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# The use of mangroves in coastal protection

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**Abstract**: Apart from many ecological advantages, mangroves in front of a coastal defence may lower the construction and maintenance costs of the defence. Although mangroves have hardly any reducing effect on water levels (and on tsunami impact) mangroves may significantly reduce wave attack on a coastal dike, and in this way reduce the cost of a revetment and lower the design height of a levee because of reduced run-up and overtopping height. This paper describes a design tool for the required width of the mangrove belt, as well as some guidance for planting the mangroves. Design graphs are presented to determine the required mangrove belt as a function of deep water wave action and mangrove density.

***Keywords***: *mangroves; coastal protection; sea dikes; revetment.*

## INTRODUCTION

### Objective

Mangroves fulfil an important role in the coastal ecosystem and are also important for coastal protection. However, many advocates of the protection of mangrove areas assign sometimes qualities to mangrove belts which cannot be fulfilled by mangroves. This paper tries to provide an overview of methods how mangroves can be used as coastal protection, including some advices how to create mangrove forests on places where the have been disappearing.

### Overview of coastal problems

In coastal areas one may distinguish two types of problems. The coast may erode (either continuously due to chronic erosion, or during storm events) or/and the coast may endure flooding during extreme high water events (storms, tsunamis). Usually mangrove forest do not slow down coastal erosion, however they may enhance coastal accretion. Planting of mangroves in that way will protect the coast against erosion on the long term.

Regarding flooding mangroves cause a considerable wave damping and decrease flow velocities. However, mangroves do not decrease the water levels. This means that mangroves do not work as food protection as such (Schiereck and Booij (1995) already showed that for a water level reduction a mangrove belt of many kilometres wide is needed).

### Mangroves and tsunamis

Tsunamis are long waves in deep water. However in shallow water the character of a tsunami wave changes and on the shoreline it behaves like a translation wave. Mangroves give an extra resistance to the flow, which might decreases the flow speed somewhat, but significantly. The water level will hardly decrease.

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Fritz (2011) surveyed Chile but also a dozen other tsunamis including Japan. In many of these events he found large swaths of coastal forests, jungles, mangroves and tsunami forests destroyed or even stripped completely of any vegetation. Examples with more than 500m in cross-shore direction of coastal forests uprooted and completely destroyed were observed not only in catastrophic events such as the Indian Ocean 2004 tsunami but also during smaller events in the past 5 years:

- Java, Indonesia 2006, on Nusa Kambangan Island
- Samoa/Tonga 2009, on Niuatoputapu Island
- Mentawai, Indonesia 2010, on Sibigau Island
- Japan 2011, the tsunami control forest at Rikuzentakata consisted of 70000 pine trees and only one single tree survived the tsunami and flooding extended 8km inland at this location.

In all the above cases there was only a barren landscape left behind.
Therefore mangroves cannot be considered as effective protection against tsunamis. However, recent disasters with tsunamis have also shown that the number of casualties behind mangrove belts was less that along coasts without tsunamis. However this is not due to the damping effect of mangroves, but because of the existence of a mangrove belt, the population did not live directly along the water line but more inland.

## THE ADVANTAGES OF A MANGROVE BELT

Mangroves have many ecological advantages; however they will not be discussed in this paper. Apart from ecological advantages, there are also social and economic advantages. Because mangroves provide a good ecosystem, fishery usually benefits from the existence of mangrove forests. Mangroves also prevent people to live too near to the coast, which may protect them from tsunamis.
But from a coastal engineering point of view a very important advantage is that the wave height is considerably reduced by mangroves. Because of this a coastal protection structure behind a mangrove belt can be lower and does not need a costly revetment.

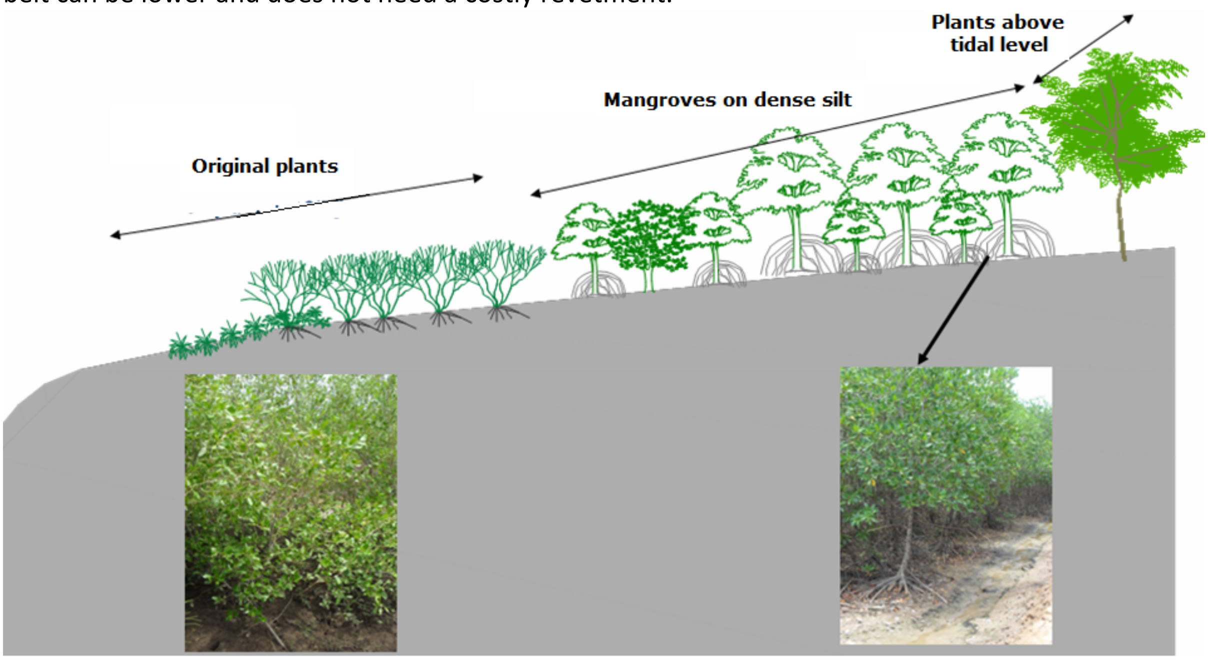


**Figure 1: Natural ecological succession of mangroves**

Another effect of a mangrove belt is that it stimulates siltation. Because currents reduce in the forest, more sediment will settle. On long term this will have the advantage that a higher foreland will even reduce wave action much more, and consequently there will be less load on the dike.
However, because specific mangrove species require a very specific average waterlevel and tidal range, the consequence is that the species in the forest will change. This natural succession process can be enhanced artificially, but should certainly not be counteracted. See also figure 1.
In some situations mangrove belts may decrease erosion. This is mainly caused by the fact that in the forest the current velocities are lower. However on the edge of a mangrove forest, especially in case of a deeper channel with strong currents, mangroves do not decrease the local erosion of the (underwater) banks of this channel. The mangroves are undermined and will be washed away.
Planting mangroves in order to decrease erosion usually does not work. Young mangrove seedlings are not able to withstand the erosive forces and therefore will be washed away before they mature. Mangrove seedlings always need artificial protection.

## PROBLEMS WITH MAINTAINING A MANGROVE BELT

Existing mangroves may suffer from ecological stress. This may be because not sufficient area is left over after the construction of fish ponds, too much pollution. Or cutting trees has made the forest vulnerable to wave and/or wind action. However, usually existing mangrove forests show very few stability problems.
Creating a new mangrove forest is quite difficult. It is much easier to maintain an existing forest than creating a new forest. The main point is that mangrove seedlings only grow to mature trees in a rather protected area. Mature trees can withstand quite some wave action, seedlings cannot. This means that mangrove plantations always need temporarily protection works.
Apart from this protection, mangroves do not grow on areas with the wrong subsoil. Also mangroves require very specific water levels, salinity and tidal ranges. Especially the percentage of submergence is an important parameter. Given the local physical conditions, one has to select those mangrove species which thrive in this specific environment. For details is referred to Marchand (2008).
This paper will give some guidance on the required width of the mangrove belt, as well on the temporary protection measures.

## DESIGN METHOD TO CALCULATE WAVE TRANSMISSION IN A MANGROVE FOREST

### Overview

As stated before, mangroves do not decrease the flood level during typhoons and cyclones. However, they do decrease the flood protection cost significantly. For the protection of land against floods usually dikes are constructed. The design height of a dike consists of design water level + freeboard. Mangroves do not decrease the design water level, but do decrease the freeboard considerably. Also because mangroves dampen the waves, often no costly revetment is needed on the dike. For a case study in Vietnam (typhoon level 4 m above mean sea level, wave height of 2 m) is was found that the reduction in dike height was in the order of 4 m, which resulted in a reduction of 30 m in dike width. Also in this case 20 $m^2$ per running meter concrete block revetment was not needed in case of wave damping by mangroves. This all gave a cost reduction for a cyclone protection dike per running meter in the order of 70 million Vietnamese Dong. The cost of planting mangroves in front of a dike is in the order of 1 million Vietnamese Dong per running meter, so a combination of a low dike with mangroves is considerably cheaper that a high dike without mangroves. The main component of saving is the fact that no revetment structure is needed for the dike. Based on measurements at this moment a relation between tree density and wave attenuation is known (Quartel *et.al.*, 2007, Quynh, 2010).

**Figure 2: Example of a dike revetment recently constructed in Vietnam because of a disappearing mangrove forest**

**Calculation of $K_t$**

Usually the reduction of wave height in a mangrove forest is expressed with the value $K_t$, where:

$K_t$ = wave height at toe of the dike, $H_d$)/(wave height at sea side of mangrove belt, $H_0$)

In international literature (e.g. Quartel et.al , 2007) also the value *R* is used, which is defined as:

$$R = \frac{H_0 - H_d}{H_0} = 1 - K_t \quad (1)$$

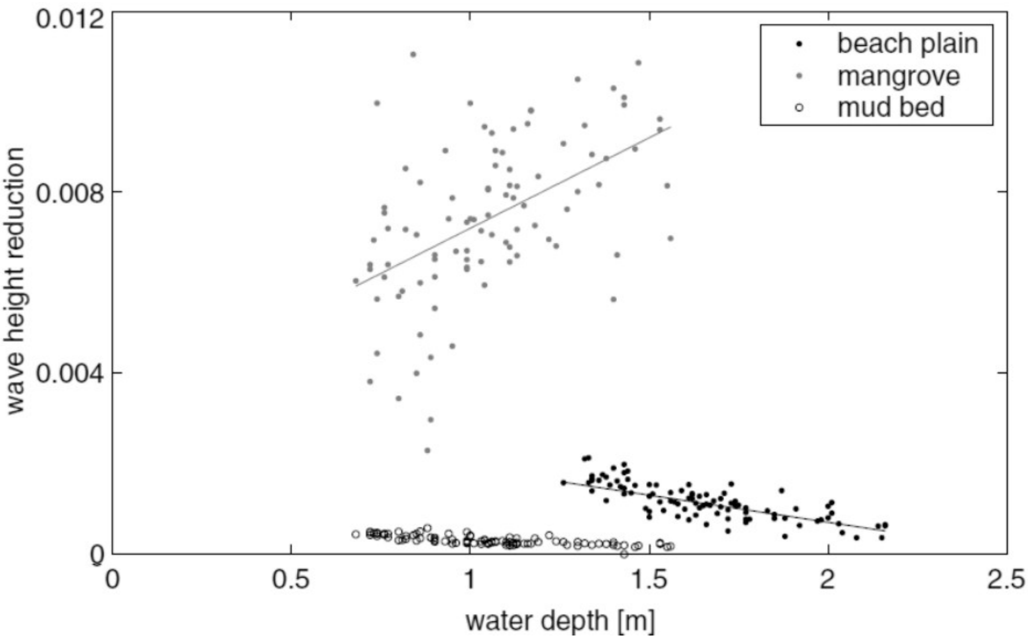


**Fig 3: Wave height reduction coefficient (*r*) as function of waterdepth. as measured in the Red river Delta (Quartel *et.al,* 2007)**

Both reduction coefficients have no dimension, but depend on the width of the mangrove belt *x*. To make plots independent of the width of the mangrove belt, sometimes the value *r* is used. This is the wave height reduction per meter.
The relation between *r* and $K_t$ is given by:

$$K_t(x) = e^{-rx} \quad (2)$$

Research by Quartel et.al showed that the value of *r* varies between 0.004 and 0.012 for a mangrove area in the Red river delta in waterdepth of 0,75 – 1.5 m. Quartel *et.al* indicate the relation between *r* and the waterdepth as $r = 0.004+0.003d$, in which *d* is the waterdepth. Physically there is no explanation of a decrease of *r* with a decrease of waterdepth. One would expect an increase. The reliability of this dependence of the waterdepth is rather low (see the spread of data in figure 3). Most probably this variation in value of *r* is more due to variations in foliage, stem diameter, etc.

Schiereck and Booij (1995) calculated the wave height reduction in terms of $K_t$ with the mathematical model Hiswa and some laboratory data. The results from Schiereck and Booij can be converted to r-values. In figure 4 their results are compared with Quartel et.al (2007). It seems that the dependence of the waterdepth as suggested by Schiereck and Booij is probably too strong. However, there is also no reason to assume that the r-value will increase with waterdepth as suggested by Quartel et.al.

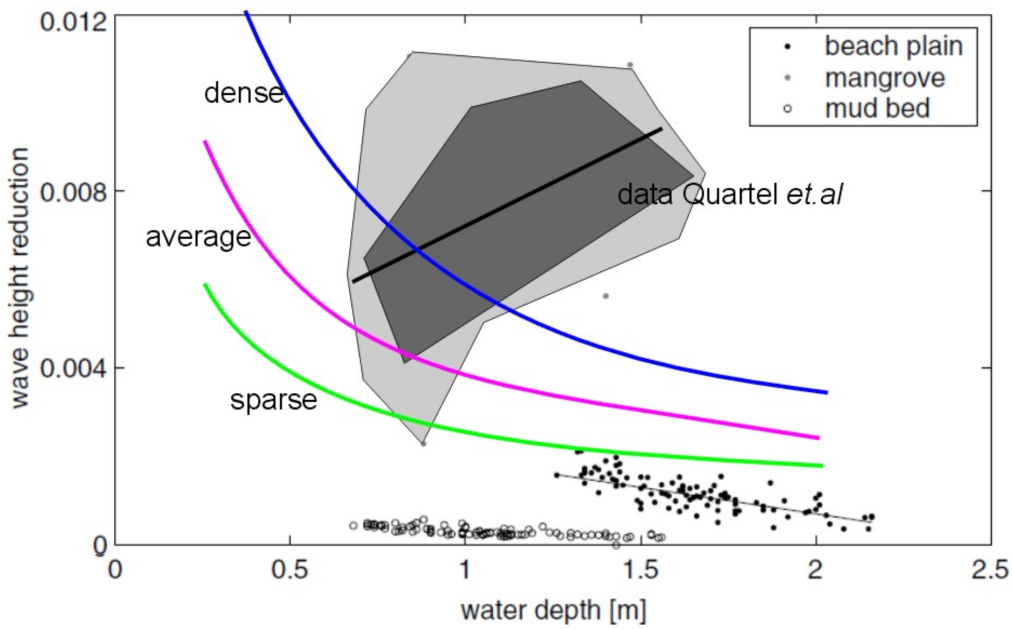


**Figure 4: wave height reduction coefficient ( r) as function of waterdepth as calculated by Schiereck and Booij (1995) compared with the data from Quartel *et.al* (2007).**

Quynh (2010) has done some measurements in the Can Gio district. On basis of these measurements the following formula are suggested:

$$K_t = \frac{a}{H_0} e^{-bx} \quad (3)$$

The two coefficients are defined as:

$$a = 1.0249 H_0 - 0.00977 \quad (m) \quad (4)$$

and

$$b = -0.0481 + 0.016 H_{vn} + 0.00177 \ln(N) + 0.0077 \ln(T_c) \quad (5)$$

where:

$H_{vn}$ = average total height of the trees in the forest (m)
$N$ = density of mangrove trees taller than 1 m (trees/ha)
$T_c$ = Forest canopy cover (%)

Note: in the original publication of Quynh b is defined as $b$ = +0.0481 – 0.016…. For consistency reasons the signs have been adapted in this note

Because the variation in field data is quite large, one should limit the accuracy of the given formulas to only 1 significant digit (for example $H$ = 1.1 m, and not $H$ = 1.0867 m). Doing so, eq. 4 reduces to a = 1.0 $H_0$. Therefore one may approach the $K_t$ formula of Quynh with:

$$K_t = e^{-bx} \quad (6)$$

This equation is identical to equation (2). This means that physically the value of b in Quynh (2010) should be identical to r in Quartel (2007). This means that also the value of b should be between 0.004 and 0.015. Because the variation in the basic data on which Quynh has derived his data, one has to be very careful with extrapolation of equation 5 outside the range of application. This range is not given by Quynh, but one may assume:

| | | | | |
|---|---|---|---|---|
| 3 | < | $H_{vn}$ | < 5 | (m) |
| 1000 | < | $N$ | < 2000 | (trees/ha) |
| 80 | < | $T_c$ | < 99 | % |

Formula 5 is very sensitive to the tree height $H_{vn}$. However in the field test all trees had heights between 3.2 and 3.8 m. Therefore one has to be quite careful with the use of the formula outside the range of application. In the paper of Quynh in Table 3 a relation is given of the wave dissipation as function of canopy diameter and mangrove density. This table is based on wave height measurements of reduction around an individual tree. It seems that this table gives somewhat too optimistic required width of mangroves zones.

It is therefore suggested to use for practical design calculations the following values:

**Table 1: reduction coefficients**

| density of the mangroves | reduction coefficient *r* |
|---|---|
| dense | 0.010 |
| average | 0.007 |
| sparse | 0.004 |

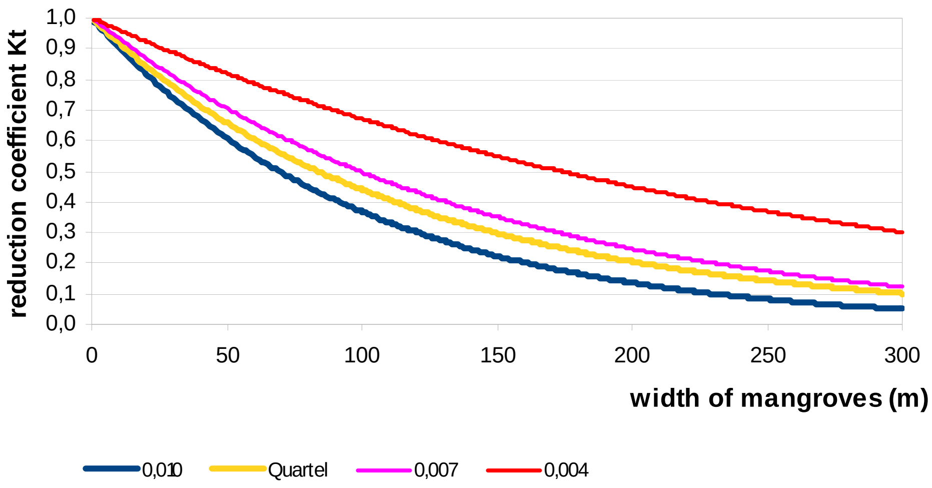


**Figure 5: Design diagram for mangrove protection belts using fixed values of *r*.**

In Figure 5 the computed values of $K_t$ for various widths of mangrove belts are indicated. For Dense mangroves one may use the blue line, for very sparse mangroves the pink line. The yellow line is the line as suggested by Quartel *et.al*. As can be seen the difference between this line and the use of an average value of $r$ = 0.007 is not very large.

**Design graphs**

When more details are available, the Quynh method can be used. One may use the formulas given above, but one can also use the design graphs in figure 6. From the graphs follow very clearly that the percentage of coverage is not very sensitive to the final answer, provided the coverage is above 80%.

***Computational example:***

Design waterlevel at a certain location is 3 m above datum. Wave height in front of the mangrove field (at the sea side) is $H_s$= 2 m, $T$= 6 s. Allowable overtopping over the dike is 10 l/s (which implies a good quality grass on the inner slope of the dike). Allowable wave height on the outer grass slope is 0.5 m. For a dike with a 1:3 slope this means a dike height of 3.6 m above datum.

Without mangrove reduction, the dike height has to be 6.4 m above datum, and a protection with concrete block is needed.

In order to obtain a wave height reduction from 2 m to 0.5 m a reduction coefficient $K_t$ = 0.25 is needed. The planting process is expected to lead to an average dense mangrove forest (r = 0.007). For obtaining a $K_t$ = 0.25 one needs a mangrove belt of 200 m width.

Using the method of Quynh, and assuming that 80% canopy coverage will be achieved at the end, and that the average tree height will become 4 m, a belt of 350 m is needed, planted with 800 trees per ha.

## IMPLEMENTATION PLAN

Not all mangroves are fitted for all locations. Each mangrove species favours a specific salinity, flooding period as well as bed material. An overview of applicable species is given in table 2.

**Table 2: preferred mangrove species in Vietnam**

| Condition | Species |
|---|---|

| | |
|---|---|
| - Unstable mud flat<br>- Monthly tidal flooding.<br>- Harsh natural condition, strong wind, wave, high salinity. | - *Avicennia marina (*Mắm biển)<br>- *Sonneratia alba (*Bần trắng) |
| - The newly formed alluvial, high salinity.<br>- Deeply flooded mud flat and frequently affected by wind and waves | - *Avicennia alba (*Mắm trắng) |
| - Average tidal flooding mud flat, stable tidal flooding period from 24 to 26 days in the month. | - *Rhizophora apiculata* (Đước).<br>- *Avicennia officinalis (*Mắm đen). |
| - Brackish water in estuary, low salinity <= 15% o | - *Sonneratia caseolaris (*Bần chua).<br>- *Nypa fruticans (*Dừa nước).<br>- *Acanthus ilicifolius* (Ô rô). |
| - High mud flat, tidal flooding period from 15-22 days in month | - *Excoecaria agallocha (*Giá biển)<br>- *Lummitzera racemosa (*Cóc Vàng)<br>- *Acanthus ilicifolius* (Ô rô). |
| - The banks rarely flooded, tidal flooding period from 5 to 7 days in month. | - *Thespesia populnea* (Tra biển) |

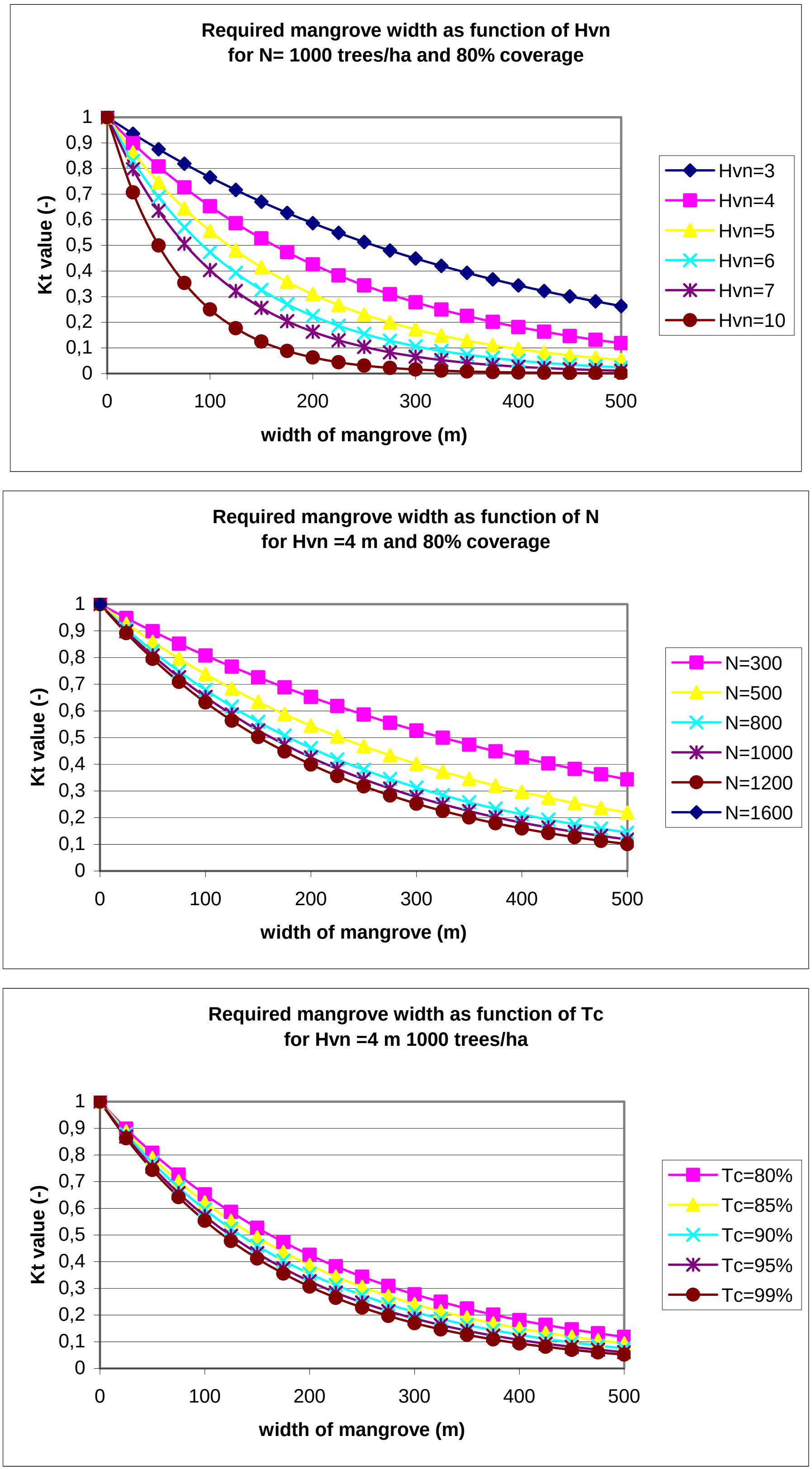


**Figure 6: Design graphs using the formulas of Quynh**

Some protection for the seedlings against wave action is needed. For this reason temporary breakwaters can be built. They can be built according to the drawing figure 7, using only bamboo, burlap (jute), small stones and local sediment. The filling of the small dam can be of stones, like in this example, but also jute bags with sand fill can be used. Apart from protection, these breakwaters also may help sedimentation in the area. The gaps between the breakwaters have to be small, so that in the largest part of the area the outflow is slow and very regular. This will increase sedimentation. The height of these small dams has to be just below high water.
Because these are temporary and light structures, one has to realize that they will suffer from typhoons. So after typhoons repair is needed. However, repairing these simple structures after each typhoon is cheaper than making them typhoon-proof.

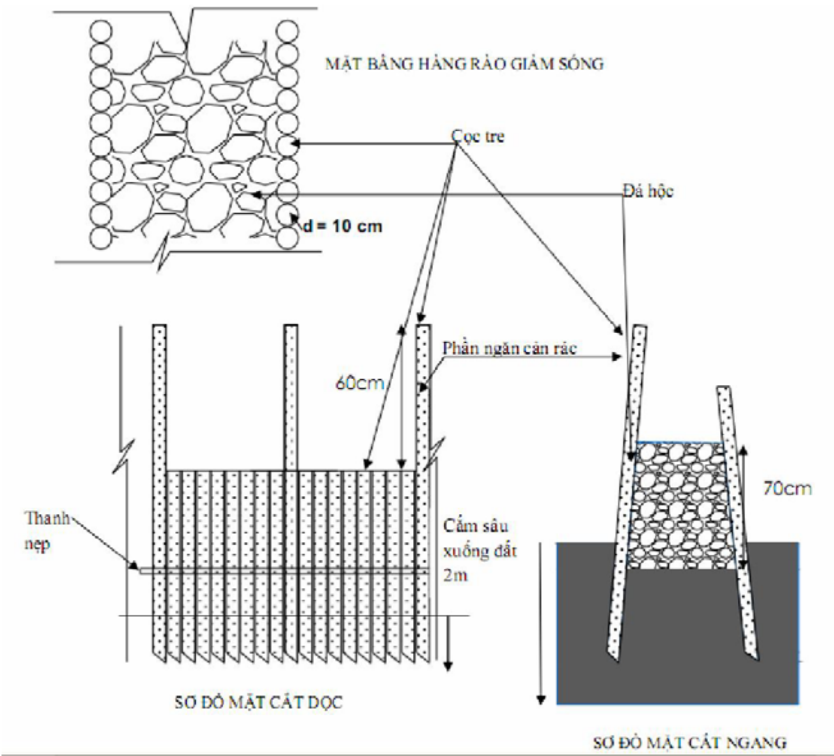


**Figure 7: Small dikes to stimulate siltation in mangrove plantings (bamboo poles with small stone filling)**

The main purpose of these dams is to allow mud and other fine sediment to settle. The small dams also prevent strong currents and medium storm waves to damage the mangrove seedlings. When the mangroves are more mature, the dams do not need to be maintained further. Because the dams consist of natural material, there is no need to remove them.
Because the dams are light and simple, cyclone waves will damage or destroy them. This implies that after a cyclone they will have to be rebuilt. Also some new planting of mangrove seedlings is required after a cyclone.
It might be tempting to make these dams stronger so that they can withstand the force of cyclone waves. However this is not at all economic. The construction of strong, cyclone resistant dams is very expensive. It is much cheaper to rebuild the simple, small dams after a cyclone than make them stronger. However, this needs to be communicated very clear to the local inhabitants. They otherwise may consider the project as a failure when the dams and seedlings are washed away after a cyclone.

Figure 8 shows an example of the lay-out of a system of dams and ditches to stimulate siltation .

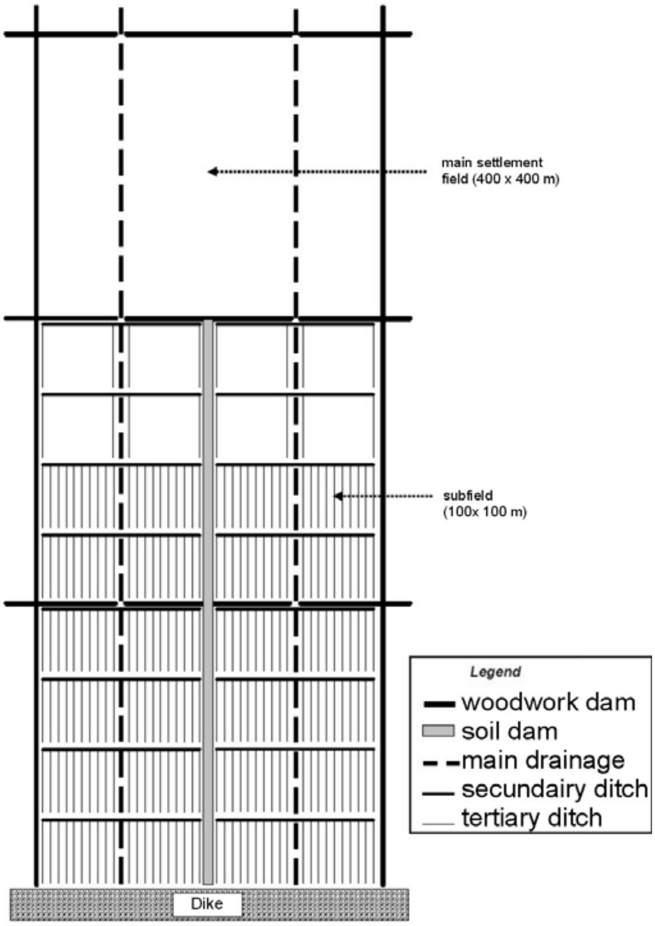


**Figure 8: Example of a settlement-field as used in the Dutch intertidal areas (Kamps, 1956)**

## CONCLUSIONS

The formulas presented in Quynh (2010) can be used for determination of the required width of a mangrove belt. Including the incoming wave height in the formula (eq. 4) is not needed, given the limited accuracy of the data. The results are comparable to other methods, even on the conservative side. However, one should not extrapolate the formulas outside the range of application. Figure 4 (based on Quynh 2010) is recommended for design.
Note: Table 3 as presented in Quynh (2010) should not be used for the time being, because it is based on limited measurements of wave decrease around single trees.

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