Erosion protection with geosynthetics

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Abstract

The NGO had its eighth study day/creative session on a windy but sunny day on the beach. The focus this time was on the use of geosynthetics for erosion protection. Three speakers set out the theoretical and practical basis for the study day. More than thirty participants from clients, contractors, engineering firms, suppliers and research institutes conducted tests and devised innovative structures with geosynthetics as protection from erosion caused by rain, waves and currents.

Introduction

Currents, wind and rain remove soil (erosion) and release it elsewhere (sedimentation). This is a natural process that has shaped our country, and continues to do so. There are times when we cannot allow this process to continue unhindered and others when we have to protect our land from erosion. Moreover, climate change is exacerbating the problems on our water banks and coasts, and those caused by rainfall. Because the sea level will rise sharply in the coming decades, an enormous upgrade operation will be necessary for our coastal defences: rainfall and water flows can also cause erosion in the hinterland.

Structures that include geosynthetics play an important role in protection from erosion: as a filter in rock revetments that protect dikes from erosion, or directly as a way of protection from erosion caused by currents or rainfall. In order to share knowledge about erosion protection with geosynthetics, the NGO organised a study day - the eighth of its kind - on the topic on a windy but sunny day on the Dutch Kijkduin beach.

Figure 1. Erosion with gully formation [Province of Limburg, Belgium]

Filters with geosynthetics

In the first presentation, Adam Bezuijen talked about filters, an important subject in hydraulic engineering. Geosynthetics play an important role here. So important, in fact, that geotextiles used to be called 'filter cloths'. Adam outlined the development of geosynthetic filter applications in hydraulic engineering using three examples: the Haringvliet locks built in the 1960s, the Eastern Scheldt storm surge barrier from the 1970s and the Mose barrier in Venice, which is still under construction. Only a thick layer of granular filters was used in the Haringvliet locks: geosynthetics were not yet considered. The filters were built up layer by layer in the temporary polder where the locks were built on dry land. A similar approach with a polder was not feasible for the Eastern Scheldt storm surge barrier and mattresses with granular material and geosynthetics were sunk in the Eastern Scheldt. However, not enough was known about the lifespan of geosynthetics to allow them to be used as a filter. The mattresses therefore consisted of a granular filter wrapped in geosynthetics. It was not until the Mose barrier was being developed that adequate knowledge became available about the lifespan of geosynthetics and that they could really be incorporated in the structure as a filter. This made it possible to use much thinner and cheaper filter mattresses.

In the design of a filter, permeability and aperture size are important in relation to the granular size of the material that one wishes to capture. The permeability of a geosynthetic structure is highly dependent on the granular material used above and below the geosynthetic; in many cases, the permeability of a geosynthetic structure is therefore much lower than the measured permeability of the geosynthetic alone. The weight of a revetment is also important for stability. There are often drawbacks to replacing a granular layer with a much lighter geosynthetic structure.

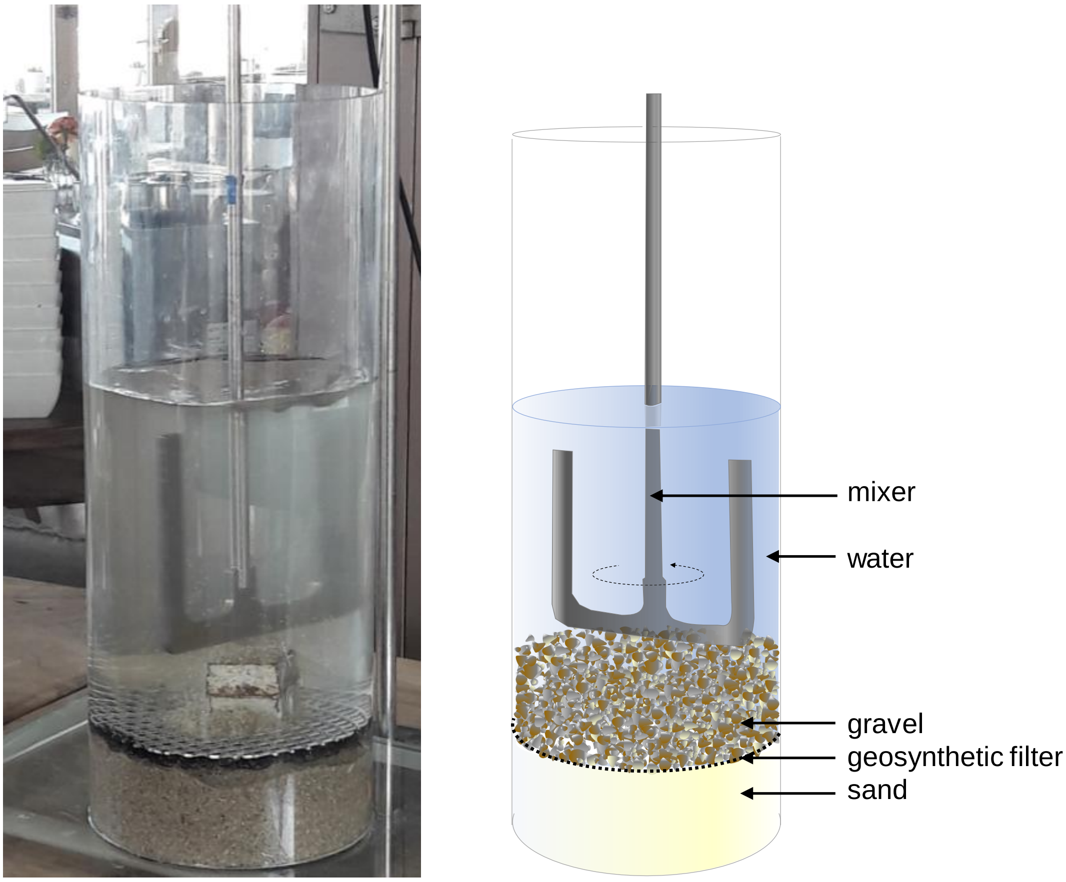


Figure 2. Erosion tests Left: photo of geogrid on clean sand. Right: gravel on geosynthetic filter on sand.

Adam used a number of tests to show how grains of sand will move if there is a failure to comply with the rules for the filter function (Figure 1). As an extreme example, he used an open geogrid on clean coarse-grained sand. It emerged that this geogrid hardly protected the sand from erosion at all. Normally these elements are filled with earth, stones and/or bitumen. When, later in the day, the same element was filled with earth during the tests outside, the combination proved to be very erosion-resistant.

Geosynthetics in coastal hydraulic engineering

Wim Voskamp started with a few forms of coastal erosion and sea defences, and outlined developments in the Netherlands in recent decades. There is a balance on the sandy Dutch coast between dune erosion during high tides and storm tides and the deposition of the eroded sand on the beach and the foreshore in calm conditions. The sand on the beach dries and is blown into the dunes by the wind. The dune recovers and new dunes form: this is dynamic coastal management. If there are sand shortages anywhere along the coast, they can be replenished through sand nourishment. Present-day sand dredgers have enough capacity to raise the coastline regularly like this economically. This is the current strategy for coping with sea level rise. Time will tell whether we can handle a metre of sea level rise in this way.

Geosynthetics can make a major contribution to coastal protection. Since the first applications in the Delta Works, geosynthetics have increasingly been used in coastal hydraulic engineering and offshore applications in mattresses, bags, tubular elements and geocontainers (Figure 3). They are used in filter structures on slopes of sea dikes, or to prevent soil removal, and they are often included in fascine mattresses. They can also be used in large sandbags, for example for the construction of groins, breakwaters, coastal defences and protection from soil removal, alongside fixed structures. Pipelines on the seabed can also be covered with block mats or concrete mattresses. Geocontainers are often used these days to make underwater breakwaters. These breakwaters reduce wave height and coastal erosion.

a. The Dutch coast: dynamic coastal management [TRDA Technical Report on Dune Erosion, 2006]

b. Seawall with filter structure, Middle East. [Low & Bonar]

c. Dune base protection with geosynthetic bags, North Carolina, USA [PIANC 2011]

d. Groin, core made of geosynthetic bags. Maroochy, Queensland, Australia [Restall et al., 2002]

e. Geotextile tubes as slope revetment [PIANC 2011]

f. Covering of a Geotube [TenCate USA]

Figure 3. Six examples of coastal protection with geosynthetics

Internal erosion protection for flood defences and slopes

In the Netherlands also, we face erosion challenges due to extreme rainfall and high river water. Rijk Gerritsen explained how the ground cannot absorb the water as quickly during extreme rainfall events, as a result of which it flows away over flood defences and earth embankments. Where there is little resistance to erosion, channels may form (Figure 1). This can constitute a serious threat to the embankments (progressive erosion/shearing) and/or adjacent structures.

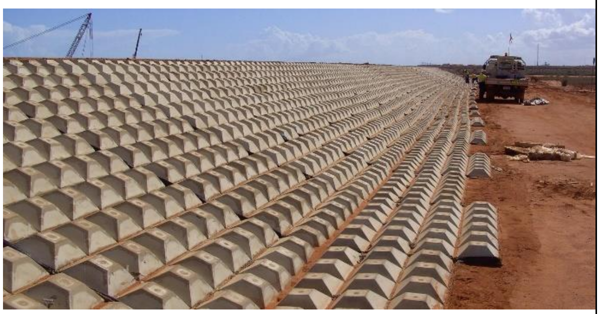
The erosion conditions determine which types of geogrids or geocells can be used. Sowing vegetation into geogrids provides green slopes and a high level of resistance to erosion. ‘Hydromulching’ can accelerate sod formation. This involves filling geogrids with a mixture of seeds, soil material and nutrients (Figure 4a). For more challenging conditions, there are geogrids filled with crushed stone bonded with bitumen (Figure 4b). Rijk emphasised the importance of a correct mixture of seed, and the correct application and approach to the installation of the geogrid. On very steep slopes, geogrids can be anchored with pins or special anchor systems, if necessary penetrating through to a firm base layer (Figure 4c).

In even more demanding erosion conditions, such as those found near rivers, canals or lakes, more extensive measures are needed such as geotextile mattresses filled with sand or concrete. These systems are used in locations where vegetation develops with difficulty, such as warm, dry areas with little fertile soil. Another option is to use concrete block mats (Figure 4d).

a. Geomat with hydromulching; anchoring with the root system

b. Heavy geomat filled with crushed stone/bitumen and vegetation growing through the mat

c. Reinforced geomat on a steep slope with anchoring



d. Concrete block mattresses on a 3D geotextile woven cloth

Figure 4. Examples of erosion protection in flood defences and embankments [source photos: Low & Bonar]

Tests

Designing sealing systems is one thing; practical application is another. Six teams of participants were challenged to build their own dike revetment. Piet van Duijnen had set up six trays and a wave flume. The assignment was to make an erosion-resistant dike that would reduce wave run-up. To make things challenging, the available pieces of geosynthetic were small (30 cm x 30 cm) and so overlaps had to be considered. Three large waves were then produced using a wave flume and ten buckets of water. A spectacular sight. The less water that impacted the dike, and the better the dike stood up to the three strong waves, the better. It was striking that the six very different dikes were very illustrative in terms of confirming different theories.

Figure 5. The test set-up with a wave flume and trays with one of the models

For example, a rough slope with gravel really does reduce wave run-up significantly. That was clear to see: the models with a gravel revetment (Figure 8b and d) had considerably less wave run-up than the models with a smooth slope (Figure 8a and c).

Clean beach sand eroded very rapidly. In Adam's erosion tests (Figure 2), we had already seen how loose sand is eroded through a geogrid with an open structure. The wave tests, however, showed that this geogrid really worked when humus was worked through it. While the loose grains of sand were set in motion by the current, the cohesion in the humus was adequate to stop them being washed out of the geogrid and therefore to prevent erosion. The model in Figure 8a showed this clearly: the smooth slope consisting of a geogrid with humus remained perfectly intact but the waves happily washed over the smooth dike.

Different groups used a smooth geomembrane (sheeting). It slid off the slope when subjected to a wave load. The slope revetment of the winning team (Figure 8b) consisted of smooth sheeting under a layer of gravel. Here also, the gravel and the sheeting eventually slid off the slope. Fortunately, we do not use this sheeting in practice but we do use a smooth geotextile. This is usually anchored at the top and bottom by digging a trench, inserting the geotextile and refilling the trench. An alternative approach to anchoring is a toe structure at the bottom of the slope with rock on the geotextile above that. The rock then rests on the toe structure. A toe structure may consist of a concrete beam fixed in place with piles.

The reinforcement of the slope with sand-filled geotextile elements was not very successful in the tests. Two dikes were protected with sandbags; sandwich bags filled with sand. When sheeting was applied under the bags, the bags slid down the slope (Figure 8d). When sandbags, gravel and soil only were used, the sand below the bags was washed away (Figure 7, left).

Figure 6. Left: the test trays. Right: the winning team: André van Hoven (Deltares), Perry Groenewegen (RHDHV) and Folkert Reitsma (Friesland provincial authority)

Figure 7. Wave loads

a. Humus in geogrid: slope stayed intact but a lot of overtopping

b. Gravel on sheeting

c. Sheeting and geogrid

d. Sandbags and gravel

Figure 8. The result. Bottom left: the winning model.

Elaboration of cases

After conducting the tests, the six teams went to work intensively on two cases that Rijk Gerritsen and Edwin Zengerink presented to them. Finally, the cases were discussed with the whole group under the leadership of the chairman of the day, Wim Voskamp.

Case 1

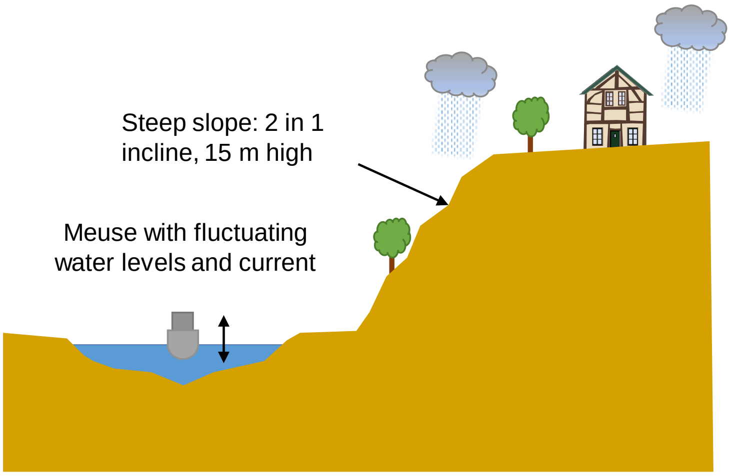


Figure 9. Case 1: erosion problem in Limburg

The first case was an erosion problem in Limburg. There is an extremely steep slope, extreme rainfall, fluctuating water levels and a strong current in the Meuse, as well as a listed house at the top of the slope that is threatened by the erosion of the slope and the riverbank. The teams were asked to design geosynthetic solutions, taking integration into the natural surroundings into account, managing contact surfaces, and providing information about the solution during an evening for residents.

Team 1 thought the slope was stable: old trees were growing on it. They tackled the erosion with a geosynthetic composite consisting of a reinforced 3D geomat. It was anchored at the top of the embankment and sown with local vegetation so that it fitted in well with the surroundings. Team 2 also initially decided to capture rainwater at the top of the slope, partly eliminating the cause of slope erosion.

Team 3 and 4 adopted a steep wall structure with reinforced earth. In this way, Team 3 created a little more space for the residents. Team 4 opted for an approach with terraces and planting vines. Team 3 placed a concrete mattress under water in the river at the bottom of the slope. Team 4 opted for an impermeable mat with a polymer gel.

Team 5 opted for a cheap, steep solution: a weed mat with a lot of anchoring covered by ivy. At the bottom of the embankment, they installed a drainage pipe covered by rock. Team 6 moved the monumental building 50 to 100 metres to create space for a gentle slope and protected the banks of the Meuse with a block mattress including geosynthetic material.

Wim Voskamp pointed out that the geomats on this steep slope work only if they are shaped 100% to the ground. Air between the mat and the ground makes it impossible for the vegetation to take root properly. Reinforced earth requires a lot of excavation and, for a wall to grow, the maximum incline of a slope is about 70 degrees. A tiered structure can help in that case.

Case 2

Figure 10. Case 2: erosion in the coastal area

The second case involved an erosion problem in a coastal area. The dunes are threatened by the water and they are in danger of being washed away (Figure 10). There is extensive coastal erosion due to the dynamic load generated by waves and currents, and by sea level rise. Sand nourishment is necessary but sand is becoming scarce in this region. This is a beach and so using rock is not an option. The teams were asked to devise manageable innovative geosynthetic solutions, to save sand and to communicate with the stakeholders.

All teams broke the waves by installing a geotextile tube or container in the sea. The tube breaks the waves and dissipates a lot of energy. Sand deposition will be reduced and, in addition, more sand will be deposited between the tube and the coast, with the possibility of silt rather than sand. Some coordination with stakeholders such as fishermen, commercial shipping and recreational shipping is therefore necessary. Some teams applied a small layer of rock on top of the tubes. These solutions with elements in the sea are regularly applied in practice but particularly in areas where tidal differences are very small, as in the case of Cannes in France where there are tubes 80 cm below the waterline. Underwater breakwaters have also been used for the 2nd Maasvlakte, in Israel, Australia and the USA. The effect of the tide on how tubes or containers work is easy to investigate in a flume.

Some teams also positioned geotextile tubes in the dunes with a covering of sand and marram grass to optimise protection from erosion. Other teams preferred 'building with nature' and opted for dynamic coastal management. Some teams installed an underwater berm. Team 6 also initially installed sheet piling to reduce excavation at the front. Team 6 expected maintenance to be necessary here but less sand was needed. This sheet piling idea sparked off a lively discussion about the benefits and drawbacks of sheet piling in a location of this kind.

The winners

After careful consideration, the jury decided to pick team 1 as the winner of the day. Their model had little wave run-up due to the use of a gravel lining and their dike remained relatively intact. Moreover, they solved the cases well! It was striking that one of the team members was also one of the winners last year. We would like to congratulate team 1 again here!

Disclaimer

This article reports on a creative session that included a brainstorming session about the applications of geosynthetics. The solutions described are not all feasible or practical. The cases were drawn up with actual situations in mind but they are by no means intended to reflect practice or possible solutions.

Acknowledgements

Piet van Duijnen and Paul ter Horst devised the wave flume tests, put together the wooden boxes and made them available. Low & Bonar, Huesker and Tensar supplied geosynthetics

and other materials for the slope revetments and test trays. Deltares and Ghent University supplied the cylinders and the set-up for the erosion tests. Rijk Gerritsen, Adam Bezuijen and chairman of the day Wim Voskamp were the driving forces behind the organisation of the substantive side of this instructive day. The board members of the NGO wish to thank everybody!