

Two-dike system along Vietnam coast

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Abstract: To get insight in the costs of a 2-dike system along the coast and to find optimum solutions for flood defence, a simple but comprehensive model is made. Total costs are calculated based on loads and strength of the dikes.

Keywords: two dike system, coastal defence, coastal zone management, sea dike

1. Introduction

A two dike system is sometimes mentioned as a good tool to improve the safety against flooding along the Vietnam coast. Little has been done until now to quantify the system and to see if and where there is some optimum in the choice between one or two dikes. To get some idea, a simple program has been made to explore the properties of this system. Basically the system consists of two dikes with space in between. The seaward dike is named here dike 1 and the landward dike, dike 2.

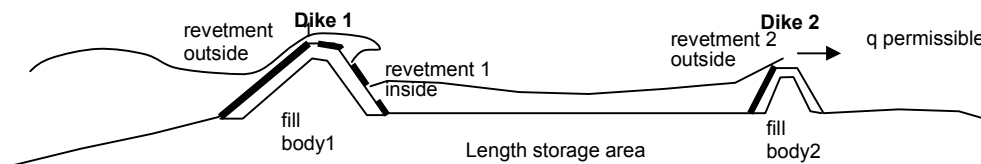


Figure 1. A double dike system

Main question is: how to design a dike system such that maximum protection of the area behind the system is reached against minimal costs. Different approaches are thinkable, like:

- there is only one dike with an amount of overtopping which is acceptable for the hinterland to be protected.
- dike 1 should be just strong enough to survive a typhoon and high enough to reduce the waves for dike 2, which is somewhat higher to withstand the water level in between the two dikes and which gives the same amount of overtopping as in the first case.
- the area between the dikes is large enough to store all the overtopping water of dike 1 during a typhoon; dike 2 is just high enough to withstand that water level (which depends on the size of the area in between) and has again the same overtopping to the hinterland.

With all variables involved it is already so complicated that a structured approach is necessary to overview all possible combinations and to find a minimum in total costs. Completeness is here more important than accuracy or scientific value, therefore a program has been made which is simple, but in which "everything" is included.

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The total costs consist of dike bodies, cover of dikes with clay/grass/filter, revetments on both dikes, cost of land to build the dikes on and costs of decrease of value of storage area (limited usability, so-called depreciation).

The loads on the system components are: wave load on seaward slopes of dike 1 and 2 depending on water levels at sea and between the dikes. The strength is indicated by the size of the revetments or the permissible overtopping discharge.

2. Model

2.1 General

As said, a model is made to calculate the total costs as a function of the variables involved. The variables in the system are mainly:

- permissible overtopping discharge dike system
- strength dike 1
- height dike 1
- strength dike 2
- height dike 2
- size area in between

Of course, all these variables are related but the height of dike 1 has been chosen as "independent" variable in the model. This only means that all other variables are shown as a function of the height dike 1. Input parameters in the model are:

- *Boundary conditions*: waterlevel outside (m above MSL), incoming wave height (m), wind velocity (m/s), storm duration (hrs), permissible overtopping discharge total system (m^3/s). This last parameter is crucial for the functioning of the system. Usually, the landward slope of dike 2 has a protection of only grass which can stand only small overtopping. In cases where the inner slope is strong the overtopping discharge is limited by the trouble it causes in the hinterland.
- *Geometry*: length between dikes (m), level of area between dikes (m above MSL), seaward and landward slopes of dike 1 and 2, crest width dike 1 and 2, roughness coefficient seaward slopes dike 1 and 2, thickness of cover layer dikes (under revetment),

The cost parameters in the model input are (values can be chosen freely):

- *Fill material*. This is the main part of the dike body, it can be sand or any other material. Default value in the model is $10 \text{ \$/m}^3$.
- *Cover material*. This the layer under the revetment and usually consists of clay. When there is no revetment (like on the landward slope of dike 2), the cover layer is covered with grass or some other vegetation. Default value in the model is $20 \text{ \$/m}^3$.
- *Revetment*. This is the protection layer on the seaward and landward slopes of dike 1 and the seaward slope of dike 2 and usually consists of concrete blocks with some filter layer. Default value in the model is $250 \text{ \$/m}^3$.
- *Land*. This is the cost of the land on which the dikes are built. Default value in the model is $50 \text{ \$/m}^3$.

- *Depreciation.* This is the loss of value of the area between the two dikes. This will appear to be a very important parameter. The general idea is that, because the area will be flooded during a heavy storm, activities in the area between the dikes are limited to those that are not harmed by flooding, like shrimp farms or salt ponds. No housing or industry will be allowed. That means that when the area does have the potential for housing or industry there will be an economic loss in the area when these activities are forbidden.

2.2 Formulas used

Note: The relations used in the program are a crude approximation of usual design formula. This is justified since they are not being used for the design of a dike itself, but to get insight into the system as a whole.

Overtopping:

$$q = 0.2 \sqrt{gH^3} \exp \left[-2.6 \frac{(h_{crest} - h)}{H\gamma_f} \right] \quad (1)$$

(see [1]) in which H and h are the wave height and water level outside the dike respectively. γ_f is the roughness coefficient of the outer slope. This expression is only valid for relatively long waves (small height, long period) which is justified since, under typhoon conditions, the waves are depth limited. Conversely, given a permissible overtopping discharge, the height of a dike can be computed from equation (1).

Water level at dike 2:

$$h_2 = q.T_t + h_{st} + \Delta h \quad (2)$$

(see e.g. [2]) in which T_t is the duration of the typhoon, h_{st} the ground level of the area between the dikes and Δh the wind surge between the dikes. At dike 1 the water level can never be higher than the crest level of dike 1.

Wave height at dike 2:

$$H_2 = \frac{0.283w^2}{g} \tanh[f(d, L, w)] + 0.5H_1 \exp \left(\frac{-1.5(h_{crest} - h_{sea})}{H_1} \right) \quad \text{with: } H_{2max} = \frac{d}{2} \quad (3)$$

(see e.g. [3] and [4]) in which the first part is the Brettschneider formula for locally generated waves and the second part is a relation for the wave transmission across dike 1.

Thickness revetments:

$$\text{outer slope: } d_{rev-out} = 0.25H \quad \text{inner slope: } d_{rev-out} \left(\frac{q_1}{q_{1-0}} \right)^{2/3} \quad (4)$$

(see e.g. [5]) in which q_1 is the overtopping discharge at dike 1 and q_{1-0} the overtopping discharge at dike 1 when the crest level is equal to the water level outside. The thickness of the revetment at the outer slopes of the dikes is computed with a highly simplified version of relations of the type $H/\Delta d = f(H, \text{dike slope}, \dots)$. For the inner slope there are no good relations available, so it is approximated proportional with the overtopping discharge.

3. Results

3.1 Base case

At first, intermediate and overall results for a base case will be shown. In 3.2 overall results for other cases will be given. The base case here has the following input:

Water level at sea	MSL +4m	Seaward slope dike 2	1:3
Wave height	2.5 m	Landward slope dike 2	1:2
Wind	30 m/s	Crest width dike 2	5 m
Storm duration	6 hrs	Roughness coefficient dike 2	0.9
Level area between dikes	MSL	Thickness clay cover	0.5 m
Permissible overtopping	0.01 m ³ /s	Price dike fill	10 US\$/m ³
Seaward slope dike 1	1:4	Price clay cover (incl. grass)	20 US\$/m ³
Landward slope dike 1	1:2	Price revetment (incl. filter)	250 US\$/m ³
Crest width dike 1	5 m	Price land to build dike	50 US\$/m ²
Roughness coefficient dike 1	0.9	Depreciation costs	0 US\$/m ²

The intermediate results will be presented for 3 lengths of the area between the 2 dikes: L1=100m, L2=500m and L3=1000m respectively. The height of dike 1 varies from the water level outside till 8 m higher.

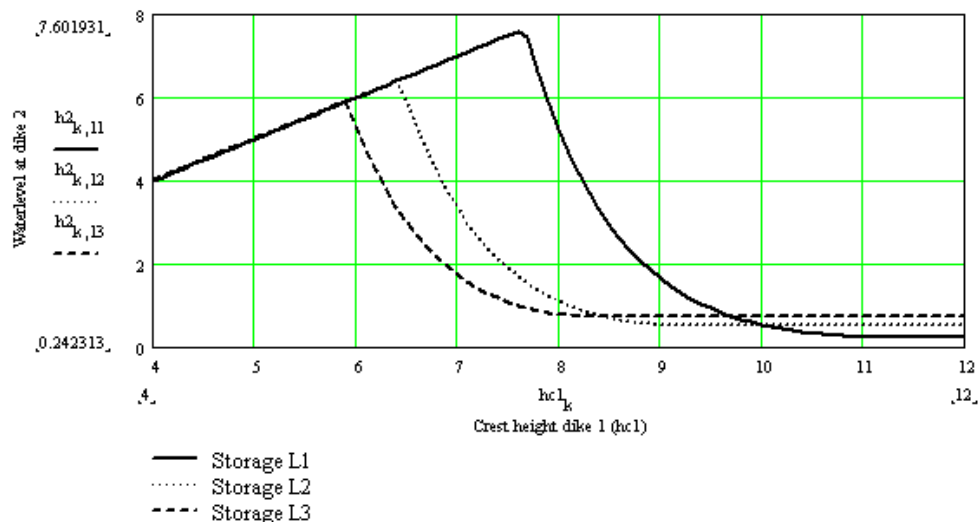


Figure 2. Water level against dike 2 as function of height dike 1 and storage area

Figure 2 gives the water level at dike 2. With a low crest level of dike 1, the water level at dike 2 is the same as the crest level of dike 1. In that case there is so much overtopping that the whole area is filled with water. For larger storage areas, the favorable effect of storage becomes effective earlier (at a lower crest level of dike 1).

For very high crest levels of dike 1 the water level at dike 2 does not become 0, because the overtopping discharge in equation 1 does not become 0 and the wind causes a set-up. This is not a physical correct representation but it is insignificant in the final cost functions.

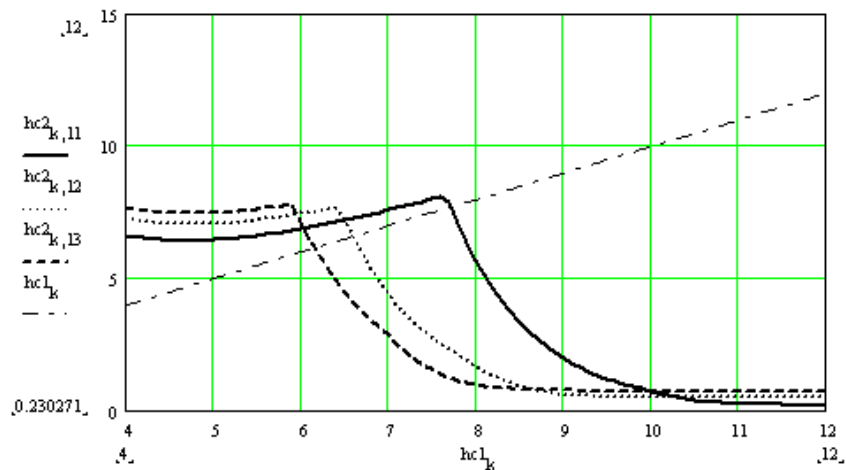


Figure 3. Height dike 2 as function of height dike 1 and storage area

With the water level from Figure 2 and the wind waves of equation 3 the height of dike 2 is computed from equation 1. Figure 3 shows the results. The thin dash-dot line represents the height of dike 1. It is clear that dike 2 is higher than dike 1 for low heights of dike 1 and becomes much lower when dike 1 is high, also depending on the length of the storage area.

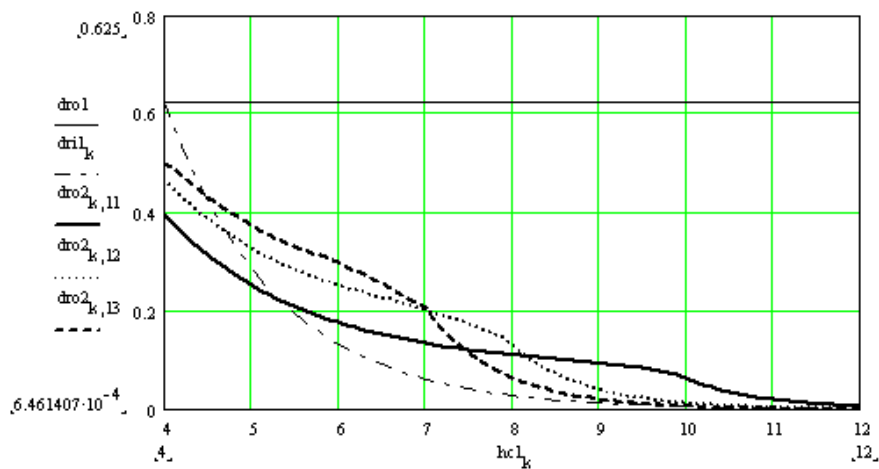


Figure 8 Thickness revetment on slopes of dike 1 and 2

With the wave height from the boundary condition, the revetment on dike 1 is calculated with equations 4. The thin solid line in Figure 4 represents the thickness of the (concrete) revetment on the seaward slope of dike 1 (independent of the height of dike 1). The thin dash-dot line gives the thickness of the revetment on the landward slope of dike 1. The other three lines with the same characteristics as in Figures 2 and 3 show the results for the seaward slope of dike 2.

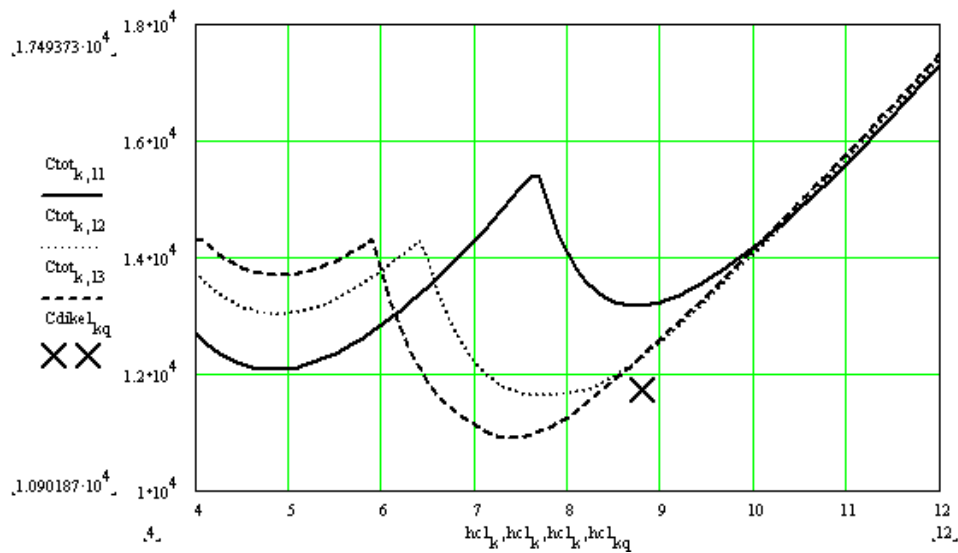


Figure 5. Total costs of dikes as function of height dike 1 and storage area (US\$/m)

With the levels of the two dikes, the thickness of the revetments, the other geometrical parameters from the input table and the price input, the total costs can easily be calculated. Figure 5 gives the total costs for the same three storage area lengths as in the other figures. For the smallest storage area ($L=100\text{m}$), the minimum costs occur for a height of dike 1 around MSL + 5m, where dike 2 has a height of about MSL + 6.5m. For the largest storage area ($L=1000\text{m}$), the minimum costs occur for a height of dike 1 around MSL + 7.5 m, where dike 2 has a height of about MSL + 2m. The cross indicates the height and total costs of a 1-dike system with the same permissible overtopping (nearly 12,000 US\$/m).

This complex situation can better be presented as in Figure 6 where the whole field is represented for all combinations of height dike 1 and length of storage areas:

The horizontal axis in Figure 6 now represents the difference between height of dike 1 and water level at sea ("freeboard") because of graphical software reasons. Vertically, the storage length is given. Figure 5 gives horizontal cross-sections of Figure 6. The costs are represented as contours in grey scale: darker means lower costs. The lowest costs are being found around heights for dike 1 of MSL + 6.5m with a storage length of 5000 m ($< 10,000$ US\$/m). Another relative low ($\sim 12,000$ US\$/m) is found for height dike 1 of MSL + 5m and a very small storage length.

These results ask for some reflection. A 2-dike system with a very large storage area in between (5000 m is not a minimum yet) seems very attractive. But in the area no high value activities like housing or industry can be located. Figure 6 is therefore misleading and so-called depreciation costs have to be taken into account..

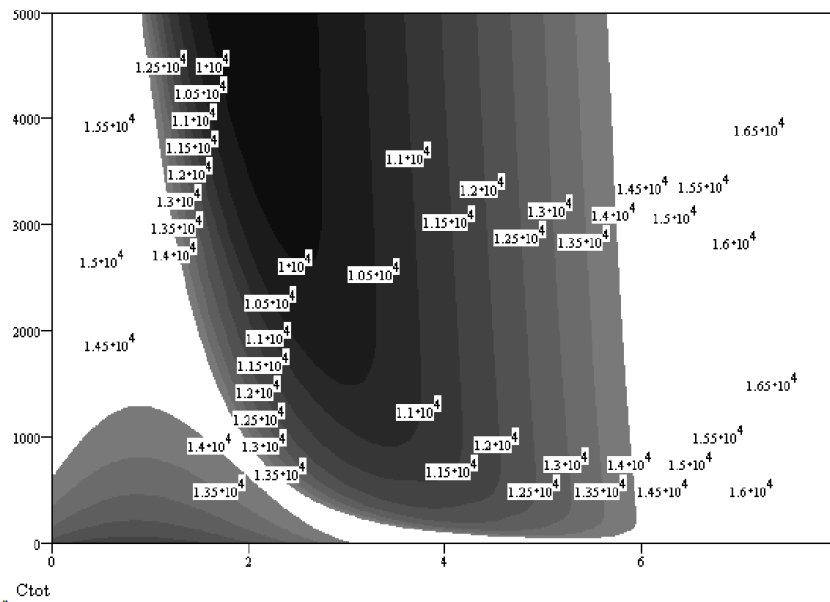


Figure 6. Total cost contours as function of "freeboard" and storage length

3.2 Depreciation costs

When the area between the dikes can not be used for high value activities, this will lead to depreciation costs, a loss of value of the land. Take for example 50 US\$/m², the same amount as the price of land to build the dikes on in this example.

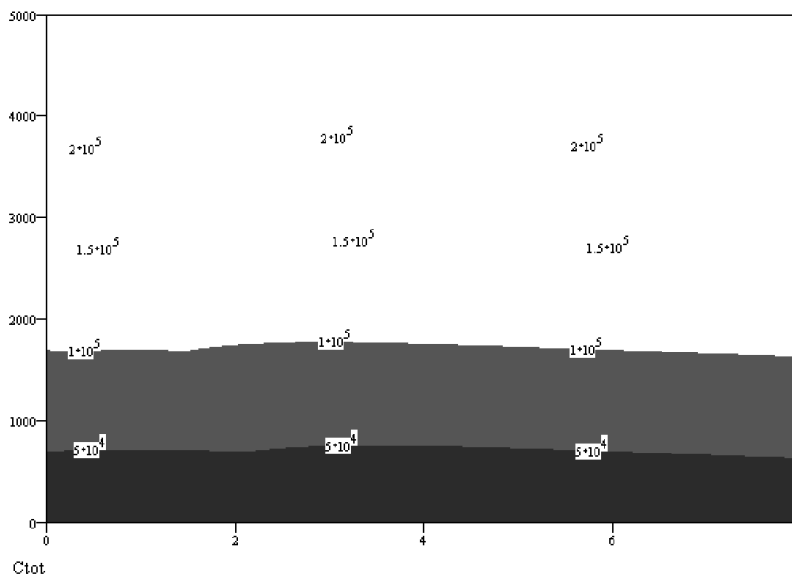


Figure 9. Total cost contours with high depreciation costs (50 US\$/m²)

Figure 7 gives the result. Now the picture completely changes! There is hardly any difference between the various heights of dike 1 and the result is dominated by the length of the storage area. The total costs are always higher than the costs for a 1-dike system. Already with depreciation costs of 2 US\$, see Figure 8, although there is a clear minimum, the costs for a 2-dike system are equal to a 1-dike system.

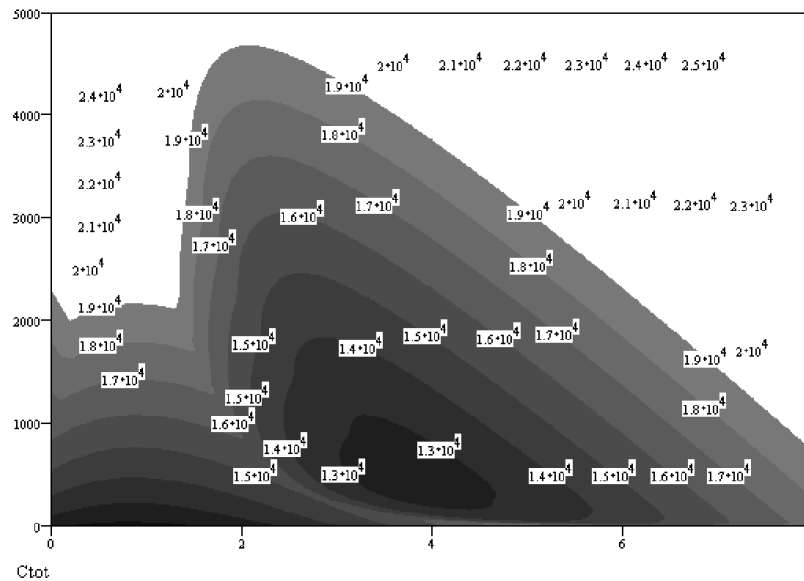


Figure 8. Total cost contours with depreciation costs 2 US\$/m²

4. Conclusions

- 1) When depreciation costs of the land between the dikes of a 2-dike system can be neglected, the presented method can be used to determine the height and other characteristics of the two dikes, using Figure 6. This can be done either by starting at a certain storage length, leading to the height of dike 1 or vice versa. Note: The method does not present a detailed technical design; that will still have to be elaborated.
- 2) When there are considerable depreciation costs (in common language: when there is any better use for the land than inundation, like housing or industry), a 2-dike system is always more expensive than a 1-dike system.

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Biography

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