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Geosynthetics and river dike improvements

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ABSTRACT
In this paper the opportunities to use geosynthetics in the improvement of river dikes is presented.
Due to the extremely high water of the rivers Meuse and Rhine in the Netherlands in 1994 and 1995, a major scheme to improve the river dikes will be implemented. The aim of the scheme is to increase the safety of the inhabitants of the areas concerned. The design of dikes and dike improvements is based on sophisticated design tools which give insight into the failure mechanisms of the dike.
The improvement of dikes usually entails raising and widening the dike, thus disfiguring the landscape and the cultural inheritance that this represents. During the period when the high water levels of 1995 posed a serious threat, flooding was successfully prevented by numerous immediate actions in which geosynthetics were used. As a result interest was focused on the use of geosynthetics in the construction of permanent dikes. Geosynthetics can be used for erosion prevention in revetments, but also as reinforcement, and for drainage, filters, impermeable membranes, and the separation of layers of construction material. This application may lead to the construction of smaller, less expensive dikes which will also comply better with the requirement of landscape architects.
The paper discusses the design principles and illustrates these with a case study.

Introduction
The Netherlands lies in a low lying delta area that is crossed by many major rivers. To reduce the risk of flooding during periods of high river discharge it is often necessary to raise the level of the river dikes. Traditionally, the width of the dikes is also increased, while the gradient of the slopes is decreased and berms are constructed to prevent the collapse of the dike. With the increase in population pressure and the increasing scarcity of natural areas, however, there is now growing opposition to the taking of the large areas of space that are required when strengthening the dikes. Increasingly too, protests are heard against the demolition of houses on or behind these dikes and against the effects of these changes on important features of landscape and ecological value on and beside the dikes .

In a study [Ref 1], research was carried out into possibilities of using geosynthetics to resolve these conflicts of interest mentioned above and into the design principles on which the use of these materials could be based. First an inventory was made of various mechanisms that cause dike failure and of the part that geosynthetics could possibly play in preventing failure and thus solving the problems. Next the design guidelines were formulated. Finally two cases were worked out, one of which is described in this paper.

Dike improvements
Possible failure mechanisms include:

- Overflowing

Overflowing of dikes occurs when the water level outside the dike exceeds the crest level. Overflowing may cause erosion of the inner slope, possibly leading to breaching of the dike which may result in the flooding of its hinterland.

- Waves overtopping the dike

Waves overtop the dike when there is a combination of high water levels and high waves. Owing to breaking waves and surface run off along the slopes the inner berm may be eroded. In addition infiltration may cause localised instability of the inner slopes.

- Piping

Piping is a phenomenon in which the ground water flow in the sand layer under the dike carries away granular material. This may cause the formation of tunnels or 'pipes' which can undermine the dike.

- Shearing on inner slopes (macro-instability)

Shearing on the inner slopes leading to collapse of the inner slopes. This occurs when the increase in the water pressure in the dike leads to reduction of the shear stress in and under the dike body.

• Shearing on outer slopes (macro-instability)
Shearing on the outer slopes leading to collapse of the outer slopes. This occurs as a result of water overpressure in the dike, due to a rapid fall in water level after a period of high water.

• Micro-instability
Micro-instability is caused by the washing out of soil particles on the inner slope by out-flowing groundwater. The slope may be completely washed away locally. If there is a high rate of erosion the entire slope may collapse (macro-instability).

• Erosion of the outer slope
Wave attack and the action of flowing water may damage the dike revetments, as a result of which the material on the slope may be washed away. If this continues, the core of the dike may be exposed and damaged, leading to the breaching of the dike.

• Squeezing
Squeezing is caused when under pressure, there is horizontal movement of weak layers in the subsoil under the dike. This phenomenon usually occurs during construction or when the dike level is being raised.

• Seepage
Seepage occurs when water flows through the dike to the area protected by the dike. To prevent the development of high water pressures in the dike and the discharge of water from the inner slope of the dike, it is necessary to ensure that the amount of seepage remains limited.

Geosynthetics and dike improvement

Geosynthetics can be used in various ways to prevent one or more of the above mentioned effects. The functions of the geosynthetic are:

• Reinforcement
Macro-stability can be improved by using a synthetic reinforcement during the construction phase to prevent squeezing when a dike constructed on relatively weak substratum is being improved.
Reinforcement may be placed in or under the inner slope of a dike. Possible methods of construction are shown in Figure 1.

• Filter
Micro-stability can be improved by the use of a geosynthetic filter. The function of a filter is to allow water to escape from the soil body without soil

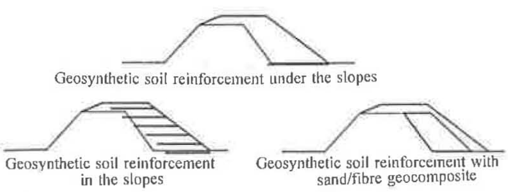

Figure 1: Construction forms to safeguard macro stability

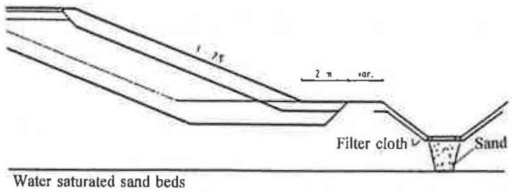

Figure 2: Relief ditch

particles being carried away. For example, a filter may be laid on the bottom of a relief ditch which has been constructed to prevent piping, as shown in Figure 2.

• Drainage
Geosynthetic drains can be used to prevent problems caused by water or to speed up the consolidation of layers which are subject to settling. A drain at the foot of the slope is intended to lower the phreatic water level in the dike. As a result, the water pressures remain lower and the grain stress (the effective soil stress) remains higher. This increases the macro-stability because it also ensures that water no longer escapes from the dike.

• Separation
Installing a geosynthetic separation prevents the washing out of soil particles or their being pressed into weak layers.

• Impermeable membrane
A watertight membrane prevents the flow of groundwater in the sand layer under the dike. Such a seepage screen is usually placed on the outer side of the dike (see Figure 3).

• Protection against erosion
The most well known use for geosynthetics is to protect the inner and outer slopes of dikes against erosion. In this paper no further consideration is given to this application.

• Special applications
Examples of special applications of geosynthetics include their use as filling material for sand- filled geosynthetic tubes or gabions, rodent resistant textiles and silt screens.

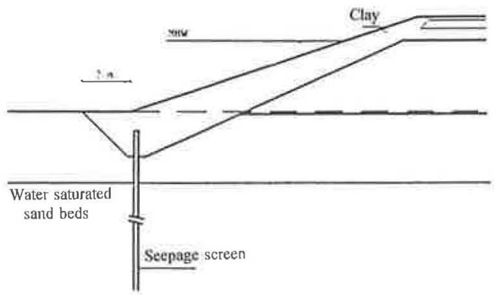

Figure 3: Seepage screen

Table 1: Uses of Geosynthetics

	Reinforcement	Filter	Drainage	Impermeable membrane	Separation	Erosion protection	Special function
Non woven	--	**	oo	--	**	**	oo
Woven	oo	**	--	--	**	**	oo
Geogrid	**	--	--	--	--	--	oo
Geomembrane	--	--	--	**	oo	--	oo
Structure mattress	--	--	oo	--	--	**	oo
Geocomposite	oo	oo	**	**	**	**	oo

-- unsuitable / oo possibly usable / .. good

Table 1. shows which products are most suitable for the functions mentioned above.

Design aspects

When structures which incorporate geosynthetics are being designed several aspects demand special attention. In the first place the quality of the geosynthetic material to be used must be guaranteed because failure endangers the safety of the land behind the dike. Certification and quality control play an essential part in this. The homogeneity of the material and the continuity of the production process are included in the assessment.

A dike is constructed for long term use and therefore it is essential that special care is taken in the execution of the work. Damage during the construction phase can lead to very serious problems at a later date and is unacceptable. For the same reason, the durability of the material used in dikes is obviously important. Resistance to aging, long term strength and creep behaviour must meet exacting requirements. In the case of filters, their are additional demands in relation to the filter stability which are intended to prevent the silting up of the filter. The water permeability of a filter can be reduced by blocking (ground material accumulates in front of or in the openings of the geosynthetic) or by clogging (fine particles from the underlying material settle in the inner pores of the geosynthetic). Finally the design must take into account the demands relating to management and maintenance of the dike and the possible need to make repairs when unforseen damage occurs.

Description of Case Study

Problem definition

As an example of the use of geosynthetics in a practical situation a design was made for a specific location in the Netherlands river areas. Within the dike is a dwelling house which is sited at the foot of the dike. The area outside the dike has a high natural value. For reasons of safety it appears that the crest of the dike must be raised by 0.60 m, to a level of NAP 8.25 m. In addition in the present situation the required degree of safety for the dike is not reached because their slopes are too steep. The data used are: gradient of inner slopes 1:1.5 to 1:2; gradient of outer slopes 1:2 to 1:3; slopes covered by a turf (grass) revetment; surface level outside dikes NAP + 2.10 to 3.00 m; soil structure clay and silt with occasionally a little sand; a continuous sand layer is found below NAP -6.50 m; traffic load 13 kN/m^2. The extension of the dike is constructed from sand and clay.

Design

Reducing the gradient of the slopes or the construction of wider berms will lead to reduction in the value of the natural landscape and demolition of the dwelling. Whether using geosynthetics would make it possible to save the dwelling and avoid disturbance of the natural landscape was investigated. A solution was found which would allow the use of geosynthetics, using steep slopes within the design requirements that had been fixed. A profile with an outer berm slope of 1:1 was designed. Because a steeper gradient had been chosen for the slope, calculations had to include a high wave overtopping factor. The design height of the crest must therefore be NAP+8.35 m (see Figure 4).

Function and position of the geosynthetic

The function of the geosynthetic is to reinforce the outer slope in order to achieve sufficient micro-stability. The position of the geosynthetic in the profile must be such that it cuts the potential shear plane. The strength and stiffness of the ground reinforcement must be great enough to guarantee the stability of the slope. The load on the geosynthetic consists of the weight of the soil body and a load that results from traffic on the dike.

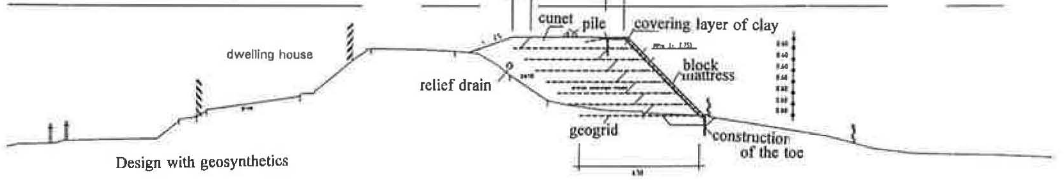

Figure 4: Case study

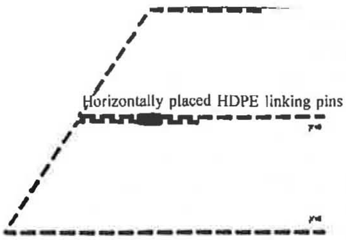

Figure 5: Fastening of the layers of the geogrid

Choice of material
The selection of the type of geosynthetic was based on aspects such as stiffness, tensile strength (short term strength), long term strength (in relation to relaxation and shrinkage), and friction force (interlocking). For geosynthetics which are to serve as reinforcement for berms there are two options; namely geotextiles and geogrids. In view of the greater stiffness and the greater shear resistance of geogrids as compared to geotextiles, the decision fell on a construction using geogrids.

Dimensions of the geogrid reinforcement
When calculating the dimensions of the geogrid reinforcement the following aspects were considered:
- spatial characteristics of the dike profile
- geotechnical properties of the dike profile and subsoil
- technical requirements with regard to water retention
- properties of the geosynthetic material

There is no standard method to calculate the dimensions of a geogrid reinforcement in dike berms. For this reason design calculations were carried out in several ways, making use of the knowledge and experience which had already been built up earlier, such as:
- manual measurements described in [Ref. 2],
- use of the program MSTAB, a computer program with which the stability of slopes can be assessed according to the method of Bishop,
- use of the program WINSLOPE, developed by the supplier of TENSAR grids,
- use of the program PLAXIS a finite element method [Ref. 3], [Ref. 4].

Results of the calculations
Although, due to the different assumptions and methods used, the results of the different calculations were not entirely in agreement, by making a critical analysis of them it was possible to produce a reliable design:
- geogrid SR 55,
- distance between the reinforcement = 0.60 m,
- first reinforcement layer at the separation of the subsoil and the embankment,
- length of the reinforcement = 6.50 m,
- number of geogrid layers = 7
- construction following the 'wrap over' method (see Execution 3)

Execution
1. To ensure a good interaction between the old dike material and the new material used to heighten the level of the dike the top layer of the existing berm is cased in steps of 0.40 * 0.40 m. The natural ground level is excavated to the depth at which the first grid layer is placed.
2. The dike improvement is built up from sand. This is placed in layers of 0.60 m and in order to seal this material a covering layer of 1 - 1.5 m clay is placed on the outer side.
3. A geogrid is placed between each of the sand layers. To protect the layer of clay against upwards pressure when there is a rapid fall in the water level outside the dike the geogrid is placed according to the 'wrap over' method. In this method the geogrids are turned back over a length of approximately 1 m and fixed with a HDPE horizontal linking pin, thus fastening them to the geogrid which lies 0.60 m higher. The layers in the new part of the dike are constructed by first placing the clay cover and then the sand. Each layer of sand and clay is machine consolidated (see Figure 5).
4. The grid can take up the greatest force in the direction of stretch. The grids are therefore placed with the ribs at right angles to the axis of the dike, in the direction of the potential shear plane. The lengths of geogrid are laid beside each other without overlap.
5. To protect the outer berm against attack by currents and waves a hard berm revetment (block mattress) is place up to the level of the dike crest.

The new dike extension will consist of a sand body that is placed against the much less permeable existing dike. To prevent the accumulation of water in the new dike extensions a synthetic drainage system must be introduced into the core of the dike extension.

Cost
The price of this geotechnical solution was compared with that of an alternative solution with a sheet pile construction placed next to the existing premises. From this it appeared that the sheet pile construction was 30% to 50% more expensive than the solution using geosynthetics.

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