OVERFLOW STRUCTURES NEAR ROERMOND

GIJS HOFFMANS

Ministry of Public Works and Water Management, Rijkswaterstaat, DWW
Delft, The Netherlands

HENK VERKERK

Ministry of Public Works and Water Management, Rijkswaterstaat, Directorate Limburg
Maastricht, The Netherlands

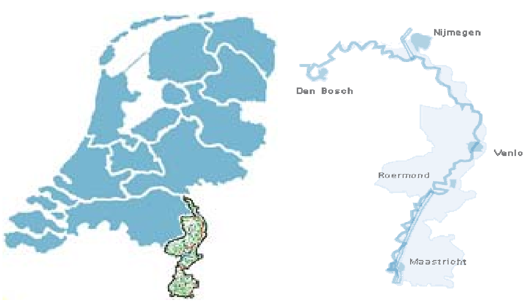
ED BERENDSEN

Ministry of Public Works and Water Management, Rijkswaterstaat, Bouwdienst
Delft, The Netherlands

Managed flood control systems will only be used with a low frequency. In Limburg, in the southern part of the Netherlands, a flood occurs on the average of once in 250 years. Some overflow structures that incorporate materials that could be applied to the slopes of embankments to withstand the hydraulic loads are discussed. The present state of the investigations into the use of grass and open stone asphalt is considered. Different variants of concrete and other innovative materials are introduced and briefly reviewed. Scouring will arise at the transitions between bed protection and the erodible bed and attention is paid to how scouring can be minimized.

1 Introduction

In December 1993 and January 1995 the river Meuse unexpectedly overflowed in the region of Limburg, affecting some 10,000 people and causing damage costing several hundred million of Euros. As a direct result of these floods the Dutch Government initiated "De Maaswerken". This integrated project aims to reduce the risk of flooding to the ‘250 year’ security level for the villages and towns protected by the embankments. To achieve this goal, not only will the Meuse be deepened and broadened over a length of 200 km, but also the height of the embankments will be increased. In addition, natural areas will be developed and economic development will be stimulated by furthering water transport.



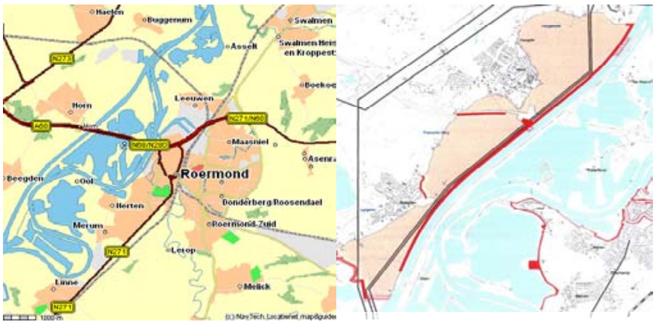


Figure 1. Overview of retention areas

The height of the embankment between the Oolderplas and the Prins Willem Alexanderhaven will be increased. Higher embankments are also planned along the by-pass river Hambeek as well as small parts of the river Roer. These works will create two retention regions near Roermond (Figure 1). During periods of high water the higher parts of these areas will be protected by removable defences.

This paper briefly discusses the design aspects of the overflow structure. Special attention will be paid to the dimensions of the revetment on the slope of the embankment. The flow velocities in the Meuse, calculated with the numerical model WAQUA (Meijer and Folkertsma, 2003), are used as a criterion to evaluate the protective materials. Not only are the classical solutions using stones considered, but also modern ones incorporating grass, geo-textile sand filled elements and open stone asphalt.

2 Revetments

2.1. *Grass*

A grassed clay dike is the type of revetment that is most frequently used to prevent erosion. The grass cover also has a number of other functions, for example, agricultural, ecological and recreational. Sometimes the grass cover is used for traffic.

As a result of the research during the last few decades, the relation between the quality of the vegetation and the erosion resistance has improved (Seijfert and Verheij, 1998). When grass alone is not sufficient, a reinforced grass cover can be used. Two main types can be distinguished:

- Cellular blocks. These concrete blocks have open cells that are filled with soil. These holes allow the vegetation to grow through. It is important that the soil is not completely eroded from these cells before the vegetation is fully grown (Figure 2);
- Synthetic mats. The main objective of these mats is to provide temporary protection to the bare soil to encourage the development of vegetation in circumstances where it is usually impossible for a plant cover to become established.

Grass covers can resist flow velocities of up to 2.0 m/s without any problem. Figure 3 shows the maximum water velocity as function of the time for three different qualities of grass (good, average and poor cover). The turf is the top layer of soil with a dense network of roots and is 5 to 15 cm thick. Though this layer can withstand the hydraulic loading for a long time, its success depends on its maintenance. Research at experimental sites showed the essentials of an adequate maintenance regime. When the sward (that is the aboveground components of plant growth) is periodically mown, the hay is removed and no fertilizer is applied, a type of vegetation with a great ecological value develops. After 3 to 5 years the grass cover is no longer vulnerable to erosion. Examples of inadequate maintenance regimes are excessive fertilizing, no maintenance at all or burning.

Figure 2. Articulated revetment mats, Hand placed concrete blocks, Established vegetation within the concrete blocks.

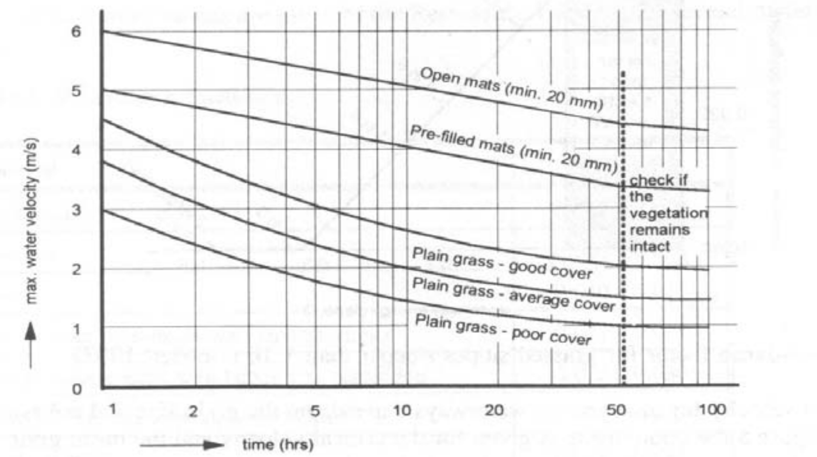


Figure 3. Maximum velocity as function of time

An open mat consists of an entirely open structure of randomly placed monofilaments and is used in situations where grass can establish itself in time. A pre-filled mat is filled with bitumen bound mineral chipping in such a way that the mat remains open. The strength of open and pre-filled mats is shown in Figure 3.

The advantages of these mats as compared to the ‘hard’ revetments are:

- From an environmental point of view protection by vegetation is often preferred. Reinforced grass is indistinguishable from entirely natural vegetation, so it fits in with the landscape.

- Grass reinforcement is cheaper than more traditional solutions.

2.2. *Grey revetments and innovative materials*

The grey revetments may be divided into two different categories:

- Protected by loose units
- Protected by interlocking units

Interlocking units are used as an alternative to riprap rock, gabions, or structural concrete. Because of the ease of installation, these units provide additional benefits. Blocks can be hand-placed or pre-assembled into mats and lifted into place to provide flexible, stable protection in high-flow, high-scour potential applications. The block system is usually used in combination with a site-specific geotextile filter, not only for scour protection, but also to dissipate the energy of vortices generated by the turbulent flow and to stabilize the toe of the embankment.

Geo-textile sand filled elements of various types and sizes are available. Geo-bags are sandbags of about 1 cubic meter in size. Usually they are used to fill scour holes, to serve as a protection against high water levels or in emergency embankments. Geo-mats are flat and have elements that are individually filled with sand. Provided they are secured at the top they can be used as protection against erosion (Figure 4). Geotextile tubes are long sand filled elements and geotextile containers are elements with a volume of between 100 and 600 cubic metres. These materials serve as alternatives for the traditional construction methods. The use of these type of elements has the advantage that local material can be applied and that it is not necessary to extract and transport expensive quarry stone.

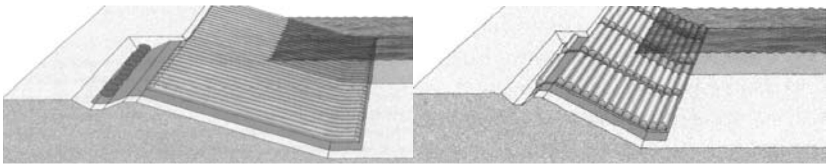


Figure 4. Geo-mats

When the river exceeds its maximum level, severe flow attack will occur on the crest and the inner side of the embankment. Usually the flow is specifically determined by the geometry and the boundary conditions. The strength parameters can be calculated by using Pilarczyk's (1990) stability relation:

$$\Delta D = 0.035 \frac{\Phi}{\Psi} \frac{K_T K_h}{K_s} \frac{U^2}{2g} \quad (1)$$

in which Δ is relative density, D is thickness of the revetment, Φ is stability parameter, Ψ is transport (or damage) parameter, K_t is turbulence factor, K_h is depth parameter, K_s is slope parameter, U is (design) flow velocity (section 4) and g is acceleration of gravity.

According to Pilarczyk, the stability parameter depends on the application. For rip rap and placed blocks it varies from 1.0 to 1.5. For block mats, gabions, washed-in blocks, geo-bags and geo-mats it is 0.5 to 0.75.

Riprap: Assuming that $\Phi = 1.0$, $\Psi = 0.035$, $K_T = 2.0$, $K_h = 1.0$, $K_s = 1.0$ and $U = 5$ m/s the thickness of the riprap is about 1.5 m (and $D = 0{,}5$ m for $U = 3$ m/s).

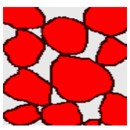
Geo-mat: Assuming that $\Phi = 0.75$, $\Psi = 0.07$, $K_T = 2.0$, $K_h = 1.0$, $K_s = 1.0$ and $U = 5$ m/s the thickness of geo-mat is about 0.6 m (and $D = 0{,}2$ m for $U = 3$ m/s).

This calculation shows that the thickness of the traditional riprap must be at least 1 m in order to withstand the representative loading. For innovative materials, for example a geo-mat, the thickness is about half of this.

2.3. *Open stone asphalt*

Asphalt is a mixture of bitumen and mineral aggregate. From these basic materials a range of asphalt mixes can be made, each designed to solve particular problems. The properties and utility of a mix are determined by the proportions and grades of the mineral components, and by the degree of 'filling' with bitumen.

Open stone asphalt is a robust and gap-graded material of mastic and (lime)stone. It contains approximately 80 percent (by weight) uniformly sized stone and 20 percent mastic asphalt. The mastic binder only coats and connects the limestone particles together. The mastic film is resistant to weathering. Its nature and viscosity lends itself to smoothly following the contours of the revetment. Due to its permeability it is possible to get a proper growth of vegetation. Mixing is carried out in two stages. First mastic is prepared and secondly it is mixed with stone.



Open stone asphalt: Bitumen coats and binds the various aggregate components, leaving voids unfilled. The bitumen acts only as a binder, so the properties of the mix are determined by the stone skeleton.

Flow resistance of open stone asphalt

The resistance of open stone asphalt against flowing water with high currents was investigated in the eighties (TAW, 1985). At prototype scale in the test weir of Lith (Netherlands), stationary flow showed that damage was observed after 34 hours with current velocities of 6 m/s, which was the maximum generated flow.

Bieberstein *et al*. (2002) developed a design graph for revetments as shown in Figure 5. The experiments validate an analytical relation that is based on a stability theory for a two-layer system in which all relevant forces act. In the tests the slope was covered with a 12 cm thick revetment. The maximum permitted load is given as function of the steepness of slope and for different angles of friction in the shear plane (between open asphalt and embankment). The friction condition in the shear plane had a considerable influence on the design and is estimated at 31°. This investigation explains that the angle of friction significantly influences the permitted load. The more gentle the slope the higher the permitted load can be. Although the method of construction can be very interesting, its application is only valid for slopes gentle than 1:4. It is remarked that the permitted load for slopes steeper than 1:3 is almost nil. The flow at the crest and at the inner side of the slope was supercritical.

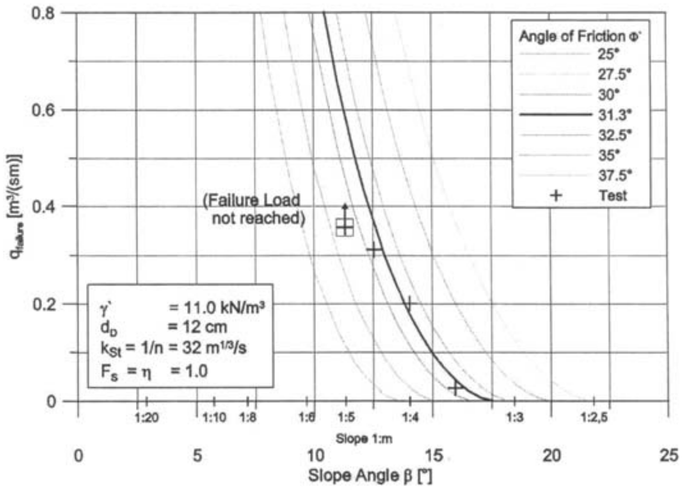


Figure 5. Characteristics of open stone asphalt (after Bieberstein *et al*, 2002)

3 Scouring aspects

Usually the flow on the inner side of the embankment starts with supercritical conditions and ends with sub-critical ones. This depends strongly on the differences of flow level in the retention reservoir and river. For the prototype scale both situations must be included. When the flow is supercritical, a hydraulic jump will develop. This region is highly turbulent and is situated near the toe of the embankment where severe scour problems could occur. Bieberstein *et al.* (2002) optimised the energy dissipation at the transition from the inner slope to the horizontal bed in order to protect the downstream area from erosion. For the overflow construction in a flood retention basin at Monchzell (Germany) where the specific discharge is about 500 l/s/m, they presented a design in which the inner slope (1: 8) is protected by a geotextile on which a revetment of open stone asphalt is placed, Figure 6.

This revetment is completely covered with soil and seeded with grass. The dimensions of the artificial deepening are 10 m in length and 0.5 m in depth. In this turbulence area the hydraulic jump is fixed. Though the revetment on the inner side is robust, owing to its short length the protection downstream of the artificial deepening could be undermined. The hydraulic jump reduces the flow velocities. However, the turbulent energy produces flow conditions that are still far from uniform so this erosion problem is usually solved by using a scour apron (Figure 7). When a geotextile is used as a secondary layer it should be folded back in order to reduce the effects of undermining.

Near Roermond the subsoil along the river Meuse consists of clayey sand (thickness is about 2 meters). Below this impermeable layer there is gravel the critical velocity of which varies from 0.5 to 1,0 m/s. If open stone asphalt is used it is recommended that this system should be connected to the gravel layer and that the gravel be infiltrated with bitumen. In this way the gravel can resist the high design velocities (see Section 4).

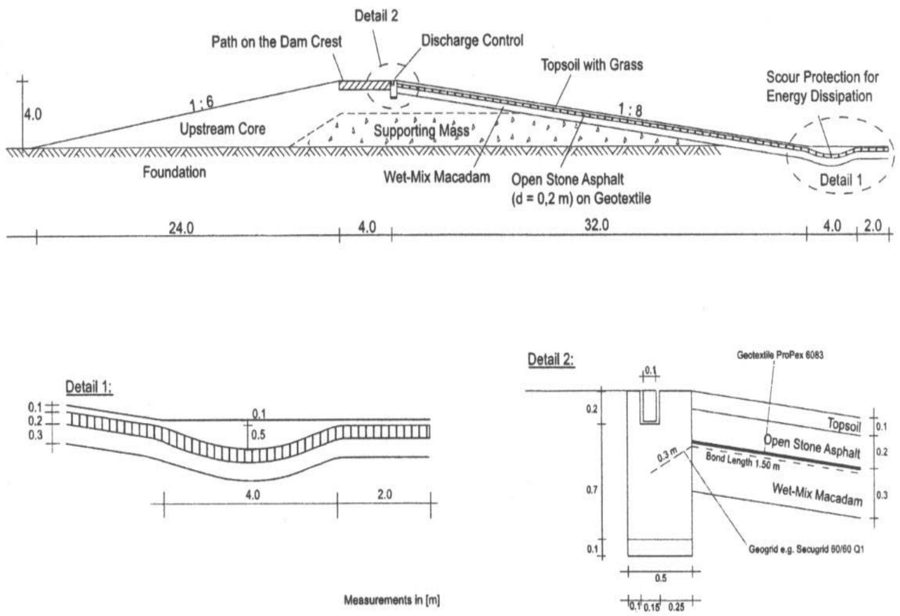


Figure 6. Characteristics of open stone asphalt (after Bieberstein *et al*, 2004)

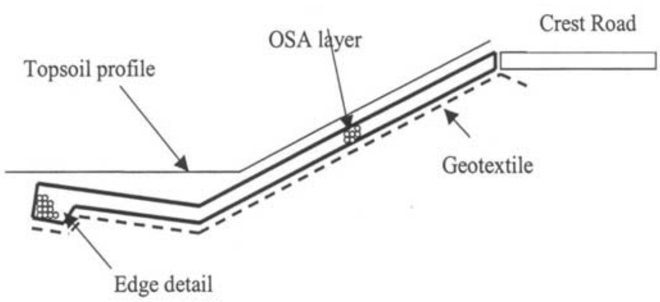


Figure 7. Revetment of open stone asphalt OSA (after Bieberstein *et al*, 2004)

4 Design methodology

The overflow construction in retention areas should focus on the following main aspects:

- Function analysis;
- Initial costs and maintenance costs;
- Environmental value.

The overflow construction will be operational on the average of once in 250 years. Then the lowlands (Figure 1) will be flooded. There will be a maximum period of ten hours during which the water in the river will not rise. Hence, the function of these areas is mainly to store water and not to discharge it.

Revetments are primarily built to reduce the hydraulic loads acting on the soil with the aim of preventing erosion. In principle several solutions are available to the designer of the overflow constructions, some of which are briefly discussed. According to Meijer and Folkertsma (2003) the design velocities on both the crest and the inner side of the embankments are estimated to be at 4 to 5 m/s. Consequently, a revetment of grass is not resistant enough. It will be eroded after a few hours and a breach will form in the embankment. However, the function of the retention area, which is to store water, will still be fulfilled. After the high water event the embankment must be repaired for the coming return period of 250 years, which differs significantly with the economic lifetime of 30 years for such structures. When the overflow construction is flow-resistant, there are no repair costs. Although the initial costs of a solid revetment (grey revetments, open stone asphalt, geo-mats) are much higher than the costs of repair, at present no conclusions have been drawn regarding the choice of overflow structure. One reason for this is that not all the aspects of environment, communication are analysed in a balanced way.

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