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Damage to dike revetments strengthened with geotextiles

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ABSTRACT: Damage is occurring regularly to dike revetments in which geotextiles have been used under the armourstone layers. This leads to high costs of repair. Mechanisms that cause the damage during the execution and service phases are apparently not fully known. Use of (heavy) armourstone without a protective layer between rock and geotextile combined with inappropriate work methods are likely the main causes of damage. Up till now safety has not been at stake. However, it is not clear which risks exist in the safety and environmental process. In view of the safety risks potentially at stake, it is deemed necessary to systematically reassess the suitability of this type of structure (without a protective layer), as compared to other types. A quick scan makes clear that this type of structure is not applied anymore in primary flood defences in the Netherlands. One project under consideration, "Brielse Maasdijk" (a dike in the vicinity of the city of Brielle), is unique at this point. During rehabilitation of this Maasdijk it was concluded that, despite observed damage to the geotextile, such additional protective layer would be superfluous, probably contrary to recently gained insight. In another project, the Sea Defence "Maasvlakte", the design was however adjusted at high costs. In the near future high costs will be involved with repairs of the revetments of the containment dike of the IJsseloog Confined Disposal Facility. To limit the possibility of damage and to keep the safety risks and costs of repair under control, it is recommended to draw up clear guidelines with regard to design, execution and quality control of slope revetments with an armourstone layer on top of geotextiles. Apparently knowledge and information on these topics are not complying with realistic data and requirements. Little is known about the influence of dumping and profiling armourstone with a crane on the geotextile and about the required mass or strength of the geotextiles; moreover, inconsistent data are provided in literature about the relation between the mass and strength of geotextiles and the mass of the falling armourstone.

1 INTRODUCTION

In bank and bed protection, filter layers are necessary to prevent washing out of subsoil by water flow and/or waves. These filters can be built of granular material. Geotextiles have been used for several decades as an economically attractive alternative for several layers of granular material.

In the past ten years failures were discovered of a few specific dike revetments. Damage had occurred to dike revetments in which geotextiles has been applied under the armourstone layers. In these cases the geotextile failed to fulfil its main function of retention of the subsoil. Teared sewn seams and perforated geotextile caused by the sharp edges of the armourstone were observed. The conclusion was that the filter structure did not meet the original requirements. Possibly the safety of the water barrier had become insufficient due to the malfunctioning of the geotextile.

Therefore a project was initiated to study this subject (CUR-F41 2004). The damage to the geocomposite in the dike revetment of the Confined Disposal Facility (CDF) IJsseloog in the "Ketelmeer" was the immediate cause. After a quick-scan three projects were selected where damage to the geotextile had occurred (see Figure 1)

- Dike CDF "IJsseloog"
- Brielse Maasdijk (along "Hartelkanaal")
- Sea defence "Maasvlakte".

2 CONTAINMENT DIKE CDF "IJSSELOOG"

2.1 *Description of the construction*

"IJsseloog" is a confined disposal facility for the storage of 20 Mm^3 of contaminated dredged material

Figure 1. Location of the projects in the Netherlands.

(CDM), situated in the lake "Ketelmeer" (see Figure 1). The containment dike was built by means of hydraulic sandfill in 1999 The embankment of the facilities area is shown in Figure 2. A geocomposite (woven plus non woven to protect against armour stones) was applied below still water level as filter between the sand and the rock armourlayer. The protection of the lower slope with a fascine mattress (a geotextile with a grid of fascines), ends there. The toe was protected with a fascine mattress; the geotextile of the mattress lies under the geotextile of the upper slope.

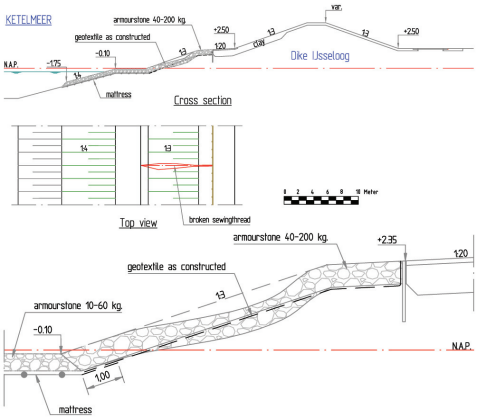

Figure 2. Cross-section dike IJsseloog.

2.2 *Description of the damage*

After a storm in February 2002, when the water reached a level of NAP + 0.6 m, deformation of the upper slope of the dike revetment was observed over a length of 600 metres. This deformation was locally concentrated at the sewn seams in the geocomposite. At least 20 to 30% of the sewn seams showed damage. At one location the armourstone sagged over a length of 15 m. The photograph of Figure 3 shows the sandfill being partly exposed. It appears that the effect is washing out of sand rather than radial shear of the sand. The thread of the sewing joint was broken. At several locations stones had perforated through the geocomposite. However, the effect of the damage was limited: sand had washed away, but the stone had sank into the perforation and partly closed it. The damage near the sewn seams was more serious: much more sand had washed away.

Figure 3. Photograph of broken sewn seams (stones removed.

2.3 *Possible causes of damage*

The most probable causes of the damage are:

(i) Overlap of the geotextile of the upper slope and the fascine mattress under the berm under was not correct. With wave attack, the geocomposite of the upper slope revetment should have been under and not above the geotextile of the fascine mattress, as there is an apparent leak for the sand to be washed out.

(ii) Heavy armourstone 40-200 kg had been applied directly on the geocomposite. Due to the space between the stones the sand of the subsoil could wash away as a result of the pore pressure in the sandmatrix (micro instability). This phenomenon caused tensile forces in the geocomposite and in the sewn seams and the latter failed, because the sewn seams are the weakest parts of the geocomposite.

(iii) The flow capacity of the geocomposite could be less than the porosity of the subsoil. This could have excessed the pore-water pressure in the subsoil and could have caused liquefaction.

(iv) Locally heavy stones perforated the geocomposite, which lead to washing out of subsoil. Most probably direct damage started by dropping the coarse armourstone on the geocomposite. As a result of this work method tensile forces in the geotextile and the sewn seams increased. At the same time the revetment shape developed to a "S-profile" (see Figure 2). This further increased tensile. This progressive mechanism went on until the sewn seams broke. As a consequence, the sand (subsoil) washed away through the toe of the upper slope and through holes in the geocomposite. Probably, the storm of February 2002 has washed away a lot of subsoil, which lead to the deformation of the structure. However, washing out of subsoil sand could have started prior to this storm.

As a consequence of this damage, repairs have been carried out; initially to a limited extent (one trial section), but it is expected that far more repair works will be needed, implying that high costs are involved.

3 BRIELSE MAASDIJK

3.1 *Description of the construction*

The revetment of the Brielse Maasdijk is located along the southern bank of the "Hartelkanaal". The dike is part of the primary flood defence, but does not directly abut the North Sea. Between NAP – 4.00 m and NAP + 3.00 to 3.30 m the revetment consists of armourstone 10-60 kg, applied on a slope of 1:4 (see Figure 4). Between the subsoil of clay and the rock armourlayer a geotextile of polypropylene with a mass of at least 180 g/m^2 and a tensile strength of 20 kN/m was applied.

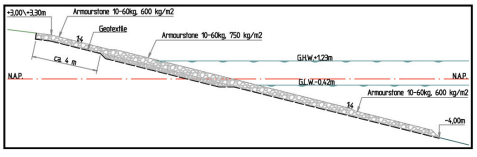

Figure 4. Part of cross-section Brielse Maasdijk.

Below NAP (Normal Amsterdam Level) the geotextile is part of a fascine mattress with reed matts knitted to the geotextile. Above NAP, geotextile without reed mattress had been applied. Between NAP – 0.50 m and NAP + 2.00 m a layer of gravel 30/80 mm (250 kg/m^2) between the armourstone 10-60 kg and the geotextile is applied. Between NAP + 2.0 m and NAP + 3.0 m the armourstone 10-60 kg (600 to 750 kg/m^2, see Figure 4) has been placed directly on the geotextile. Underneath the revetment a clay layer is present (0.40 m to 1.00 m thick). The quality of the clay varies from good to poor (poor = little clay with much sand).

3.2 *Description of the damage*

In 1996, about 15 years after construction, damage to the geotextile was discovered over a total length of 14.9 km. Afterwards this damage was investigated systematically to assess the safety risks for the area behind the dike. Large and minor tears were found in the geotextile between NAP + 2.00 m and + 3.00 m, where the armourstone had been applied directly on the geotextile. The damage was investigated by a 'periodic systematic random check'. To this end the armourstone was removed and the damage of the geotextile was determined in 19 testsections at equal distances of approximately 750 m. The dimensions of each testsection were 2 m (along to dike) by 4 m (across the slope). In each testsection the number of tears, the length of each tear and the total length of tears were measured. The result was that all 19 testsections showed damage. The average number of tears was 1.6 per m^2, with an average length of 0.37 m per m^2 and 0.22 m per tear.

An important conclusion of the investigation was that no excessive damage to the dike was detected. Probably the stones had tightened the tears. The subsoil under the geotextile, consisting of cohesive clay, could apparently not be washed out by waves and wind. It is be noted that significant hydraulic loads had not occurred yet.

3.3 *Possible causes of damage*

The dike revetment was constructed in 1980/1981 and the damage was detected in 1996 during adjustment/rehabilitation of the slope protection. It is not fully clear what caused the damage. The applied geotextile had a mass of 180 g/m^2 (without stitched reed mattress or non-woven). Probably the damage to the geotextile was caused by the inappropriate mass and strength of the geotextile, taking into account that the armourstone 10-60 kg had been dropped directly on the geotextile, and had been re-arranged by the crane to get a well-packed armourlayer. Designrules recommend applying a geotextile with a mass of at least 300 g/m^2 for similar situations with armourstone directly on a geotextile. Insufficient knowledge is at hand about the influence of stacking the armourstone with a crane and the required weight or strength of the geotextile. Moreover, inconsistent data are provided in literature on the topic of the relation between the mass and strength of geotextiles and the mass of the falling armourstone.

3.4 *Consequences of damage*

In the worst case teared geotextile is existent on a subsoil of sandy clay and the tears are directly exposed to significant wave height of 0.5 m to 0.7 m, depending of the location. A scour depth of 1 to 2 m can be expected. The erosion is however limited, because of the construction is not directly attacked by sea waves. At that time (1997) the conclusion was drawn that the strength of the dike was sufficient considering that in almost all cases the stone, which caused the damage, covered the observed damage areas.

4 SEA DEFENCE "MAASVLAKTE"

4.1 *Description of the construction*

The revetment is part of the sea defence "Noordwesthoek Maasvlakte", which has to protect the various port facilities against extremely high tide and waves from the North Sea. Initially the revetment (slope angle 1:4) would consist of armourstone 6-10 ton, with an underlayer of 40-200 kg rock and a geocomposite (polypropylene woven with a mass of 550 g/m^2 and a stitched non-woven of polypropylene 150 g/m^2) between the rock revetment and the compacted sand fill (see Figure 5 left part).

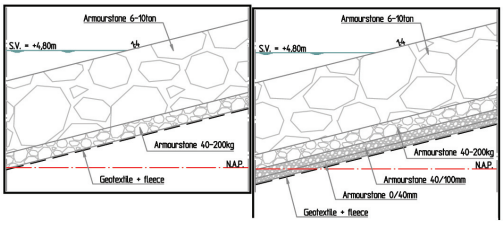

Figure 5. Initial (left) and adjusted (right) plan Maasvlakte.

4.2 *Description of the occurring damage and possible causes*

Damage to the geocomposite has been detected during construction of the revetment. The detected gaps, tears and teared sewn seams were caused by the impacts of the heavy toplayer armourstone combined with the effects of the sharp edges of the filter layer rock 40-200 kg, its relatively small layer thickness (0.6 m) and the application of a geocomposite with insufficient mass or strength. The placement of the stones of 40-200 kg using a crane, with its bucket scraping the stones over the geocomposite, caused tears in both the woven fabric and the non-woven. The chosen work method did result in additional damage to the geotextile because of the rather rough method of placing the heavy armourstone 6-10 tons.

4.3 *Adjustment of design*

Due to the damage occurred during execution, it was decided to adjust the design. Several alternatives have been considered: the application of a heavier/stronger geocomposite, application of more geocomposites, a better distribution of the load on the geotextile by applying extra granular filter layers etc. The last alternative has been chosen: two extra layers of stone (0/40 mm and 40/100 mm) were added (see Figure 5 right part). The main function of these extra layers is to get a more even distribution of the load on the geotextile.

5 CONCLUSIONS

In this paper, the possibility of damage of geotextiles by applying (heavy) armourstone without a protective layer between rock and geotextile was investigated. Mechanisms that cause the damage during the execution and service phase are apparently not fully known. Little is known about the influence of dumping and profiling armourstone with a crane on the geotextile and about the required mass or strength of the geotextiles with inappropriate work methods are likely the main causes of damage.

To limit the possibility of damage and to keep the safety risks and costs of repair under control, it is recommended to draw up clear guidelines with regard to design, execution and quality control of slope revetments with an armourstone layer on top of geotextiles.

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