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THE APPLICATION OF A TANDEM DIKE SYSTEM IN VIETNAM

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Abstract

In the low-lying coastal regions coastal defense structures are usually designed with a main function to protect the hinterland from highly vulnerable of sea flooding. Sea dikes are usually the most common and important elements which form the coastal flood defense system. Sea dikes are designed at a pre-defined circumstance and requirement. For instance, dikes are designed where no overtopping, some overtopping or large overtopping water is allowed. The most interesting issues at the preliminary design stages of a sea dike are its height, layout and associated overtopping discharge criteria. There have been many discussions on whether sea dikes should be designed high enough to not allow any overtopping water or using relatively low but "strong" dikes in order to allow from some to large overtopping water. Recently, the ComCoast[1] project develops and demonstrates innovative solutions for flood protection in coastal areas. In which different types of dike cross section and layouts of defensive system were proposed. Concepts of defensive zones are presented beside the already existing concept of defensive lines. However, within the ComCoast project, attentions are paid mainly to developments of the innovated concepts rather than focusing on comparison of the proposed system with the conventional sea defenses. Thus, there is still lack of guidance and comparative tools to determine the best choice amongst the conventional or innovated options in decision making process. This study focuses on development of the comparative framework and generic guidance to support the decision making process in selection of the best suitable layout option of the sea dike system for a given location. Based on overtopping criteria two situations are considered for the analysis: (i) using one defensive line; (ii) using two defensive lines (defense zone). The multi-criteria analysis (which takes social, economic, environment and technical aspects into account) and the cost-benefit analysis are used in the selection of the best option. Finally application is made for several case studies of coastal flood defense in Vietnam.

Keywords: sea dike, tandem dike, flood defense system.

1. INTRODUCTION

Sea defense systems are of interests for many nations all over the world, depending on the nature, climate, topography characteristics and development states these systems are at different levels. Sea dike defense systems are built to protect the low-lying coastal regions/countries from sea floods e.g. in Netherlands, Germany, Belgium, Bangladesh, China, Vietnam, etc.

[1] ComCoast - COMbined functions in COASTal defence zones - is a European project which develops and presents innovative solutions for flood protection in coastal areas.

Main function of sea dikes is preventing sea water to flood into the polder at a pre-defined circumstance and/or criteria. For example, dikes are designed to allow no overtopped or some overtopped or large overtopped water. Therefore, at the preliminary design stages of sea dikes, the height of the dikes and its associated overtopping are most important.

Experiences in many countries show that, for most of sea dikes, the damage by wave overtopping is a major failure mechanism. The actual situation of sea dikes in Vietnam supports the statement very well (Vrijling *et al*, 2000; Mai *et al*, 2006). Wave overtopping leads to several consecutive failure mechanisms, i.e. erosion of dike crest, inner slope and dike body; breaking of crown walls; functional failures due to too much overtopped discharges, if duration and intensity of storm are large enough. So, the overtopping mode is the most important aspect which relates to the main function of sea dikes and it safety.

As the first attempt, an international research project, named ComCoast, had been appointed within European countries which border the North Sea. Project objectives are to develop and demonstrate innovative solutions for flood protection in coastal areas. A new approach, known as ComCoast approach, has been conceptually proposed. The ComCoast approach is to search for alternative defense systems and new sustainable sea flood management strategies to cope with increasing sea loads. The chosen concept involves the use of a wide coastal area for water defense, which means a gradual transition from sea to land. This coastal transition area is referred to as a coastal defense zone, instead of coastal defense line. The concepts of “Crest Drainage Dike”, “Overtopping resistance dike”, “second dike” and “flood storage area” are mentioned. A number of studies have been done regarding to understanding of social, economic as well as physical insights and safety aspects of the proposed innovated concepts. Case applications have been done for several locations along the North Sea. However within the project much attention is put on developments of the innovated concepts rather than focusing on a comparison of the proposed system with the conventional sea defenses. Thus, there is still lack of guidance and comparative framework to determine the best choice between conventional or innovated options for decision making.

In order to fulfill the gap, this study focuses on development of the comparative framework and generic guidance to support the decision making process in selection of the best suitable layout option of the defense system for a given location, in which two situations will be considered for the analysis: (i) using one defensive line; (ii) using two defensive lines (defense zone). Aspects of social, economic, environmental and technical characters are taken into account to perform analysis criteria. Finally application is made for the case studies of coastal flood defense in Vietnam.

2. PROBLEM DEFINITION AND STUDY APPROACH

Problem definition

For certain low lying coastal regions the main interest is how to protect the regions from sea floods. At present, different solutions may be considered, which varied from conventional approach (using one dike line) to integrated coastal zone defense approach (as concepts proposed by ComCoast project). Questions that arise in the decision making process at a certain location are “which solution should be applied” and “why is that so”. To present date there is still lack of tools and knowledge to give a proper answer to the question.

In practice, at different places, the applications of both solutions have been done so far and the defense systems were constructed long time ago, even though it is not clear why the solution came up. It is exactly the case for Vietnam’s coastal flood defense systems. For instance, along the coastlines in the North of Vietnam, sea dikes are used as a single defensive line in Quang Ninh and Hai Phong province. However, in Nam Dinh and Thai Binh province the dike system consists of two defensive lines. The choices of dike configurations as indicated above, were probably rather arbitrary or by local expertise with lots of trials during the time. Thus, there is a need for assessing effectiveness of each existing solution.

Study approach

To reconsider/reconstruct dike system in Vietnam, which are often in need to repair, one can choose between a traditional one high dike system or a combination of two dike with land in-between and with varying heights and strength. This study presents a generic approach to the various options in order to help making the right decisions for defense system construction in various cases. Beside this, alternatives for coastal defense systems are an important topic at the moment (see the EU ComCoast project).

Considerations are not only related to technical points of view, but also need to meet the societal requirement of the people living in the protected area, the economic development and the environmental aspects when the defense solution is applied. The study results aim at providing important basic for establishment of guideline in sea dike design in terms of selection of layout (master plan) and dike heights. Specifically, based on the analysis results of the case studies in Vietnam, a guideline for sea flood defense, which take into account country specific aspects, is proposed. Besides that, lesson learnt from existing Vietnam's sea flood defenses is thought to be useful for other low-lying countries/regions where sea dikes are needed.

In this paper the following steps and methods are adapted (i) establishment of a generic framework to support decision process in selection of a suitable layout of a sea dike system on the basis of multi-criteria analysis and cost-benefit analysis; (ii) applying the risk based approach to establish relation of dike heights and admissible/permissible wave overtopping discharge, giving different scenario of safety standards; (iii) demonstration of the approaches by a case study in Nam Dinh, Vietnam.

3. ONE VERSUS TWO DEFENSIVE LINES

General philosophy

This study uses wave overtopping as the dominant failure mode which plays the most important role in the determination of the height as well as the layout of a sea defence system. Wave overtopping and its permissible overtopped discharges will be used as a central concept in all analysis and comparisons of the considered options. The dike height/layout of a defence system is mainly determined by the quantity of wave overtopping.

Dikes can be made resistant to wave overtopping in two ways: making them so high that there is hardly any or no overtopping during storm period or make them lower and strong (especially the crest and the inner slope) so that they can withstand the wave load and allow more overtopping flow. The first approach (making dike so high) leads to very high and wide dike, which also means money and space consuming. By this approach we need only one line of flood defense system. The second approach (making dikes lower and strong enough) leads to a low and strong first dike line, and possibly a lot of water in the area behind the first dike line. Thus we need another dike line to prevent the water coming further inland. The water due to flooding from sea will be stored in a transition area lying in between these two dike lines. Therefore, a compromising solution has to be found between the height and the strength of the inner slope of a sea dike. A permissible amount of wave overtopping will determine the dike height. In return, to withstand such an overtopping flow, appropriate reinforcements of the crest and the inner slope should be applied. Application one of both approaches depends on the lands where you are, the living and the activities in that areas. Both approaches are analyzed on basis of the current safety standard of Vietnam for sea dike design. In which actual sea dikes in Vietnam are designed for an extreme storm condition with return period of 25 years (design frequency is 1/25). Some concluding remarks will be pointed out by applying different return periods (50 and 100 years).

Global option 1: One defensive line

One defensive line of a sea dike system are used in many countries in the world (e.g. The Netherlands, France, Germany, etc.). The dike bodies of this system are very strong and high that almost no overtopped water is allowed. The outer slope is heavily protected by revetment while it is not a must to protect the inner slope and crest from wave attacks. However, it is often the case that dike crest and inner slope are partly protected in combination of other purposes, for instance to avoid soil erosion due to rain water and using crest as traffic road (see *Figure 1*).

Global option 2: Two defensive lines

Since two defensive lines of a sea dike system is used some sea water is allowed to overtop the crest of the first dike under some circumstances. Therefore, during sea storm condition there can be amount of sea water behind the first dike. The first dike has not only revetment to protect outer slope, but also revetment to protect its inner slope. Therefore, the first dike is un-breakable. To prevent the flood water to flow landward further, a second defensive line of sea dike is constructed (see *Figure 2*). The area in between two defensive lines is considered as space to store sea flood water during sea storm. The questions are: Do people allow living in this transitional area? If it is possible, how to evacuate when flood occurs? What is the height of the second dike? How do waves attack on the second dike?

Dimensions of these sea dike systems are determined on the basis of cost balancing between initially investment cost (construction cost), maintenance cost and value of land behind the first and second dike as well as safety standard of the whole region.

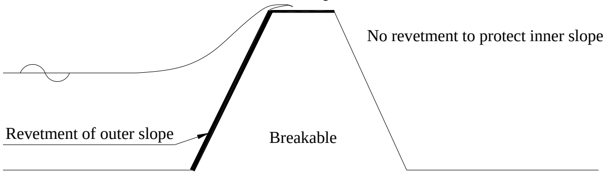


Figure 1: Cross-section of one defensive line

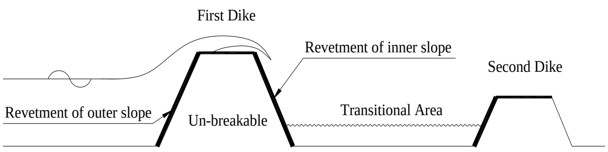


Figure 2: Cross-section of two defensive lines

Overtopping criteria for design dike heights

It is obvious that too low dikes lead to flooding by breaching of the dike due to too much wave overtopping. A safe approach is if no significant overtopping is allowed. In general this means that the crest height should not be lower than the 2%-wave run-up level (Pilarzyk, 1998).

Basis approaches for overtopping determination are introduced in *Figure 3*. This figure presents various methods which are applied for various slope protections under different conditions.

Definition of protection options is based on overtopping criteria. In this study four options are considered. The coastal flood defence system may be designed with condition of:

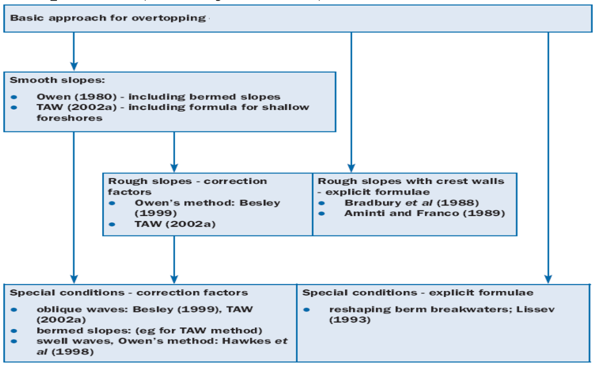


Figure 3: Calculation method for wave overtopping (CIRIA/C683, 2007)

1) *Non-overtopping*: the dike is designed high enough to avoid most of the wave overtopping. In this study it is referred to as a limit state of [*q*] = 0.1 l/s/m: no damage of buildings; no damage of embankments and seawall even crest is not protected; no need storage basin for flood water => no second dike is needed.
2) *Small overtopping* which is based on a limit state of [*q*] = 1-10 l/s/m: Damage if crest is not protected for embankment seawall; no damage for revetment seawall; no need a basin to store flood water => no second dike is needed.
3) *Medium-large overtopping* which is based on a limit state of [*q*] = 100 l/s/m: Damage if inner slope is not protected for embankment seawall; a basin need to be prepared for storage of overtopped water => Second dike is needed.
4) *Large overtopping* which is based on a limit state of [*q*] = 1000 l/s/m: Damage if exposed components are not well heavily protected (includes: outer and inner slopes; crest; outer and inner toes; and transition between components). A basin is certainly needed to be prepared for storage of overtopped water => Second dike is needed and considered as primary defense line.

Defensive options (alternatives)

On basis of overtopping criteria the following defense options are applied:

1. <u>Non-overtopping: one dike system</u>

This option aims at constructing one primary defense line which is designed under almost unable-overtop conditions. This defense line must be able to withstand all loads from the outer water as well as the waves (see *Figure 4*).

Main features: The total volume of constructed materials (core, filter and revetment) is large. High cost of investment but low cost of maintenances compare with the following options.

Range of application: This option is usually applied for a large coastal low-lying area in which floods may cause catastrophic disaster for the area. This is also applied for important economic and populated areas (e.g. a coastal city with many activities along coastline).

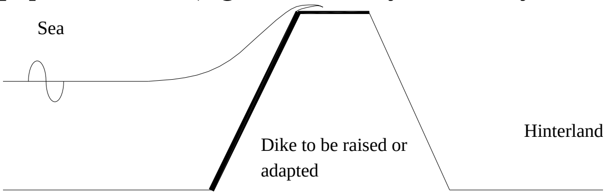


Figure 4: One dike system without overtopping

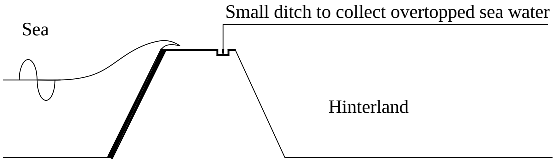


Figure 5: One dike system with small overtopping

2. <u>*Small overtopping: one dike system*</u>

Main features: The total volume of constructed materials is less than *Option 1*. Lower cost of investment but higher cost of maintenances compare with *Option 1*. Inspection of minor damages and in-time repairs are required after occurrence of sea storms. A small ditch to collect/ return overtopped sea water is recommended at inner side of the dike crest (see *Figure 5*).

Range of application: This option is suggested to be used in the case of unavailability of high investment cost while yearly minor maintenance is available with respect to cost and man power. The option is used to protect less important areas as in the previous case, in which due to overtopped water there is not any significant affect to the daily activities in the region.

At present this option has been used for most of the coastal flood defenses in Northern Vietnam.

3. <u>*Medium large overtopping: two-dike system*</u>

The first approach by using a two-dike system is making a high crest level of the primary dike (first dike line) in combination with a low crested second dike, see *Figure 6*. With this lower first dike some wave overtopping will occur but the overtopping discharge is quite low. The low crested second dike further inland protects the hinterland without inundation due to the overtopping water.

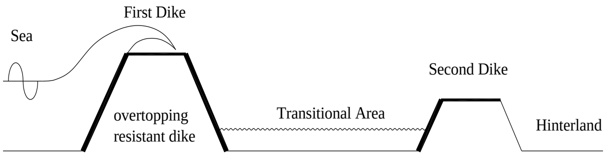


Figure 6: Using two dikes system with medium large overtopping

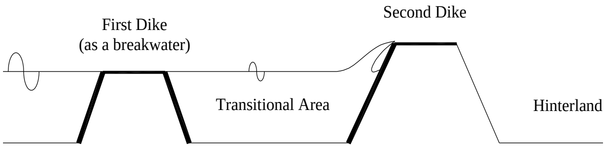


Figure 7: Using two dikes system with large overtopping

Main features: The total volume of earth and materials for dike body is larger than second option and comparable to the first one. Although heavy protection of the first dike is required, the investment cost for this option is lower than that of two previous options. Permanent land loss (ground used for dikes) is comparable to first option. However, large area between these two dikes is needed to keep flooded water. Depending on the land-use in between two dikes (e.g. in case housing and industrial sector take place), evacuation in area is needed, but the area is shortly accessible again after the storm. Inspection and regular maintenance of the first dike are necessary to ensure it is “non-breachable” dike.

Range of application: This option is usually applied for a relatively low land value coastal low-lying region in which floods may not cause serious damages for the regions. In practice this option is used as a coastal flood defense in rural/ aquaculture areas. This approach has been applied and developed in Vietnam during last 20 years at many places in the North. Local people take advantage of the basin between two dikes to develop aquaculture i.e. shrimp farms.

4. <u>*Large overtopping: Two-dike system – the first dike is a wave-breaker dike*</u>

The dikes in this approach combine a wave breaking line and a water defensive line. A lower first dike in combination with a higher second dike is used. The main purpose of the first dike is to absorb wave energy such as a near-shore breakwater (see *Figure 7*). The second dike endures less wave attack due to waves absorbed by the first dike. Thus, design waves for the second dike are chosen as wave condition after the absorption of first dike.

Main features: The total volume of earth and materials use for dike body is smaller than in the case of the above options. However, construction of the first dike is very costly. Land loss is comparable to third option (two dikes with medium overtopping). The area between these two dikes is flooded permanently and this may cause some environmental problems.

Range of application: This option particularly should be used to protect coastal zone in which its shoreline is exposed to large wave attacks. In addition, application of this approach may be suitable for a relatively low land value at a narrow strip along the shore but a high value hinterland. Moreover, use of this approach for flood defense in combination with shore protection in eroded coast would be of help. It could be suitable to protect high productive/value islands by this option.

4. MULTI-CRITERIA EVALUATION (MCE)

Comparative criteria

In the previous section various options for a coastal defense system have been discussed and presented. Distinction between these options is made by overtopping conditions. However, based only on the overtopped discharge criteria is not enough to come up with the proper option for selection of a certain sea defense system. Several criteria are needed for consideration to select the best option. In this study an MCE tool is used, in which following criteria will be taken into account.

Investment: Total investment cost of each option is considered as an important aspect. The investment takes into account the cost of dike body and the cost of dike protections. The most expensive solution would be *Option 1* while *Option 3* is the cheapest. *Option 2* & *3* are fairly equal. In this section only qualitative volume of materials used to construct the dikes is considered.

Maintenance: The potential damages, frequency and intensity of repairs of each option are considered as a criterion. It is often the case that an option with expensive investment results in a cheaper maintenance.

Safety of hinterland: An assessment of the current safety level of hinterland in each option will be carried out. The options are all designed on the same safety level, therefore their value is equal. In general, the safety of hinterland is weighted heavily because it is considered very important.

Potential flood risk: Potential risk is defined as

Risk = *Probability of failure* x *Consequence* (see CUR/TAW141, 1990)

in which, *Consequence* is the loss of assets due to flooding, evacuation cost, etc. The failure probability is similar for all options and is assumed to be equal to absolute value of design frequency. However, the consequence when a flood occurs is different in each option. Thus the potential risk is different as well. This criterion is important for any long term plan of coastal defense works.

Environmental issue and ecology: Implementation of a system will certainly have its effect on the current ecology and environment. Due to salt water intrusion and higher water level the ecology can be disturbed and changed severely. Due to construction of dikes natural environment/wetland area can certainly be damage or destroyed.

Land loss and interference: When a new system is implemented, extra space has to be created to construct it. Sometimes due to construction and dike rehabilitation local houses and villages have to be demolished or land with a certain use has to be bought from the current owners. The amount of land will be included in this criterion. Losses of economical value as well as the amount of damage of the transition area when this area is inundated are aspects that cannot be neglected.

Re-used materials: At some place the existing dikes are there and can be used as the base for new system. The level of re-use of existing dike bodies and elevations is important, therefore this is also a criterion will be used in the analysis.

Technical feasibility: This criterion is about the availability of technology, resources, construction materials and construction equipment in implementation of the system. The available space for construction and conditions such as weather and accessibility of the construction site are also considered.

Conceptual framework for assessments

A performance matrix will be used in process of assessing eight comparative criteria, which are proposed in previous section, for each option. In this matrix, weight and rank factors are depended on own subjective.

Weighting: Eight comparative criteria are proposed to assess options. The weight factor is introduced for each criterion and the value of this factor is based on the importance of each criterion in each option. The total weight factor is 100 points and these points are distributed among eight criteria as in *Table 1*.

Ranking: Each option is ranked based on the advantage of each option for each criteria presented above. Each criterion is ranked for every option from 1 (very bad) to 5 (very good). For example, the construction costs of *Option 1* (very high and big dike) are highest so *Option 1* is ranked of 2 (bad option based on high construction costs). On the contrary, *Option 3* (lower and smaller dikes) has smaller construction costs, and this option is ranked of 5 (good option based on the construction costs).

After that we multiply the weight factor and the ranking point of each criterion for each option results a called "*score*" of each criterion. The total score of each option is obtained by summing up all scores of the option. The best option has the highest total score.

Beside above four options, when applying the MCE tool for any case study a "*zero option*" will be introduced. The zero option demonstrates the present situation of coastal flood defense of the case study area.

5. RISK BASED COST BENEFIT ANALYIS (RBCBA)

Methodology and assumption

This section presents the application of risk based cost benefit analysis to find out the best solution amongst given other options. Again three scenarios (with return period of 25 years, 50 years and 100 years) could be considered in the analysis.

According to the method of fundamental economic optimization (Dantzig, 1956), the total costs in a system (C_{tot}) are determined by the sum of the initial investment cost ($I_{initial}$) for building the dike; the present maintenance cost during the lifetime of the system $C_{maintenance}$; the expected value of land space which is used for building the system (to place the dike system), $C_{land\ use}$; and the present expected value of the economic damage $E(D)$ in case of flood occur. The optimal economic solution is the option which has the lowest total cost.

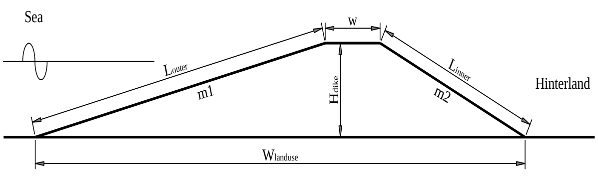
$$C_{tot} = I_{initial} + PV(C_{maintenace}) + C_{landuse} + PV(E(D)) \quad (1)$$

Due to time limited therefore only scenario 1, with return period of 25 years and is actually used in Vietnam, is considered. An analysis of other scenario could be easily done by applying a similar approach. Previous section already narrowed down the better sea defence options, these are: (i) *Option 1*: non-overtopping dike; (ii) *Option 2*: Small overtopping dike and (iii) *Option 3*: Medium-large overtopping first dike and second dike is needed. In this section, three better options are considered and compared to find out the best option.

Establishment of costs of option 1 & 2 (using one dike line)

Initial investment cost:

$$I_{initial} = f(H_{dike}) = C_1.A_H + C_2.L_{outer} + C_3.L_{inner} + C_4.w \quad (2)$$



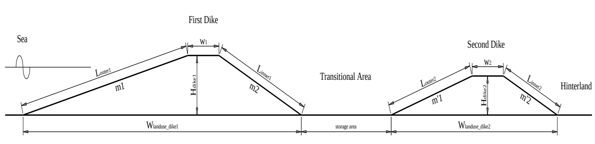


Figure 9: Specific parameters of one dike line system *Figure 10: Specific parameters of two dike lines system*

in which, C_1 is the rate of constructed dike body (Mil. USD/m^2/km); C_2, C_3 & C_4 are the construction rate of the outer slope, inner slope and crest protection, respectively (Mil. USD/m/km); A_H is the cross section area of the dike (m^2), L_{outer} and L_{inner} are the length of outer and inner dike slope, respectively (m). The detail estimation of these variables is given in Mai (2008).

Expected maintenance cost: $C_{maintenance} = f(q)$, in which q is average overtopping discharge in l/s/m. The present maintenance cost is estimated by:

$$PV(C_{maintenance}) = C_{maintenance} * \sum_{i=0}^{i=T} \frac{1}{1+r'^{\ i}} \quad (3)$$

in which, T is the lifetime of the dikes (years) and r' is the reduced value rate.

Cost of land-use of one dike system is determined by:

$$C_{landuse} = C_5 . W_{landuse} \quad (4)$$

in which, C_5 is the rate of land use (Mil. USD/m/km) and $W_{landuse}$ is the length of the land which is used to place dike system (m).

The expected value of economic damage has to be discounted to present value with the reduced value rate $r' = r - g$, in which r is the real interest rate and g is the economic growth rate. The expected value of the economic damage can be calculated from the probability of flooding (P_f), the damage caused by the flood, D (see Eq. 5, in which T is the lifetime of the structure).

$$PV(E(D)) = P_f * D * \sum_{i=0}^{i=T} \frac{1}{1 + r'^{\,i}} \quad (5)$$

Establishment of costs of option 3 & 4 (using two-dike line)

The initial cost of this option is calculated by:

$$I_{initial} = f_1(H_{dike1}) + f_2(H_{dike2}) \quad (6)$$

in which, $f_1(H_{dike1})$ and $f_2(H_{dike2})$ are the initial cost function of the first dike and the second dike of defence system, respectively. These initial costs can be estimated by Eq. 2;

Expected maintenance cost:

$$C_{maintenance} = C_{maintenance\_dike1} + C_{maintenance\_dike2} \quad (7)$$

in which, $C_{maintenance\_dike1}$ and $C_{maintenance\_dike2}$ are the maintenance cost of the first and second dike, respectively. The present maintenance cost is determined by Eq. 3.

The cost of land using of two dikes system is determined as

$$C_{Landuse} = C_5 .(W_{landuse\_dike1} + W_{landuse\_storage} + W_{landuse\_dike2}) \quad (8)$$

in which, C_5 is the rate of land use (Mil. USD/m/km), $W_{landuse\_dike1}$ and $W_{landuse\_dike2}$ are the widths of land which are used to place the first and second dike, respectively (m); $W_{landuse\_storage}$ is the width of land which is used in storage area to place sub-crossing dikes (m).

Expected value of economic damage when flood occurs is determined by Eq. 5.

6. RESULTS AND DISCUSSIONS

Application in Hai Hau, Nam Dinh

<u>MCE approach:</u> *Table 1* summarizes all weight factors, ranking factors and scores of eight indicated criteria above for the application of MCE in Nam Dinh's coastal area.

As shown in *Table 1* the total score of *Option 3* - medium large overtopping (two-dike system) has the highest score. The second highest in the total score is *Option 2* - small overtopping (one dike system). The different of total scores of these both options is considerable (60 scores). Therefore, a two-dike system which allows medium large overtopping is suggested in Nam Dinh coastal area. This is interesting that this agrees well to actually use of the sea defense system in Hai Hau, Nam Dinh.

Table 1: Application of MCE in Nam Dinh coastal area

No.		Criteria	Weight	Zero Opt	Opt.1	Opt. 2	Opt. 3	Opt. 4
1	Investment	20	Weight	20	20	20	20	20
			Rank	5	2	3	4	1
			Score	100	40	60	80	20
2	maintenanc e	5	Weight	5	5	5	5	5
			Rank	1	5	3	4	2
			Score	5	25	15	20	10
3	Safety of hinter land	20	Weight	20	20	20	20	20
			Rank	1	5	5	5	5
			Score	20	100	100	100	100
4	Potential flood risk	20	Weight	20	20	20	20	20
			Rank	2	2	2	4	4
			Score	40	40	40	80	80
5	Environme nt Impact	10	Weight	10	10	10	10	10
			Rank	4	2	4	3	1
			Score	40	20	40	30	10
6	Land loss for defence system and its value	10	Weight	10	10	10	10	10
			Rank	5	3	4	2	2
			Score	50	30	40	20	20
7	Re-used material	10	Weight	10	10	10	10	10
			Rank	5	2	2	4	1
			Score	50	20	20	40	10
8	Feasibility	5	Weight	5	5	5	5	5
			Rank	1	3	3	4	2
			Score	5	15	15	20	5
Total Score		**100**		**310**	**290**	**330**	**390**	**260**
Selection (1=best; 5=worst)				3	4	2	1	5

Zero Option: Do nothing

Option 1: Non-overtopping - q = 0.1 l/s/m, one very high dike system

Option 2: Small overtopping - q = 10 l/s/m, one relatively high dike system

Option 3: Medium large overtopping - q = 100 l/s/m, two dike system, first dike is higher than second dike

Option 4: Large overtopping - q = 1000 l/s/m, two dike system (first dike - as breakwater, is lower than second dike)

Ranking factor: 1 (very bad) to 5 (very good)

<u>RBCBA approach:</u> The total cost of *Option 3* (with two-dike system) is the lowest among three considered options. The optimal economic solution for flood defense system in Hai Hau is, therefore, the option of using two-dike line (*Option 3*). This is similar to the actual use at several places along Hai Hau coastal zone. The

application of this two-dike system should be implemented widely for coastal flood defences in Nam Dinh.

Advantage of MCE method is to find out the best solution of sea flood defense system. Based on the general information of socio-economic development, people's living condition, and economic strategy developments as well as required safety standard of protected zone, etc. the MCE tool could be used to develop the master plan of flood defence system.

MCE tool also has disadvantages in process of assessing the performance matrix. It is difficult to distribute weight factor for each criterion and this assessment is depended on own subjective. Thus, to apply an MCE tool more effectively and close to the actual situation, some activities should be under taken before making the matrix of MCE. They could include:

- Survey public opinion by distribute surveying forms to civilians in the region;
- Organize multidisciplinary meetings with all stake holders in the region;
- Final decision on weight factor should be based multidisciplinary expert assessments and practical situations in the area.

Nevertheless, for a preliminary stage, the MCE is a useful tool to orientate well and to indicate briefly which defensive option should be considered. In order to come up with more consistent answers, further analysis must be done i.e. cost benefit analysis, partly and/or fully risk assessment, etc.

Result of RBCBA for the case study in Nam Dinh's coastal zone shows that *Option 3*, using two-dike system, is the best solution for this area. The total cost of *Option 3* depends on the width of the transitional area between two dikes and the unit cost of land use in the region (see *Figure 11*). As showing in *Figure 11* the total cost of the defense system is proportional to the unit cost of land use (C_5) and disproportional to the width of transitional area (L). In coastal areas which have widely land space (in the direction of perpendicular to the coastline) and low land values (at present), the two defense lines could be more applicable, e.g. in Hai Hau coastal area. In addition, if the width of transitional area increases from 250 m to 1000 m the total cost of defense system decreases rapidly and if this width increases continuously up to 2250 m the total cost of defense system decreases slowly. This means if the width of transitional area continuity increases the total cost is reduced not considerable.

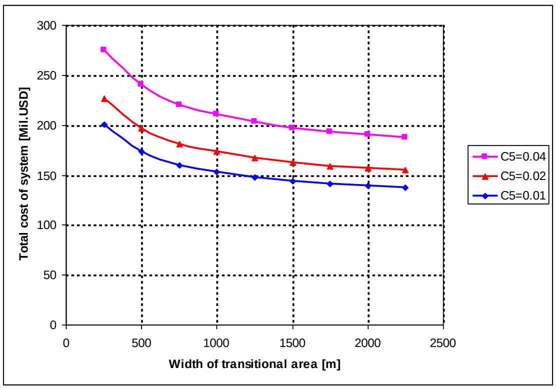


Figure 11: Sensitivity of total cost of Option 3

7. CONCLUSIONS

The MCE, which is developed and applied in this study, is a useful tool for a preliminary decision making stage when comparing different coastal flood defense options. The MCE tool takes into account various criteria in its comparison process such as cost of investment and maintenance, safety of hinter lands, potential risk of protected region, environmental issue, land use problem as well as technical feasibility and re-using the material from old defense systems. These criteria reflect well considerations of both technical and social economic aspects regarding to the local condition of a certain protected region. By using the MCE tool, not only better defense options are detected but also the best defense option can be found in view of social, economic and technical considerations.

As soon as some better defense options are narrowed down by application of the MCE tool, a so-called "Risk Based Cost Benefit Analysis" approach (RBCBA) is used to validate and confirm in the comparative process to find out a more consistent answer. In this study three better options among five indicated options are selected by applying the MCE tool. The best option is defined consistently based on the risk based cost benefit analysis of given three options.

Applications of the MCE framework and RBCBA to the Vietnamese case studies give us interesting results. The case of coastal flood defense in Hai Hau, Nam Dinh, *Option 3* - medium large overtopping which requires a two-dike system has the highest score in MCE and lowest total cost in RBCBA. The second highest in total score is the *Option 2* - small overtopping which uses one dike system.

This study could provide important basic elements for establishment of guidelines in sea dike design in terms of the selection of layout (master plan) and dike heights. The methods and approaches used in this study have shown to work out well in the case of coastal flood defenses in Vietnam. This could be useful for the actual Sea dike research program in Vietnam as well as for many other cases of coastal flood defenses.

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