 32 kilometres of sea dikes and 14 dike crossing structures i.e. sluices and pumping stations. Due to Damrey Typhoon 2005 several dikes section of Namdinh were breached (some 10 kilometers), including some Haihau seadike sections [5]. In

attempt of rehabilitation of the sea dike system, a new design cross section was introduced by MARD and Hai Hau is selected as a pilot locations. It is necessary to check with the new design method to see if current rehabilitation works provided enough safety according to the present safety regulation and if safe is safe enough for current Vietnamese situation.

4.2 Reliability safety assessment of sea dike system in Vietnam

Follows the method given above, the reliability of Namdinh sea dike system is conducted from reliability analysis. All possible failure mechanisms in previous section will be analysed for Hai Hau case based on given above limit state functions. Using level III method Monte Carlo simulation the failure probability of possible failure modes and of the whole system are calculated and shown on Figure 2.

Total length of Hai Hau sea dikes is 32 kilometers. It is naturally divided into 7 sections which belong to 7 commutes along. It gives $P_f^{system}=0.19 \approx 1/5$ years. From the actual sea dike design standard of Vietnam the required safety level is $[P^{system}]=1/20=0.05$.

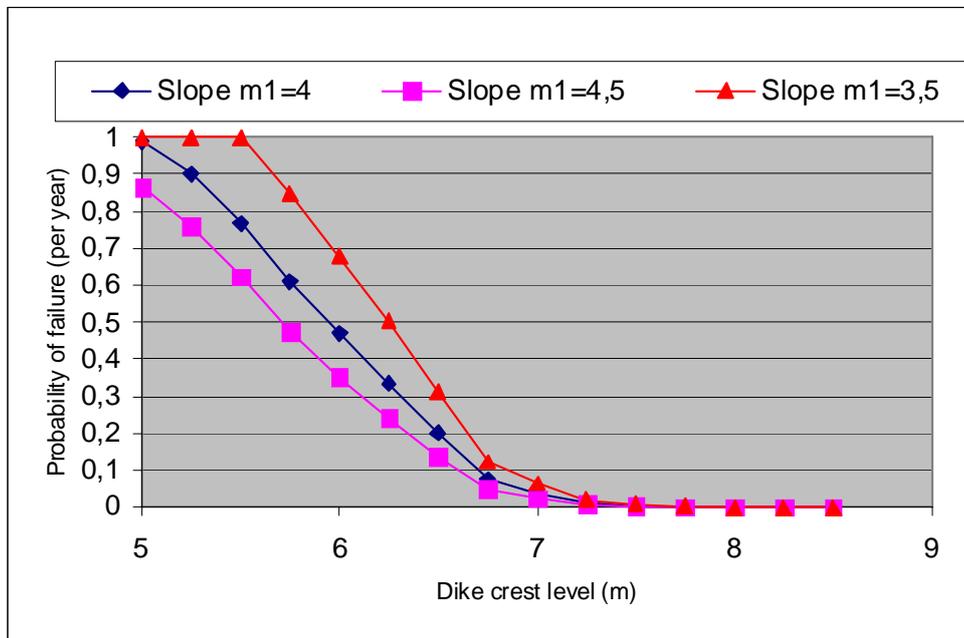


Figure 2: Fragility curve of Vietnam sea dikes: presents relation of dike crest level and failure probability by different outer slopes

4.3 Acceptable risk levels in Vietnam

Establishing norms for Vietnam situation - risk due to natural causes

To establish a norm for the acceptable level of risk for engineering structures in Vietnam it is more realistic to base oneself on the probability of a death due to a non-voluntary activity in the factory, on board a ship, at sea, etc., 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 (526,150, estimated 2007) and the total population (85 million, estimated up to year of 2007), giving $r=6.19 \cdot 10^{-3}$ per year. The multiplication factor for Vietnam (MF_{VN}) can be calculated:

$$MF_{VN} = \frac{1.3 \cdot 10^{-5} * 85 \cdot 10^6}{20} \approx 550 \quad (18)$$

This multiplication factor for Vietnam is reasonable if comparing that of Netherlands ($MF_{NL}=100$) and the factor for South Africa ($MF_{SA}=750$), based on calculation made by Van Gelder in [13]. Therefore the norm for Vietnam situation can be selected at $\beta \cdot 550$. This norm is used for all later calculations.

Risk of road traffic accidents

In Vietnam a major hazardous activity is road traffic, which causes 12.300 deaths per year in (according to National Road Traffic Safety Committee, 2007). The following data has been collected and assumptions are made:

- Vietnam population: $85 \cdot 10^6$
- Number of vehicles (according to Vietnam Automobile Association and Vietnam National Centre for Statistics): $N_A = 19.5 \cdot 10^6$ (in which 18.2×10^6 number of motobikes and 1.3×10^6 number of autos)
- Total number of casualties: 12.300 per year
- Number of people on the vehicle is assumed at 2 and the probability to die in a crash at $p_{d|f} = 0.1$

$$E(N_{di}) = N_{Ai} \cdot p_{fi} \cdot p_{d|i} N_{dij|f} = 238$$

$$\sigma(N_{di})^2 = N_{Ai} \cdot p_{fi} \cdot (1 - p_{fi}) \cdot N_{dij|f}^2 = 17$$

in which: $p_f = 1.45 \times 10^{-4}$; $N_{Ai} = 19.5 \cdot 10^6$; $p_{d|i} = 0.1$; $N_{pi} = 1$;

It can be derived that: averaged failure probability due to traffic accidents is $P_f = 12300/85 \cdot 10^6 = 1.45 \times 10^{-4}$; and if $\beta = 1.0$ is adopted, as indicated in table 1 for traffic activities, the acceptable probability of a car accident is $6.5 \cdot 10^{-6}$ ($= 550/85 \cdot 10^6$) per year per individual. The expected total number of casualties amounts to 550 per year.

Assuming that the behavior of Vietnamese population towards risks are reflected by the above statistics of road traffic accidents, based on Eq. 2 the policy factor β_i can be determined:

$$IR = P_{fi} P_{d|Fi} = 1.45 * 10^{-4} * 0.1 < \beta_i \cdot 10^{-4} \Rightarrow \beta \geq 14.5$$

A choice of $\beta_i = 23$ leads to an increase of the acceptable probability of an accident to 1.5×10^{-4} per vehicle per year. The expected total number of casualties amounts to 12,300 per year with a standard deviation of 115, in case of risk aversion factor $k=3$.

Therefore, societal risk would be acceptable, if $\beta_i = 23$ describes the attitude of the society towards road travel. It seems likely that the situation sketched will require a national debate to decide if improvements have to be made, as $\beta_i = 1$ reflects the public attitude better.

Risk of flooding

Based on National Statistics of Vietnam (2007) the yearly number of fatalities due to sea flooding (inventory by every storm event) the probability of occurrence and the number of fatalities are determined. With this data a probability density function of the number of fatalities has been formed and an FN curve can be derived (see Figure 3). The FN curve for the flooding in Vietnam is compared to some other risks in the Netherlands in Figure 4. The figure shows that the risks of sea flood in Vietnam are much higher than other risks for various installations in the Netherlands. However the upper tail of the flood FN curve of Vietnam is intensity lower than that of the Netherlands. This could be due two reasons: (i) natural different between Vietnam and the Netherlands, Vietnam has relatively narrow low-lying coastal strip along the country while in Netherland more than half of the country is below mean sea level; and (ii) the fact that Vietnam populations are more used to floods than most Western populations. Therefore the acceptance of personal risks might differ from this acceptance in Western countries.

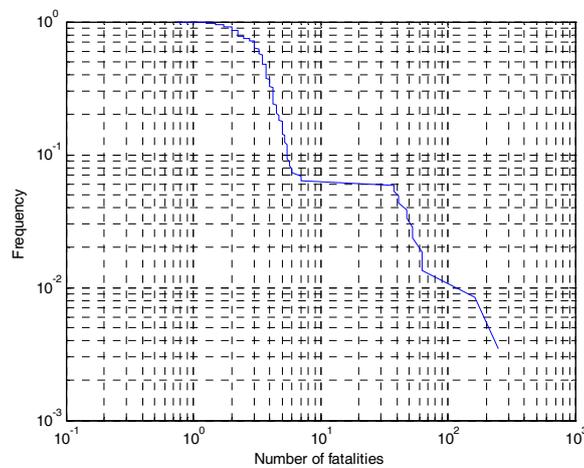


Figure 3: FN-curve due to flooding in Vietnam

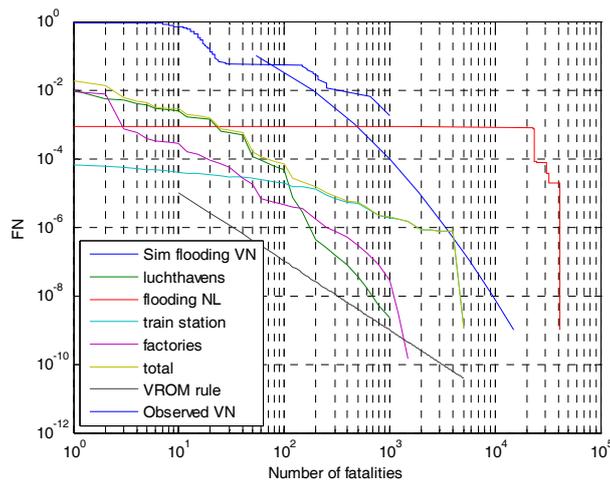


Figure 4: FN-curve due to flooding in Vietnam comparing with various installations in Netherlands

From collected data an expected value of the number of deaths per year and the standard deviation are derived for national scale:

$$E(N) = 154.4(\text{fat} / \text{yr}) \quad \sigma(N) = 547.8(\text{fat} / \text{yr}) \quad (19)$$

In order to satisfy criteria by Eq. 13: $E+k \sigma < \beta * 550$, different selection of k gives different policy factor β as shown in Table 3 approximately ranging from 1 to 4, while the policy factor for flood risk standards in Netherlands is in range of 0.001 to 0.1.

Table 2: Policy factor tested for Vietnam situation

k	Fatalities	β
1	729,2	1,3
2	1304,0	2,4
3	1878,8	3,4

Economic optimizations of protection level for a dike ring in Nam Dinh province, Vietnam

The demonstration of analysis results for the case of Hai Hau sea dikes are on Figure 5. This example takes an average rate of interest of 0.045 and economic growth rate of 0.085 (as current situation of Vietnam) and an average damage USD 500 millions in case of failure of the dike ring under consideration (similar to the damage of the Damrey typhoon 2005 [12]).

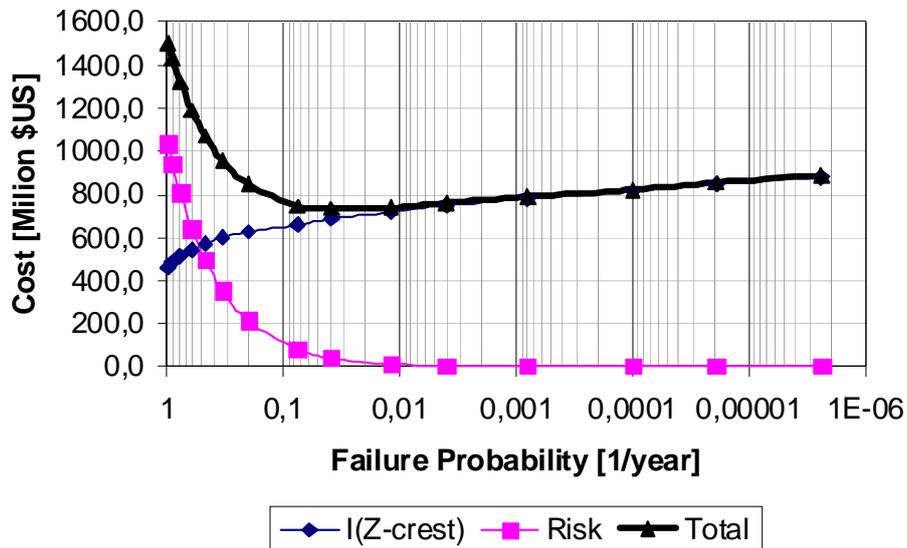


Figure 5: Risk based optimal safety levels

The optimal level of safety is at around 1/50 year which corresponds to the point of minimal total cost. 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. Selection of the design return periods is less than 25 years leads to very high expenses for maintenance and repair and is therefore a bad choice in this situation.

Actually, for Vietnamese situation of flood defences and coastal protection, the safety levels were set by design frequencies from national code, which varies by locations and importance of the elements. It is known as a fixed values and indicated in National Design Standards (i.e. for provincial sea dike is 1/20 years, river dike 1/25 years) [5]. These safety levels were selected approximately 30 years ago. Due to significant changes of social, economic situation during the last 30 years it is necessary to update these design safety levels and safety regulations. Example of Hai Hau sea dikes in this paper shows that it is applicable to derive such a framework of risk analysis and risk-based design in Vietnamese situation.

5 DISCUSSIONS

This study presents and reviews partially the methods of probabilistic reliability and risk based approaches with applications in the field of sea flood defences and coastal protection. When the geometry of the flood defence system is known and the joint probability distribution of load and strength variables is quantified, the probability of failure of the system and its components can be found. This can be applied for technical management purpose to determination of safety levels of any existing system and to find out the weaker/weakest points of the system. Also this answer well question of how safe the dikes are.

Given a population of 85 million people and assuming that every inhabitant of the Vietnam is exposed to risks resulting from road traffic, this implies an individual risk of $1.45 \cdot 10^{-4}$ for each citizen per year, which by far exceeds amply the individual risk criterion of $1 \cdot 10^{-6}$ /yr by VROM in the Netherlands although this number is quite in the same order of magnitude with the traffic induced personal risk in the Netherlands ($1.4 \cdot 10^{-4}$).

At national scale, risks by nature causes in Vietnam is in the same order of that in Netherlands, however for different installations, i.e road traffic and sea flood, results show significant changes over different countries. Consequently the norms are country specific and the acceptable risk levels are varied as well for different nations. This could be due to the fact that the attitude of the society towards risks is not the same for everywhere.

In risk-based design the effectiveness of the protection system as a function of its failure probability can be modeled. The two main components of the model are the cost of protection and a characteristic value of the consequences of flooding, both as a function of the probability of failure. This model could be a powerful tool supporting decision process to set (or re-set) the safety levels of protection in relation to investment levels and acceptable consequences for any scale of protection system. This framework can be applied widely in other types of structured system in civil engineering.

Application of reliability and risk analysis for study case of Hai Hau gives interesting results. The actual relative low safety level of the whole system were figured out. Analysis shows that the failure may occur at once every 5 years at the existing new design dike system and once in every 33 years. The actual safety levels are unacceptable in term of the whole system but accepted for a single dike section if according to present Vietnamese design codes (once in every 20 years). The effect of system length to probability of failure is also indicated. From that one can realize that with 2-dimensional design (no consideration of system length) the actual safety level of whole system may reduce by factor 10 or more!

Reliability and risk analysis in the field of flood denfence and coastal protection has been developing effectively Western countries. Applying this modern approach in the same field in developing countries, therefore, should be implemented. Especially for the country where the safety levels of the actual flood protection are relatively low and safety regulations are not usually clear defined. A general framework of implementation of state of the art is thus important. Specific reliability and risk based models should be developed in those countries which should account for some developing characteristics (e.g. limited initial investment, cheaper man power, fast economic growing) and some limitations of data availability, lack of modern construction equipments, poor professional knowledge etc.

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