

VETIVER GRASS FOR RIVER BANK PROTECTION

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ABSTRACT

In many parts of the world, bank failure in rivers, canals and other waterways is a major concern for engineers and also for environmental reasons. Erosion results in loss of land and it threatens dikes. These problems tend to become even bigger due to a lack of effective erosion controls, an ever increasing intensity of boat traffic and a change in hydraulic boundary conditions. An economically attractive and readily available solution might be the application of the Vetiver System using Vetiver grass. However, the influence of Vetiver grass on the physical processes governing bank failure are for a large part still unknown. More insight on these effects may drastically reduce the risks as well as the costs of applying the Vetiver System. Also the growth characteristics of Vetiver grass on the banks has to be reviewed, since no qualitative values are known.

In order to obtain a higher level of qualitative and quantitative knowledge on the effects of Vetiver grass on the main eroding agents, a number of experiments have been carried out.

1. Influence of soil type and phreatic level on Vetiver grass: It was found that a cohesive soil reduced the growth rate of Vetiver grass by approx. 50% compared to a non-cohesive soil, which was a very significant result. Furthermore, a decrease in phreatic level of 0,17 m resulted in significant higher growth rates: differences were found in the order of 10-20%.

2. Vetiver grass as bank protection against vessel-induced loads: The influence of Vetiver grass on small scale mass failure was tested using a physical model test. The drawdown caused by passing ships was reproduced with the use of a wave flume. The amount of eroded material of cohesive soil (clay) was approximately 8-10 times smaller using Vetiver grass. The erosion of non-cohesive soil was also reduced drastically. Because the non-cohesive soil was inherently unstable and because of the extremely high erosion rate no quantitative statements could be made on this soil type. It was found that a combination of cohesive soil and Vetiver grass did have the lowest amount of erosion, and after approximately 800-1000 cycles the erosion even fully stopped.

3. The use of Vetiver grass as an armour layer on a dike under wave attack: A single hedge of Vetiver grass planted on the outer slope of a dike can reduce the wave run-up volume by 55%, in contrast with sod-forming grasses that give no reduction. Planting multiple hedges along the contour of the outerslope might result in even more reduction. The application of Vetiver grass on existing dikes may provide a substantial reinforcement of these dikes.

Key Words: Wave run-up, bank protection, vessel-induced loads, phreatic level

1.0 INTRODUCTION

Boat-induced loads and waves by wind are important causes of river and canal bank failure. Bank protections in deltas are often designed to cope with these loads. The protection can consist of wood, rock or concrete, sometimes in combination with an earthen body in case of a dike. The earthen bodies and the stony materials used, are often expensive since space, stones and wood can be scarce in deltas.

The use of vegetation as bank protection can be a less expensive measure. Mangroves, reeds and grass sods are already applied as bank protection in many deltas in the world. In addition to these species other vegetation can be used as well. A prime candidate for use as bank protection is Vetiver grass.

It has been tested as a bank protection on several test sites in China, Vietnam, Australia and the Philippines. These tests showed promising results for the use of Vetiver grass as a bank protection [e.g. Ke *et al* 2003, Le Viet Dung *et al* 2003] but give no insight into the processes involved and their quantitative effects. Therefore research was focused on the effects of Vetiver grass on the governing physical processes of bank erosion.

The following subjects were studied:

- Influence of soil type and phreatic level on Vetiver grass
- Vetiver grass as bank protection against vessel-induced loads
- The use of Vetiver grass as an armour layer on a dike under wave attack

To study these subjects, tests have been performed at the Laboratory for Fluid Mechanics and the Botanical Garden both of Delft University of Technology.

2.0 INFLUENCE OF SOIL TYPE AND PHREATIC LEVEL ON VETIVER GRASS

Besides the investigation of the effects of Vetiver grass on erosion, it is also important to obtain data on if and how Vetiver grass thrives on river banks. For application of Vetiver grass the influence of phreatic level and soil type on its growth rate are mostly unknown but both may be very important, especially in the establishment phase. The experiments with respect to this subject are discussed first, after which the experiments with respect to erosion are considered.

2.1 Experimental Design

Vetiver plants (obtained by splitting full-grown Vetiver plants and, as far as possible, washing out the material between the roots), were planted into three pots filled with non-cohesive soil (MX) and three pots with cohesive soil (C). The stems of the Vetiver grass were cut off at a length of around 30 cm, while the roots were cut off at a length of 20 cm, both measured from the surface level. The pots were put into PVC pipes that were watertight with a PVC plate at the bottom as shown in Figure 1.

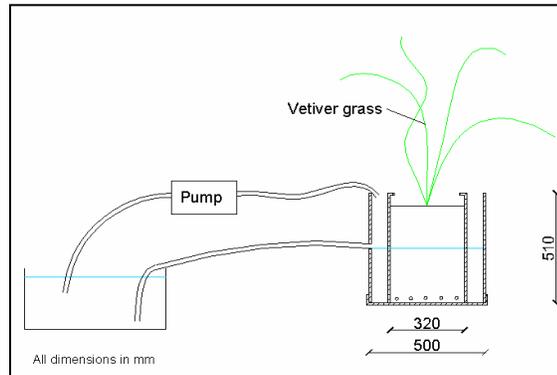


Figure 1: Sketch of the test setup (medium groundwater level)

The PVC pipes were filled with water up to three different levels, 1, 18 cm and 35 cm below surface level, respectively referred to as high, medium and low. The water level in the PVC pipe corresponded with the groundwater level in the pot through holes in the pot and was kept constant. The temperature was kept approximately at 20-25°C (with the use of heating lamps) and that the atmospheric humidity was also kept high. Each stem of Vetiver grass has several leaves and each leaf was measured individually from the cut to the top, 2 times a week for a period of 54 days.

2.2 Results

All results are based upon the observations with respect to length increase of the leaves with time. With respect to the groundwater level differences with the non-cohesive soil type (MX = mixture of sand, some silt and small gravels) the following results were obtained: Vetiver grass with a low groundwater level did have a higher rate of growth than the plants with a medium (10%) and with a high groundwater level (30%). The plant with the high groundwater level did have the lowest rate of growth considering length increase, namely 20% lower than medium groundwater level.

When considering the groundwater level differences of the cohesive soil type (C = clay) the following results were obtained: The plant with the high groundwater level did have a lower mean rate of growth than the medium groundwater level (17%). However, the plant with a low groundwater level showed a deviation from the expected higher growth rate. It had a sudden increase in growth rate around 42 days, which was probably caused by a lower level of light intensity, while the other pots did have full light. However, the cause of this light interception (by another Vetiver grass plant) was removed after 42 days after which the light intensity became equal again for all three pots. The high level of sensitivity of local circumstances on the growth rate of the plants is clearly to be seen in Figure 2.

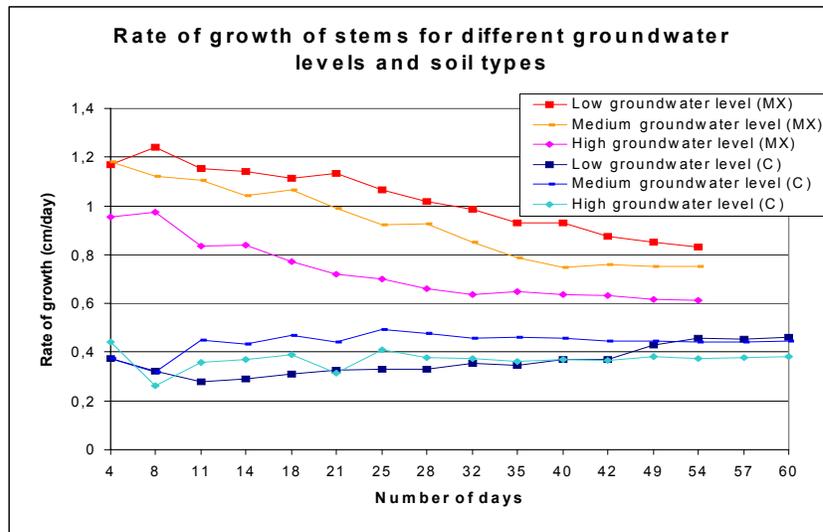


Figure 2: Experimental Results

All comparisons were made after 54 days. The results of the pot with the low groundwater level were not included in the comparison because of the above mentioned inaccuracy.

A possible explanation of the decrease in growth rate at a higher groundwater level may be the lower level of available oxygen for the roots. Chinese research showed that vetiver takes about three weeks to adapt to the wetland conditions by developing aerenchyma tissue to supply oxygen to the roots [Liao, 2000]. Therefore better growth could be expected over longer period of time. Another possible explanation may be that the roots grow towards the groundwater level as quickly as possible, in search of water. Therefore the presence of water in the initial phase (high groundwater level) will then result in a lower growth rate.

The growth rates of the plants with the cohesive soil were approx. 40-50% lower than the growth rates of the plants with the non-cohesive soil. This trend is in agreement with the theory put forward by Kirby and Bengough (2002) that the rate of root elongation is slowed down in hard soil.

3.0 VETIVER GRASS FOR BANK PROTECTION AGAINST BOAT-INDUCED LOADS

Boat-related erosion, erosion of unprotected banks and the protection of banks by vegetation are all still poorly understood phenomena at the current state-of-the-art. Therefore, more insight in the relevant physical processes is necessary. A theoretical investigation of all possible influences of Vetiver grass on bank erosion, including erosion caused by ship traffic was carried out by Jaspers Focks (2006). In total 14 possible adverse and/or beneficial effects were found. This investigation resulted in hypotheses related to the mechanisms with which Vetiver grass should be able to prevent erosion, and therefore it needs to be investigated into more detail by experiments. The results provide implications for the suitability of the usage of Vetiver grass as a bank protection mechanism.

River banks are pre-dominantly cohesive [Mosselman 1989]. Erosion of these river banks can be divided into two distinct processes: entrainment of particles or mass failure under the influence of gravity [e.g. Mosselman 1989, Duan 2005]. A third process, sub aerial preparation [e.g. Abernethy and Rutherford 1998] is not mentioned by all authors, for it has no direct relation with river-processes. In contrary with fluvial entrainment of non-cohesive material, the mechanics of fluvial erosion of cohesive sediments is poorly understood [Millar and Quick 1998]. Cohesive soils are normally more resistant to particle entrainment than non-cohesive soils [ASCE 1998]. CUR (1993) after Riemsdijk and Van Eldik (1992) mentioned that the loads caused by currents (tested at 1.1 m/s) are too weak to significantly erode cohesive soils. When considering the erosion of cohesive banks by vessel-induced loads, it is therefore assumed that mass failure is the dominant eroding mechanism. The limiting riverbank stability usually occurs when bank strength is reduced by increased unit weight of the soil and the excess pore-water pressures during a drawdown [Darby and Thorne 1996]. A rapid drawdown at the bank is caused by either the waterlevel depression caused by a ship or by the water movement just before a secondary wave breaks on the slope. Experiments with respect to erosion were focused on mass failure caused by rapid drawdown. In this study mass failure was divided into small scale and large scale mass failures. Large scale refers to deep-seated failure planes, while small scale refers to shallow-seated failure planes and the so-called "pushing off" of material. The direct influence of Vetiver grass on relevant soil parameters (undrained shear strength and saturated specific weight) related to large scale mass stability was investigated by execution of laboratory tests. An increase in the factor of safety (as used in limit equilibrium methods) of approximately 20% by the presence of Vetiver grass was found [Jaspers Focks 2006], mainly by an increase in undrained shear strength. These results, however, showed a large spread and were not significant. Therefore these experiments are not discussed into more detail. The focal point is at the experiments with regard to small scale mass failure.

3.1 Experimental Design

The influence of Vetiver grass on small scale mass failure was tested using a physical model test. The drawdown caused by passing ships was reproduced with the use of a wave flume. Several series of successive drawdowns were carried out on a representative bank. The variables in these tests were the soil type, namely a cohesive (C) or a non-cohesive (MX) soil, and the presence or absence of Vetiver grass. A sketch of the test setup is shown in Figure 4. The position of the hydraulic wave flap was adjustable into detail in x-direction and in time. The Vetiver grass with soil type MX was planted three months beforehand and the Vetiver grass in soil type C was planted two months beforehand. The soil samples were placed on the wooden construction. When testing soil with Vetiver grass, two Vetiver grass samples were tested at the same time. After placement of the samples the surface water level was raised up to half of the height of the soil sample. The initial topography of the slope was determined at equidistant intervals of 0,05 m parallel (horizontal y-direction) and vertically (z-direction) in reference to the slope, with a horizontal measuring needle (precision 0,001 m) in the horizontal direction incident on the slope (x-direction). A wave height meter (precision 0,0005 m) was used to obtain the number of simulated ship passages and the water level changes. The groundwater level at 0,25 m behind the slope was measured before the start of the test to check whether or not the groundwater level corresponded with the water level in front of the slope. These measurements were performed with a measuring rod (precision 0,001 m) in a borehole

(\varnothing 0,02 m). The test was started at the moment the groundwater level and the surface water level were equal. During the test with soil type C the groundwater level was measured regularly (after each 100 cycles) to check if it remained constant. At several moments during the experiment, after a certain number of cycles the experiment was paused. The hydraulic wave generator was brought back into its resting position and the topography of the soil was measured, after which the experiment continued.

3.2 Results

The erosion of the cohesive soil was observed to be dominantly caused by small scale mass failure. The amount of eroded material of the cohesive soil was approximately 8-10 times smaller using Vetiver grass, which is also to be seen in Figure 5. These numbers solely serve as indicative numbers.

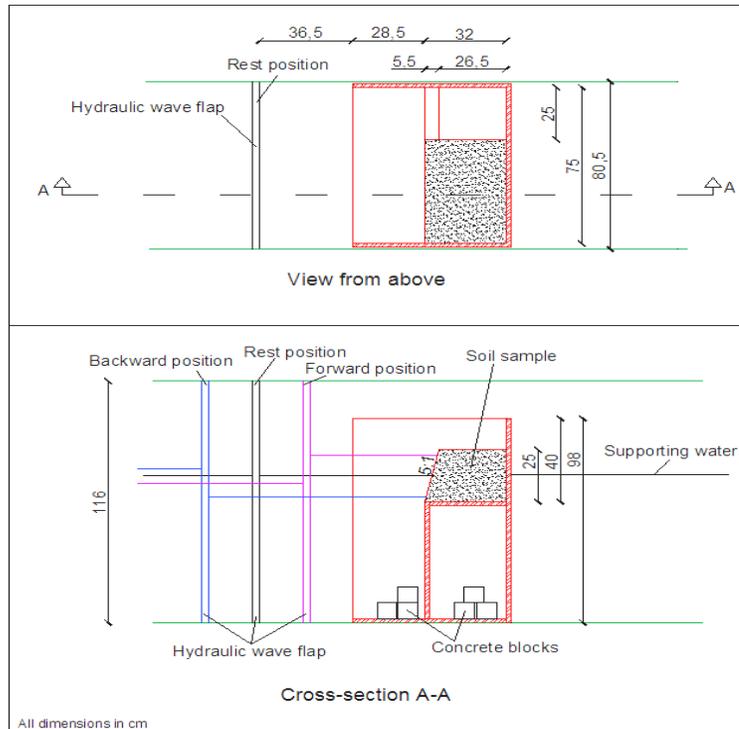


Figure 4: Experiment setup

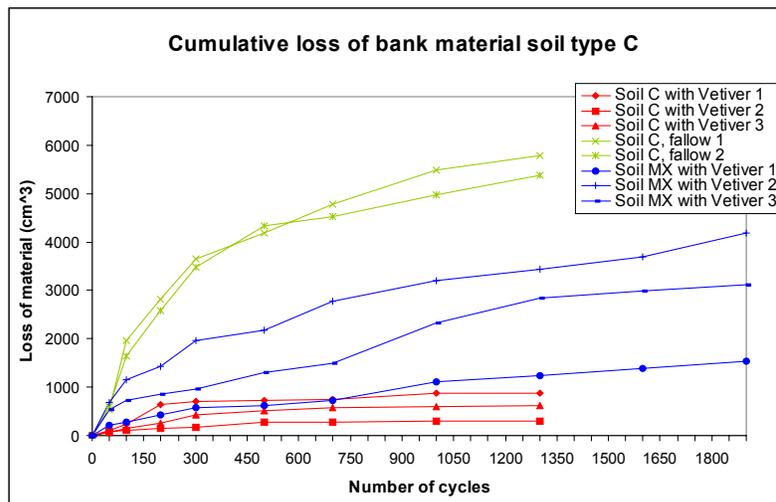


Figure 5: Experimental results

The erosion of the non-cohesive soil was observed to be not specifically related with small scale mass failure, but was also drastically reduced. The fallow non-cohesive soil was inherently unstable and showed an extremely high erosion rate. Due to this, no quantitative comparisons could be made. It was found that a combination of cohesive soil and Vetiver

grass did have the lowest amount of erosion, and erosion was fully stopped even after approximately 800-1000 cycles.

4.0 VETIVER GRASS FOR WAVE RUN-UP REDUCTION

Vetiver grass can be planted on the outer slope of a dike to reduce the wave run-up. The roots of Vetiver grass will retain the soil on the outer slope and the stiff stems will reduce the amount of water overtopping the dike. Vetiver is able to grow in brakish environments [Maaskant, 2005]. The outer slopes of sea dikes, especially the higher parts, do occasionally get splashes of salt water, because of wave run-up. However, the situation can be considered as a fresh water environment because Vetiver is mainly under the influence of rainwater when placed above the still water level during storms.

Vetiver grass cannot form a sod as low growing grasses. Vetiver grass therefore should be planted in rows along the contour with low growing sod forming grass in between. The combination of sod forming grass and Vetiver grass hedges reduces the construction costs and material use of a dike. Vetiver grass planted on the outer slope can reduce the run-up in two ways:

- Reduction of the run-up height
- Reduction of the volume of water passing the level where Vetiver grass is planted

Research has been done on the reduction of run-up by rough slopes [Van der Meer, 2002, Klein Breteler et al. 1996]. However, no research could be found on the effect of objects protruding the run-up flow other than crown walls on top of a breakwater.

4.1 Experimental Design

To determine the effect of one hedge of Vetiver grass, small scale tests have been performed in a wave flume of 0.8 m. wide. In the tests the run-up height and the run-up volume is measured for situations with and without a hedge. The dimensions of the elements of the tests are shown in Figure 6.

It is not possible to scale Vetiver grass for the run-up tests, because of scale effects related to the viscosity of water and the complex interactions of the stems in real Vetiver grass. [Algera, 2006]. Therefore the backwater-discharge relationship has been used to model Vetiver grass. Vetiver grass hedges have been tested for stationary flow situations in flumes [e.g. Dalton et al, 1996, Metcalfe et al, 2003, Dabney, 1996, Meyer 1995]. From these tests a backwater-discharge relationship can be found. In Figure 7 the relationship found by Dalton et al, (1996) is shown together with the theoretical backwater discharge relationship of a plate with vertical slits with a blocking of 75 %.

For stationary flow situations a plate with a blocking factor of 75% can be compared to a Vetiver grass hedge. Different plates with a width of 8 mm. with different sizes of the openings have been tested, as can be seen in Table 2. With the oscillatory flow through the gaps, flow through the slits might become laminar and the width of the slits might influence the results. Therefore different plates were tested to see whether laminar flow would occur.

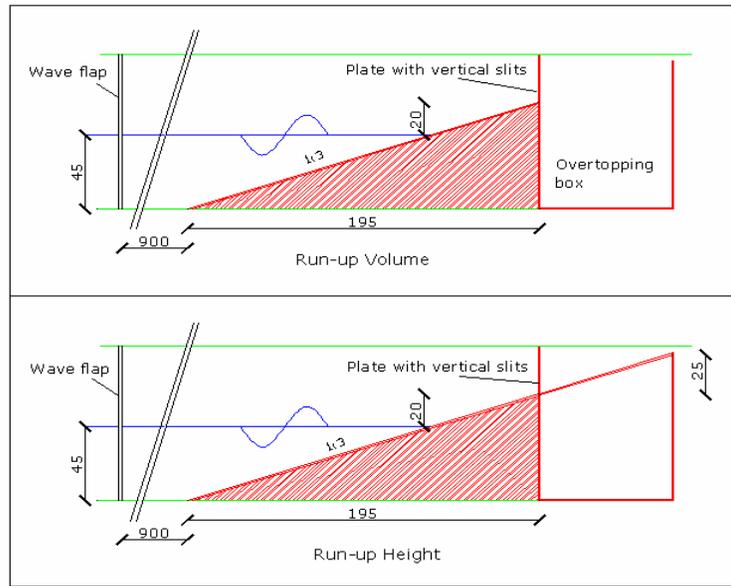


Figure 6: Experimental Set-up (dimensions in cm.)

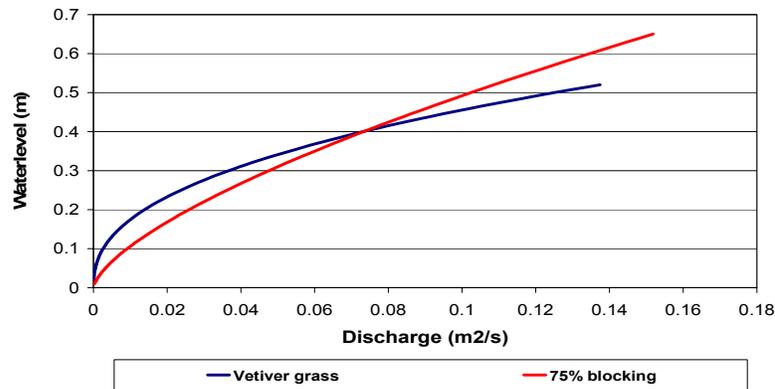


Figure 7: Backwater-Discharge relationship Vetiver grass

Blocking	Number of slits	Width of slits	Spacing
0%	1	80 cm	-
75%	8	2.5 cm	10 cm
75%	4	5 cm	20 cm

Table 2: Different plates used for testing

Wave climates used for the tests are all regular waves and range from 0.12 to 0.16 m. The wave generator used was equipped with automatic reflection compensation. The run-up level is measured with a point gauge (precision 0.001 m). The average of several waves is used to determine the run-up height. After the run-up level is determined the slope above the hedge is removed and the water passing the hedge is collected in a box. After a controlled number of waves is passed, the box is closed and the volume of water is measured with a weighing

device (precision 1.0 kg). The measurements are compensated for water level decline because of collecting water in the box. Secondary effects caused by the partial reflection of the tongue against the plates is considered negligible. The overestimation because of the fact that no water is running down the slope, when the water is collected in a box, is taken into account. A detailed description of the tests can be found in Algera, (2006).

4.2 Results

The results of the run-up tests are presented below. The reduction of the run-up height and the volume are set out versus the run-up height of the smooth slope (R_u) minus the vertical distance of the plate to the undisturbed water level (z).

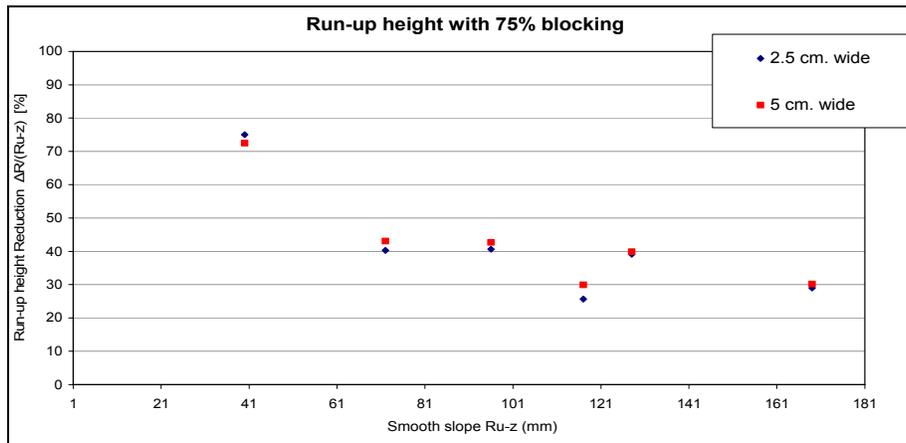


Figure 8: Reduction of the Run-up height

The results for both the plates with the different opening size are quite similar. From the test results it can be seen that no clear trend can be observed from the graph showing the reduction of the run-up height. Further tests have shown that the reduction of the run-up height mainly depends on the surf similarity parameter [Algera, 2006].

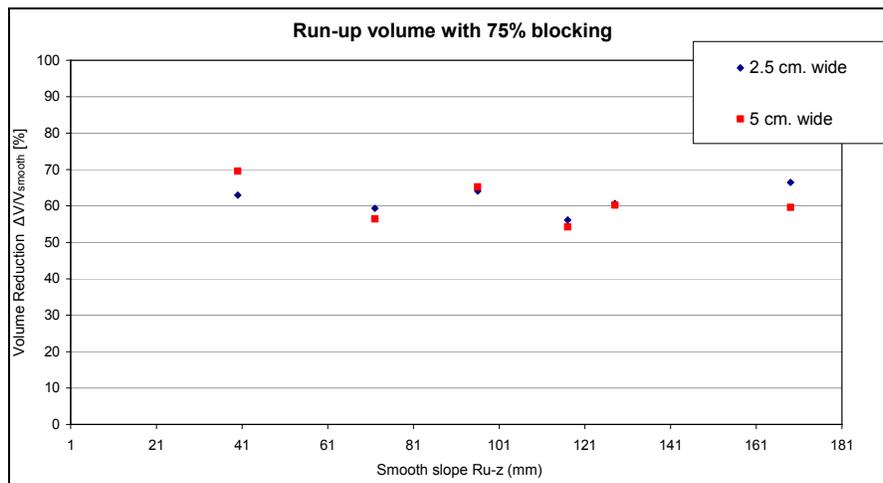


Figure 9: Reduction of the Run-up Volume

The similarity of the reduction in volume indicates that the flow through the openings during the run-up tests is mainly quasi-stationary. The plates, that resemble the Vetiver grass hedge in stationary flow, also resemble Vetiver grass well in run-up situations. The reduction of the run-up volume is above 55 % and is constant for the different run-up heights tested. This is in good agreement with the theory of [Algera, 2006]. Also for higher run-up heights than the heights tested the reduction of the run-up volume remains constant [Algera, 2006]. Tests with plates with a blocking factor of 60% gave a reduction of 40% of the run-up volume.

4.3 Use in Design Practice

Planting multiple hedges on an outer slope of a dike might reduce the overtopping by more than 55%. Hedges can be planted one meter apart to allow people to move between the hedges for inspection and maintenance. Hedges planted near to the still water line will be overtopped by the run-up tongue. These hedges will serve as artificial roughness elements, but will give less reduction than 55%.

The strength of the stems and the density of the hedge determine whether water will flow mainly through the hedge or flow over the hedge. No systematic research has been done on the failure of mature hedges in flow. In tests in flumes with hedges in stationary flow backwater depths up to 0.4 m. have been reached [Dabney, 1996, Meyer, 2005].

For the layer thickness of the run-up tongue for smooth slopes Schüttrumpf, (2001) finds for regular waves:

$$h = 0.284 \cdot (R_u - z)$$

When the run-up tongue is hitting the hedge, part of it will be reflected and the water level behind the hedge will exceed the thickness proposed by Schüttrumpf, (2001). Therefore, Vetiver grass planted at a height on the outer slope where $(R_u - z)$ is more than 1 meter apart cannot be expected to reduce the run-up volume by 55%. Vetiver grass planted lower than 1 meter will still reduce the run-up as artificial roughness element but the reduction is less than 55%.

Vetiver grass hedges have to withstand the most damaging waves in a wave spectrum, concerning both overtopping volume and frequency of occurrence. Occasional overloading is not a problem as long as the level of occurrence is low and most of the waves overtopping the dike are reduced by flowing through the hedges. When overloaded the lower 0.4 m will bend through an elastic range.

Overloaded vetiver hedges planted on the lower parts of the outer slope can still serve as artificial roughness elements. The roughness factor of those artificial roughness elements is not clear. However, Vetiver grass can be much cheaper than stones or concrete blocks and the roughness is much higher than low sod forming grass. So it is beneficial to plant as many hedges as possible. It is not likely that Vetiver grass can cope with the wave impacts of breaking waves. So at the heights where those impacts can be expected a conventional armour layer should be applied.

4.4 An Example

To illustrate the effect of Vetiver grass hedges on the outer slope on the design of a dike, an example is presented here. In the Netherlands the following design rule from [Van der Meer, 2002] is used to determine the crest level:

$$\frac{q}{\sqrt{g \cdot H_{m0}^3}} = \frac{0,067}{\sqrt{\tan \alpha}} \cdot \gamma_b \cdot \xi_0 \cdot \exp\left(-4,3 \cdot \frac{h_k}{H_{m0}} \cdot \frac{1}{\xi_0 \cdot \gamma_b \cdot \gamma_f \cdot \gamma_\beta \cdot \gamma_v}\right)$$

With a maximum of:

$$\frac{q}{\sqrt{g \cdot H_{m0}^3}} = 0,2 \cdot \exp\left(-2,3 \cdot \frac{h_k}{H_{m0}} \cdot \frac{1}{\gamma_f \cdot \gamma_\beta}\right)$$

Where:

q = average overtopping discharge (m ³ /m per s)	$\tan \alpha$ = slope angle (-)
ξ_0 = the surf similarity parameter $\xi_0 = \tan \alpha / \sqrt{s_0}$ (-)	γ_R = the influence of oblique wave attack (-)
H_{m0} = significant wave height at the toe of the dike (m)	h_k = crest level above still waterline (m)
γ_f = the influence of the roughness of the slope (-)	γ_b = the influence of a berm (-)
s_0 = wave steepness $s_0 = 2 \cdot \pi \cdot H_{m0} / (g T_{m-1,0}^2)$ (-)	g = acceleration of gravity (m ² /s)
$T_{m-1,0}$ = spectral wave period: $T_{m-1,0} = m_{-1} / m_0$ (s)	

The average allowable overtopping discharge is determined by the state of the inner slope of the dike. In [TAW, 1989] the following average allowable overtopping discharges are proposed:

- 0.1 l/m per s for sandy soil and a bad grass cover
- 1.0 l/m per s for clay with a reasonable well grass cover
- 10 l/m per s for a good grass cover or an armour layer.

When the still water level in front of a dike is 2.5 m then the significant wave height can be determined by a rule of thumb: [d'Angremond, 2001] $H_s \leq 0.55 \cdot h$. So the maximum significant wave height is 1.375 m. The spectral wave period is taken 7 seconds.

For a dike with an armour layer of placed granite stones the roughness factor is 0.95. The outer slope has an angle of 1:3 and the average overtopping discharge allowed is 0.1 l/m per second. The crest level then becomes 4.58 meters above the still water level.

Planting one hedge will increase the q to be entered in the formula. An average allowable overtopping of 0.22 l/m per second can now be entered since a hedge will give a reduction of 55%. The crest level then becomes 4.12 meters above the still water level.

Planting a second hedge will give again a reduction of 55% so the allowable q can be 0.49 l/m per second. This leads to a crest level of 3.67 m. The reduction of the overtopping volume will be even more since the amount of water that remains between the hedges is neglected. The hedges have to be planted one meter apart so the second hedge has to be planted 0.3 meters lower than the crest of the dike.

To test whether the second hedge will be overloaded the 1% run-up height is considered. Van Gent, (2002) proposes the following equation for the 1% run-up height:

$$\frac{R_{u1\%}}{(\gamma \cdot H_s)} = c_0 \cdot \xi_0 \quad \text{for } \xi_0 \leq p \quad \frac{R_{u1\%}}{(\gamma \cdot H_s)} = c_1 - \frac{c_2}{\xi_0} \quad \text{for } \xi_0 \geq p$$

$$c_2 = 0.25 \cdot \frac{c_1^2}{c_0} \quad p = 0.5 \cdot \frac{c_1}{c_0} \quad \text{for } R_{u1\%} \quad c_0 = 1.45 \quad c_1 = 5.1$$

In this case the average $R_{u1\%}$ is 4.31 meters. Since the lower hedge is planted at 3.37 m. from the still water line it will not be overloaded by the $R_{u1\%}$. Less than 1% of the waves will overload the Vetiver grass hedges and will be reduced less than expected. This is considered to be safe. So planting two hedges on the top of the outer slope can decrease the crest level needed by 0.9 m.

The crest level can be decreased from 7.08 m. to 6.17 from the toe. This results in a reduction of the dike volume of 20%. The construction costs can be reduced even more since the costs of labour is often low in developing countries and therefore the use of Vetiver grass is much cheaper than the application of granite stones.

5.0 CONCLUDING REMARKS

Vetiver grass is a sustainable and innovative solution for the protection of river banks and dikes. It thrives under a wide variety of conditions. Although the growth rates is lower with a high groundwater level it still thrives around the SWL, in contrary with sod-forming grasses. This clearly shows that Vetiver grass can be used at SWL as well as on dikes were the phreatic level can be low.

It is shown that Vetiver grass is able to establish a full-stop of bank erosion caused by rapid drawdown. Therefore it provides us with strong indications that it is highly suitable as an anti-erosion measure. A combination of cohesive soil and Vetiver grass provides the best protection against erosion, which implies that it is highly suitable for banks in delta areas, which consist pre-dominantly of cohesive soil.

A single hedge of Vetiver grass planted on the outer slope of a dike can reduce the wave run-up volume by 55%, in contrary with sod-forming grasses that give no reduction. Planting multiple hedges along the contour of the outerslope might result in even more reduction. The application of Vetiver grass on existing dikes may provide a substantial reinforcement of these dikes.

The advantages of Vetiver grass above conventional methods with the use of stone are numerous:

- Vetiver grass is not invasive and no significant diseases are known. Vetiver grass will, in contrary with traditional methods, increase in strength in time.
- Vetiver grass is an economically attractive solution. In most countries in South-East Asia Vetiver grass can be planted for less than \$ 3 per meter, while solutions consisting of stone and concrete are expensive in delta areas.

- Vetiver grass allows people to protect their own property. Since the costs are low and it is easy to use local initiatives can be easily achieved.
- Vetiver grass can be an aesthetically good solution and is a socially acceptable solution for bank protection.

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