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Scouring Of A Root Reinforced Bed And Broader Applications

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Scouring of a root reinforced bed and broader applications

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This paper presents the results of a partial examination of the position stability of willows on river banks. The investigations have been focused on the erosion around an individual willow tree. It appeared that willow woods decreases the current velocities considerably, which leads to increase of sedimentation between the willows and a steeper slope in the transition zone from willow woods to the river. It is evident from experiments in an experimental flume with willow roots and a comparable mattress structure, that roots decrease the erosion itself and the equilibrium depth of the erosion considerably.

Introduction

Eroding riverbanks in The Netherlands have been protected for centuries by means of hard materials (like rock, stone pitching, asphalt and concrete). Public resistance against these unnatural protections has increased during the last decades. Therefore, in the nineties, the Dutch Ministry of Transport, Public Works and Water Management started to investigate the possibility of protecting river banks from erosion by planting willow trees. This was one of the many investigations of environmental bank protections.

The rivers, with their dynamical character, show important differentiation in all kind of environmental processes, resulting in different kinds of environment. These dynamic processes are the engine for the development of the river landscape. With the realization of soft, environmental friendly bank protections like willows, a more natural ecological development in the bank zone is stimulated.

In April 1990 willows were planted in three eroding stretches of river banks between groynes. These willows can stand dry periods as well as inundation, grow fast, and have a good recovering capacity.

However after two years it was recognizable that willow trees at the riverside were lost by washing away or drowning. At the land side willows died because of water shortage. Comparing these three stretches with unprotected banks, it was clear that sedimentation within the willow forest increased. On the other hand, just in front of the first willows at the river side, severe erosion took place, resulting in the outflank of some willow trees. From these results, it was suggested that a group of willows could be stable when the willows at the river front are capable to stand the pressure of the flow and don't fall down in their own scour holes, protecting the trees behind.

Apart from these field tests it was necessary to investigate two aspects more general: the influence of willow forest on the currents and the stability of an individual willow tree in eroding conditions.

Influence of a willow forest on the current

At first a study was carried out to investigate the influence of the willow forest on the current pattern in the river, especially on the protected bank. Three different roughness formulas were used, programmed in DUTCHESS, a computer program that is based on the two dimensional shallow water flow equations.

Depending on the roughness parameter of the vegetation and the waterdepth above the groynes, the vegetation can reduce the current velocity up to six times.

Stability of an individual willow tree in eroding conditions

Secondly the stability of the individual willow is investigated. Two types of root structures can be distinguished (see f.i. [1]):

(1) Wound roots grow from the cutting end of a willow branch (cutting) and are strong, long and numerous and can penetrate deeply into the bed. Therefore the tree is anchored deeply in the bed.
(2) Bast roots are scanty, weaker and shorter.

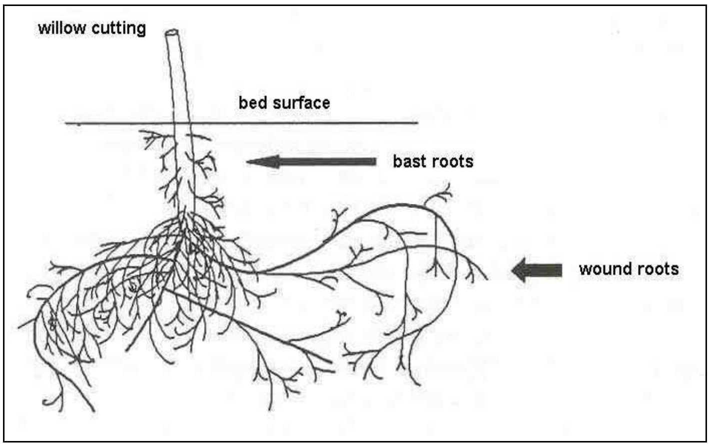

Figure 1. Different root structures

The willow planting on the three riverbanks were carried out by pushing willow cuttings deep into the bed (> 1m), resulting in a root structure as in figure 1. On some riverbanks a forest is developed naturally from seeds and branches washed ashore. In these situations a root mattress structure is visible at the surface of the bed, capable to protect the bed material.
Due to the two different types of root structure it was necessary to cultivate the willows in different ways for laboratory testing.
Willows were sowed (Salix Viminalis and Salix Triandra) and slipped (Salix Viminalis 1 year old) in crates which fitted in the discharge flume. The willows grew during 1 year under laboratory conditions (using fertilizer, UV lamps, and biological vermin fight (using the ichneumon (Encarsia Formosa), the lady-bird (Hyppodamia) and predatory mites (Phytoseiulus Persimilis)). The sand bed was constructed with very uniform sand with a mean diameter of 470 μm.

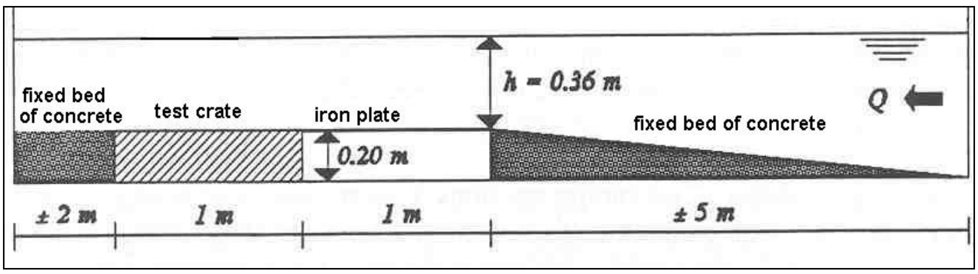

Figure 2. Flume design with dimensions (not on scale)

At first scour tests around only hollow cylinders were carried out using the same bed material for comparison.
Secondly scour tests were carried out with the willows of which the trunks were carefully cut off and replaced by the cylinders; the cylinders were placed on the root structures which were still present in the bed. In both situations the equilibrium scour depths were measured and compared. The mean reduction of the equilibrium scour depth due to the protection of roots was found to be:

(1) 42 % in case of the willow cuttings;
(2) 76 % in case of the sowed willows, with a surface root structure.

Analysis of biophysical and biochemical bindings

The results of the experiments described above indicate influence of the roots on the scouring process. Two main mechanisms are possible: the roots are reinforcing the *bed strength* (for example mechanically, biophysically or biochemically) or the roots are reducing the *loads*, e.g. the water movement near to the bed.
From erosion processes in grass root structures, it is known that it's fine structure is responsible for it's strength, especially in combination with a subsoil of clay [3]. The rhisobioms improve the particle to particle interaction and cause strong connections between root and particles by biochemical and biophysical processes.
It was assumed willow roots interact with the subsoil the same way. One can observe however two major differences with the grass root system. First, willow roots are not as uniformly structured as grass roots. Willows grow at relatively large distances and the roots are concentrated around the trunk. Secondly, in the experiments coarse sand was used instead of clay. In these scour tests with the willow root reinforced bed it became clear that there isn’t any chemical or mechanical root-sand binding as described in f.i. [4]. In every test all the bed material between the roots was washed away.
Microscopic detail observations of various types of willow roots were carried out to investigate mechanical or chemical bonds between roots and soil particles. Parts of excavated roots were observed with a maximum magnification of 70 times. Willow roots are divided in different branches and sub-branches. The smallest visible root types have approximately the same thickness as the smallest sand particles, about 50 μm. There seemed to be a strong relationship between the presence of this smallest root types and particles connected to the roots. Only one side of the particles had contact with the smallest roots (no enclosing) and at some places the root structure with the connected particles was three times as thick as the root branch itself.
From this qualitative analysis it can be concluded that only the smaller particles (approximately 50 μm) are biochemical connected. Sprangers [3] explained this with the rate between the weight and the surface of the particles. Because the weight is proportional with the third power of the diameter and the surface to the second power of the diameter, smaller particles are better connected.
In the experiment with willows in the flume, much coarser sand was used, so biochemical bindings are negligible. However, the willow roots cause a significant reduction of the scour hole. So biochemical or biophysical bindings are at least not the only cause of the observed scouring reduction. Another factor might be mechanical influences on the bed-current interaction.
An explanation for this can be found in the energy loss of the flow around a pile (trunk) due to the presence of roots. Although the small scale turbulence probably increases due to the presence of the roots, probably the mean velocity decreases, or the vortices become smaller or change shape, resulting in reduction of scouring.

Flume experiments on the root reinforced bed - current interaction

Flume experiments were carried out to examine how roots influence the scouring process of sand beds and which the most important parameters are.
The first purpose was to examine whether the roots reduce current forces or increase the bottom strength. Figure 3 gives a schematic view of these two main types of mechanisms.

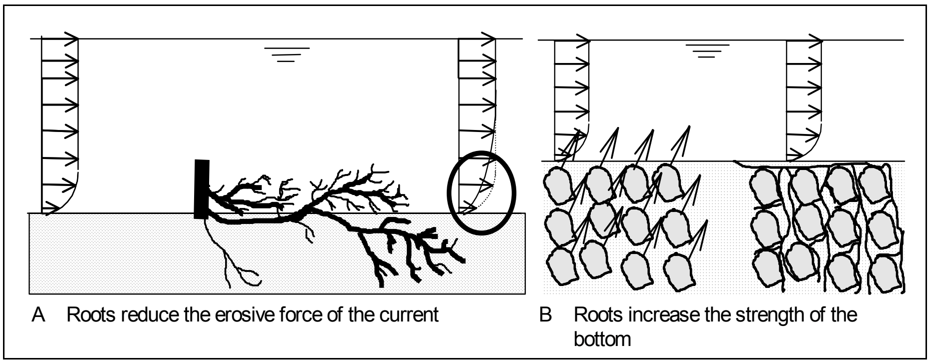

Figure 3. Schematic view of two possible mechanisms

The second purpose was to examine the influence of the individual root thickness.
The third purpose was to examine the influence of the roots on the *development stage* of the scour hole, for only the equilibrium depth of the scour hole was measured in the first experiments.
In these experiments artificial willow roots were used with mechanical characteristics similar to real roots, without significant (bio)chemical influence. Different types of Enkamat® were used; this is a commercial available mat, often used in hydraulic engineering to protect slopes against erosion. These mats have an open, three-dimensional random structure of plastic filaments. Contrary to the most real root structures, all filaments per type have the same thickness. Therefore it was possible to examine the influence of the thickness of particular roots. The mats were easy to use and re-use in the experiments.
In the flume a situation of clear water scour was created. Just behind a horizontal concrete bed, the mats were placed in a sand bed. Figure 4 gives the dimensions of the laboratory situation.

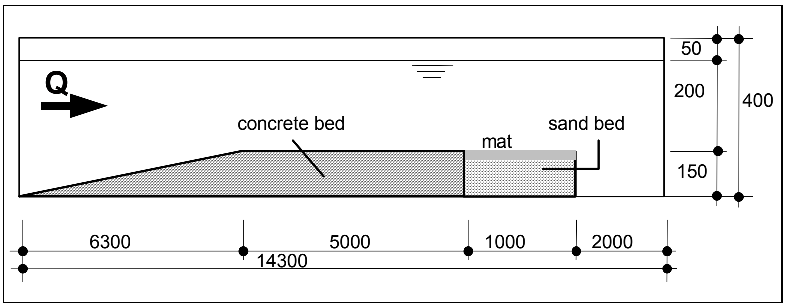

Figure 4. Flume design with dimensions (mm) (not on scale)

The water depth was constant during all the experiments. The series of experiments were made for different current velocities. During each experiment the current velocity was held constant.
Each experiment started with placing and filling the mat with sand as shown in figure 4. The sand bed consisted of narrow graded sand (d_{50}=750 µm).
The bed level is measured at different times in three different ranges in a defined interval together with the maximum scour dept in each range. The interval between the first locations was shorter because at those locations the biggest changes took place. Also the time intervals were shorter directly after the start of the experiments. The accuracy of the bed level measurements is approximately 1 mm; this is the order of one sand particle. The accuracy of the horizontal position is less important and is approximately 5 mm. The accuracy of the mean velocity determination is about 0.01 m/s.

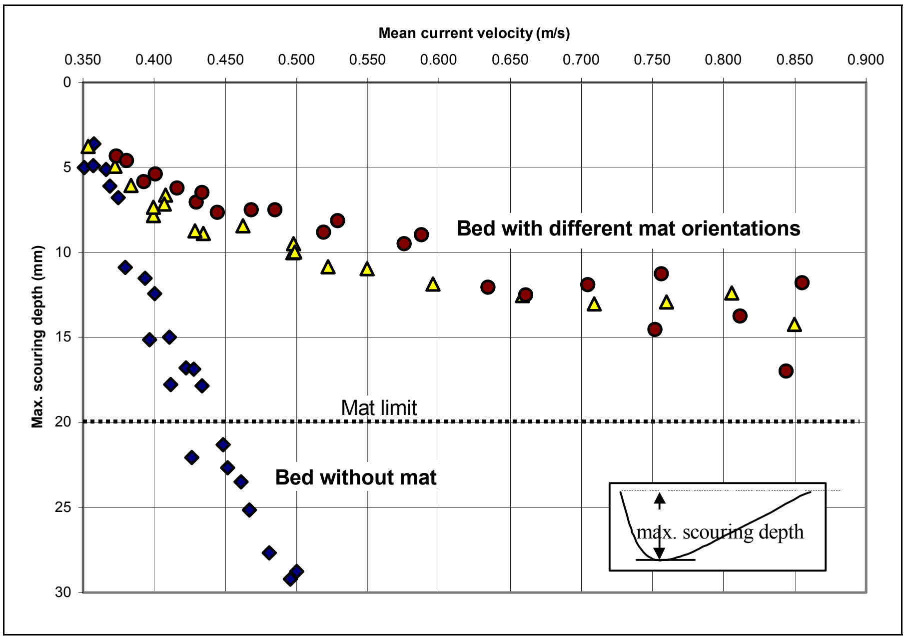

Figure 5. Maximum scour depths as function of time on t= 30.0 min

Results

Figure 5 gives the results for two orientations of one mat type compared with a bed consisting of only sand (without mat), 30 minutes after start of the experiment. The horizontal axis shows the mean current velocity and the vertical axis shows the maximum scour depth. The intermittent line indicates the lower limit of the mat. The upper limit equals a scour depth of zero.
From this figure the influence of the mat is clear. Without the presence of the mat, the maximum scour depth reacts very sensitive to an increase of the mean current velocity. The mats reduce the influence of the current velocity, resulting in much lower scour depths for the same current velocity. For bigger scour dephts the influence of the mat increases, resulting in a decreasing curve gradient for higher current velocities.
Figures similar to figure 5 can be made for the mean scour depth and for other time intervals. Figure 6 shows the development of the scour hole in time.

The maximum scour depth each time is presented for approximately the same current velocity (0.50 m/s).

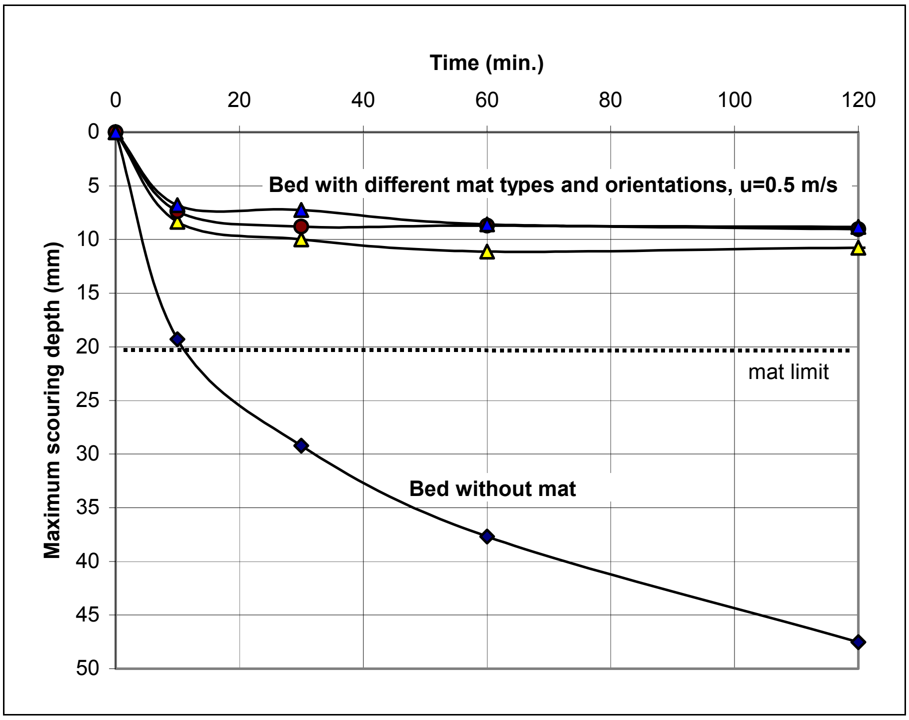

Figure 6. Development of the maximum scour depth

In a situation with mats, the equilibrium depth is reached after about 20 minutes. Without a mat the equilibrium depth is not reached even after 120 minutes.
Different orientations (upside up or upside down) of the mats correspond with a different distribution of the filament density over the heigth. The *maximum* scour depth was not significantly influenced by the different orientation of the mats. However, the *mean* scour depth was significantly different, indicating a different form of the scour hole.
Different types of mats, with slightly different filament thicknesses, heights of the mats and densities of the structure were examined. The effects of the differences on the scour depths are not significant. However, the differences in filament thickness were small, so it is not possible to draw final conclusions.

To compare the earlier experiments in which real willows were used with the experiments with mats, a trunk was placed in the sand bed with a mat. The comparison of the situation with a trunk could only be made for lower velocities after a relatively short time, because the scour hole around the trunk developed too fast by higher current velocities. Also the transition between the horizontal bed of concrete and the sand bed has more influence on the scour depth than the trunk for higher velocities.
In this situation (pile in a sand bed) the presence of the mat results in a significant reduction of the scour depth. It can be concluded that a mat around a trunk gives results comparable with roots around a trunk.

Interpretation of the results

In literature the first movement of sand particles is often used as a measure for sand transport. The disadvantage of this measure is its subjective character. In this research tests the first movement is defined as the mean current velocity which results in a mean scour hole of 2 mm over the first 20 cm in the first 30 minutes. This is still a subjective definition, but it can be used in exactly the same way in all situations.
The relation between the mean current velocity and the mean scour depth is nearly linear. A linear trend line has been added to measured points (see figure 7). The intersection of the trend line with a scour depth of 2 mm is the velocity at first movement corresponding to the given definition.

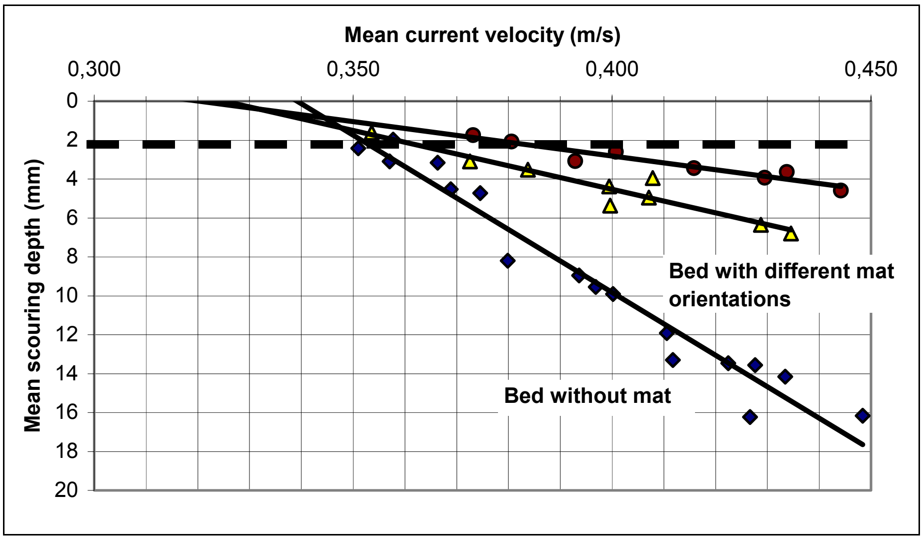

Figure 7. First movement

There is little difference between the intersection points with the 2 mm line. For this three presented situations the velocity at first movement varies from 0.35 to 0.37 m/s (following the given definition). From this it can be concluded that the mat does not have much influence on the first movement. The mat within the sand bed does not affect the first moving particles on the bed. Because the top of the mat has just the same level as the surface of the sand bed, at the beginning there is no difference between a bed with a mat and a bed without a mat. The influence of the mats increases with the increase of the scour depth. This interpretation corresponds with the results presented in figure 5.
McKay [2] presents measures of velocities within the same mat types, which supports this interpretation. The higher the filament density, the lower the velocities and turbulence intensities near the bed. However, this research is carried out with current velocities below the critical velocity, so there was no transport. He found a relation between the filament density, and the velocity and turbulence intensity. This is supporting the interpretation presented above.

Destructive experiments

Also some destructive flow tests were carried out with the willow cuttings. At low current velocities (0.23 m/s) small and shallow scour holes around the trunks started to grow. The depth of these holes decreases, as the trees stand more behind.
The destructive flow tests showed that the willows in front indeed improve the situation for the willows behind (until they collapse), due to reduction of the flow and extra incoming sand from the holes around the trees at the front.

Conclusions

The next conclusions can be drawn from this research.

(1) Tree or bush vegetation on a riverbank between groynes can reduce the current velocities significantly.
(2) The way of planting willows, sowing or slipping of cuttings, influences the kind of bed protecting root structure.
(3) Only small bed particles (≤50 μm) have some (bio)chemical binding with the roots.
(4) The presence of roots reduces the scour process by influencing the loads.
(5) The mean reduction of the equilibrium scour depth round a pile due to the protection of roots was found to be: 42 % in case of the slipped willows (cuttings) and 76 % in case of the sowed willows, with a surface root structure.
(6) Destructive flow tests showed that the willows in front improve the situation for the willows behind, due to reduction of the flow and extra incoming sand from the holes around the trees at the front.
(7) The distribution of the root density (mat orientation) has influence on the *form* of the scour hole, but not on the maximum scour depth.
(8) There seems to be no significant relation between the thickness of individual roots and the depth or form of the scour hole. However, there are not enough research results to prove this.
(9) Roots influence the scouring process and not only the equilibrium depth. Scour holes develop much slower with the presence of roots than without.

Broader applications

Some broader applications of the investigation may be found for example in reducing the foundation depth of bridge piers or reducing the length of bed protections by placing artificial roots (mattresses) around the pier or behind the bed protection respectively.

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