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The Development and Application of Geotextiles on the Oosterschelde Project

Développement et application de géotextiles du project de l'Oosterschelde

A number of estuaries are located in the south western part of the Netherlands. Since the flood disaster of 1953 all these sea inlets but one have been closed (the Delta Project). The last inlet is the 9 km wide Oosterschelde, which for environmental reasons will be shut off from the sea only in heavy storm conditions by a storm surge barrier (the Oosterschelde Project). For the large areas of scour protection of the Delta Project and specially the Oosterschelde Project new techniques have been necessary. This paper reports the development and the application from the conventional mattress, the semi-conventional mattress and the permanent ballast mattress to the fixtone mattress, the block-mattress and the gravel-sausage mattress. The storm surge barrier in the Oosterschelde will be built up from prefabricated elements, which will be placed in the channels by special barges. The piers will be placed on prefabricated filter mattresses, built up from geotextiles and holding natural filter material. Around the foot of each pier special gravel bags are suspended. These last two constructions are only possible because of the use of geotextiles.

Au sud-ouest des Pays-Bas se trouvent un nombre de bras de mer, qui après le raz de marée en 1953 furent fermés. Le dernier bras de 9 km de large est l'Oosterschelde qui pour raison de sauvegarder le milieu naturel, sera fermé par un barrage anti-tempête. Des nouvelles solutions comme protection des fonds sont exigées pour le Plan Delta et spécialement pour les travaux dans l'Oosterschelde. Ce rapport traite le développement de ces nouveaux revêtements, depuis le matelas de fascines croisés, par le matelas à simple couche de fascines, jusqu'au carapace souple, comme le paillasson en empierrement asphaltique, le matelas de blocs en béton et le matelas de bourrelet en gravier. Le barrage anti-tempête dans l'Oosterschelde sera construit par la pose d'éléments préfabriqués dans les chenaux au moyen de bateaux spéciaux.Les piles seront posées sur les matelas filtre, composés de géotextiles et remplis de matériaux naturels filtrants. Des bourrelets spéciaux bourrés de gravier sont mis autour du pied de chaque pile. Ces deux dernières solutions étaient uniquement possible grâce à l'application de géotextiles et le développement de techniques totalement nouveaux.

1. PROJECT REVIEW

1.1 Introduction to the Delta Project

In the history of the Netherlands there have been many floods: this has been inevitable, as so much of the country - particularly in the southwest - is low-lying. The rivers Schelde, Maas and Rhine flow through a combined delta to the sea, and the coastline is complex with deep seawater channels (Fig. 1).
In the past flooding has been controlled by a system of dikes, however this was inadequate in February 1953, when gales and a spring tide combined to breach the dikes in many places in a disaster reminiscent of the floods of earlier centuries. The number of deaths rose to 1,850 and the losses in livestock, buildings and agricultural land were beyond quantification.

A special commission quickly set to work to discover what measures were necessary: it devised a plan, called the Delta Plan, which involved closing off the Veerse Gat, Haringvliet, Brouwershavense Gat and Oosterschelde estuary. Working in that order, from the smallest to the largest, has enabled the engineers to learn by experience. The closure of these inlets shortens the coastline of the Netherlands by seven hundred kilometres.

1.2 The Oosterschelde Project

The Oosterschelde Project was started in 1967 with the building of harbours, with quays, jetties and yards. The actual construction of the 9 km dam started in 1968. Three construction islands, Roggenplaat (1969), Neeltje Jans (1970) and Noordland (1971), the Geul dam section (1972) and Schouwen (1973) abutments were built on the shallower parts of the river bed. By the end of 1973 5 km of dam had been completed. According to the plans, the remaining three channels, Hammen, Schaar and Roompot, should have been "plugged" with quarrystone and slag, covered with concrete blocks, gravel and sand between 1974 and 1980. The intention was to dump the concrete blocks from cableways.

1.3 Safety versus the environment

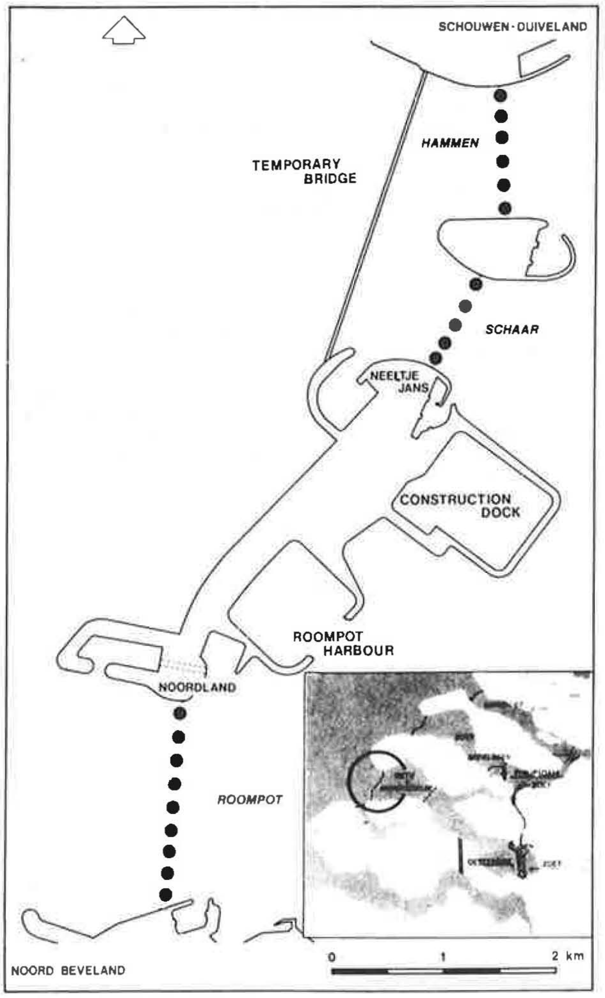
In the meantime, by the early Seventies, the plans to close the Oosterschelde had become the subject of heated discussions. A number of groups, opposed to complete closure, began to state their views more and more vigorously. They argued that the area could be sufficiently protected by raising existing dikes, and that the Oosterschelde should be kept open in order to preserve the existing tidal environment with its shellfish beds. Supporters of complete closure pointed out that this was the only way to guarantee the complete safety of the land in the area. The discussions led the Minister of Transport and Public Works to appoint a committee whose terms of reference were to report on all aspects of safety and the environment connected with the Oosterschelde Project. The committee issued its report on 1 March 1974. The conclusion was that in the interests of safety and of the environment, it would be best to build a storm surge barrier across the Oosterschelde which could be closed when necessary. Following the publication of this report, the DOS Consortium and the Public Works Department put forward other technical proposals for the design of the storm

surge barrier, taking into account three conditions laid down by the Government:
a. it must be technically feasible
b. it must be completed by 1985
c. the costs must be within certain limits
Designs were made for a triple storm surge barrier in the remaining channels, Hammen, Schaar van Roggenplaat and Roompot. The designs all had one thing in common: the barrier was to be prefabricated because construction cofferdams could not be built in the channels, since they would have temporarily closed the estuary to the detriment of the environment (Fig.1).

1.4 The selected design

The design finally selected, was for a storm surge barrier consisting of monolithic piers, the seabed between them being raised by a sill construction of quarry stone and threshold beams. The piers, the sill and the beams together form the frame within which steel sliding gates can be raised and lowered. During normal weather conditions the gates will be kept raised so the water can pass freely through the barrier and thus preserve the tidal environment. During gales the gates will be lowered (Fig.2).

Fig. 1 : The Oosterschelde Project.



The size of opening is designed to allow an average tidal range at Yerseke of 2.70 m (77% of the existing range). An effective opening of 14,000 m^2 is needed to achieve this. The storm surge barrier will be over 2,800 m long, with 63 closable openings and a total of 66 reinforced concrete piers: 16 in the Hammen, 17 in the Schaar van Roggenplaat, and 33 in the Roompot. The piers have baseplates of 25 x 50 m, their heights vary between 35 m and 45 m and they have a maximum dry weight of 18,000 kg. The distance between the piers, centre to centre, is 45 m.

2. SCOUR PROTECTION

2.1 Development

For centuries scour protection in the Netherlands has been made of wood (willow, osier wood). However for the Delta Project which requires enormous areas of scour protection, the use of protecting mattresses of wood was not feasible. First of all there was a shortage of wood, furthermore the special skilled labour to make the wood mattresses was not available in such a short time. Also the stones required to sink the mattresses are very expensive and sinking is labour intensive. Finally ship-worms flourish in the Delta waters and the mattresses would be attacked by these worms reducing their durability considerably. Therefore it was necessary to develop new types of more suitable scour protection.
Initially, at the end of the late Fifties, an attempt was made to reduce the use of wood in mattresses by using plastic layers and steel wire-mesh; only the fascines were still of wood.
This mattress was rolled on to a tube, shipped to the exact position, and lowered down onto the sea-bottom by unrolling and sinking by dropping stone onto it. These mattresses are the first types which were sunk under control as opposed to the former types the sinking of which was not controlled. In addition these mattresses are the first types of scour protection which used geotextiles. Because there was insufficient knowledge about the permeability of the geotextiles this type of mattress did not work effectively because it was impermeable to water.
The next step in the development was the use of relatively light nylon geotextiles instead of plastic layers and steel wire-mesh. For the Veerse Gat closure a nylon scour protection was used consisting of a nylon geotextile fabric to which are connected nylon geotextile tubes filled with sand. These mattresses were placed, using a vessel. The vessel towed the mattress over the scour as the scour protection was unrolled.

2.2 Semi-conventional mattresses

However this nylon scour protection, referred to in the previous section, was not entirely satisfactory and on several occasions the water permeability was insufficient. Therefore the search for a more suitable geotextile continued. Eventually a geotextile was found, made from a heavy polypropylene woven fabric weighing about 750 g/m^2. For this mattress a small amount of wood was used as stiffening and to give it buoyancy. The wood also protects the geotextile during stone dumping operations. In addition the method of placing also completely changed. The new procedure worked faster, and was much more accurate. The mattress was towed by a tug between two pontoons. A heavy weight, placed on one end, pushed the mattress down to the sea-bed. Then a stone-dumping machine was positioned above the mattress and stone was dumped on to the mattress so that the whole protection was correctly placed. This method is also possible if there is a small current flow. To resist the forces during the sinking procedure a geotextile is required with a breaking load of 150 kN/m; the conventional wooden mattresses had only 20 kN/m breaking load. The edges of the mattress are protected against instability in currents by concrete blocks weighing 800 kg/m.

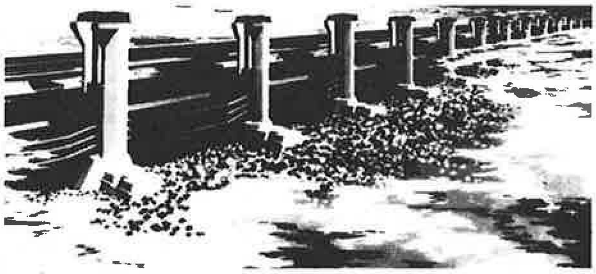


Fig. 2 : An artist impression of the Oosterschelde Storm Surge Barrier.

This construction worked satisfactorily and is still used on a large scale for instance as a shore protection for the artificial islands in the Oosterschelde Project. In recent years the construction has been further improved by testing and evaluation, so that it now has good water permeability, is impermeable to sand and is very durable in water.

2.3 Bottom protection with permanent ballast

The semi-conventional mattress was much better as a filter than the conventional protection of osier wood. The geotextile in the mattress combines great strength and filter properties. But the ship-worms which flourish in the Oosterschelde, also attacked the wood in the semi-conventional mattress. Other materials are required, particularly if the mattress is to be used for more than one year and on slopes. Also a lot of labour would be required for the large areas of scour protection in the Oosterschelde as the semi-conventional mattress is labour intensive. Therefore the Delta Department of the Ministry of Public Works and the contractors searched for another form of scour protection which would not have these problems. Starting with the semi-conventional mattress and using the same type of polypropylene geotextile they developed a scour protection with permanent ballast which involves no osier wood and only on some occasions a small amount of stone. This protection is completely factory-made and is placed by a special vessel.
Three new types of bottom protection with permanent ballast have been developed:

- the fixtone mattress
- the block-mattress
- the gravel-sausage mattress

The first two types are used on the Oosterschelde Project.

2.3.1 The fixtone mattress

a. General description

The mattresses are 17 m wide and will vary in length from 150 to 200 m. They are composed of fixstone applied to a permeable polypropylene geotextile in two layers, total thickness 0.12 m. The mesh size of the filtercloth is suited to the average sand-grain diameter in the Oosterschelde, $O_{90} \leq 0.150$ mm. The mattresses are weighted at the ends with concrete blocks so that the edges will be able to follow the configuration of the sea-bed. Since the mattresses are pulled forward during the production process and stresses are exerted on them while they are being laid on the sea-bed, they are provided with 18 cables and wire-mesh reinforcement. The diameter of the cables is directly related to the stresses that will be exerted on the mattresses and these stresses in turn depend on the depth of water in which the mattresses are to be laid. The cables are attached to the reinforcement by clamps. The concrete blocks and cables are connected to the permeable sheeting (Fig.3).

b. Fixtone

The product fixtone is 80% crushed stone (20-40 mm) and 20% asphalt mastic. The composition of asphalt mastic is 60% sand, 20% limestone filler, 20% asphalt bitumen. The fixtone is made in two stages in the same mixing plant; first the asphalt mastic is produced after which it is mixed with the crushed stone at a temperature of 110°C.

c. Fixtone mattress manufacture

Manufacture of the mattress takes places on board the of vessel. Sand and crushed stone are brought to the vessel the "Jan Heijmans", in hoppers from stock piles. Reels of geotextiles, 4.75 m wide, and the wire-mesh reinforcement are transported to the floating factory and there placed in bearings.
The manufacturing procedure is as follows. The strips of geotextiles are unwound from their reels and the edges are fastened together. The sheeting is then drawn through under a spiked drum until a length of about 6 m rests on the production platform. When the position of the geotextiles on the platform has been checked, the end ballast of concrete blocks is placed on the leading end of the geotextile. The concrete blocks are then attached to the geotextile and to the steel-wire cables of the mesh reinforcement.
The balance beam, used when placing the concrete blocks, is then put on the geotextile and fastened at one end to the steel wire cables and at the other to one of the winches on the vessel. By pulling on this bar, while the spiked drum continues to exert pressure on the geotextile, it is possible to tighten the geotextile and the wire-mesh reinforcement over the entire width of the mattress. When these operations have been completed, a start can be made on applying the fixtone.

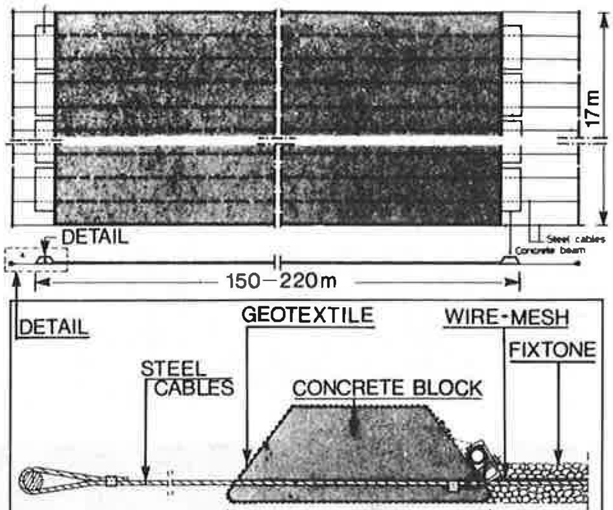
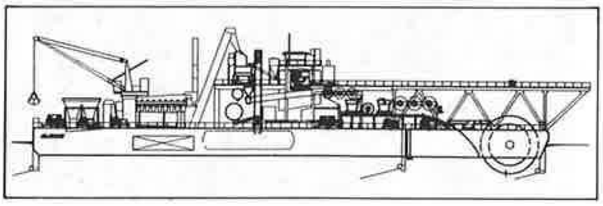


Fig. 3 : Shape and construction of the fixtone mattress.

Fig. 4 : The "Jan Heijmans" - mattress layer.



Fixtone is applied in two layers, the bottom layer by using the spreading trolley nearest midship, and the top layer by using the other spreading trolley, the latter after the wire-mesh reinforcement has been placed on the first layer. The spreading worms attached to the trolleys are fed with fixtone from the mixing plant. During these continuous operations the mattress is drawn forward along the production platform by the winch, using the bar of balance beam. When, however, the leading edge of the mattress has nearly reached the sloping part of the platform the matting drum takes over from the winch. The bar is removed and replaced by the tail beam. The drum is rotated by jacks. In this way the mattress is drawn towards the drum and then wound on to it. When the end of the mattress has nearly reached the sloping part of the production platform, the end ballast of concrete blocks is placed on the geotextile. When the last fixtone has been spread on the sheeting the mat is wound further onto the drum. The maximum speed at which the mattress moves during production is 1.5 m per minute, corresponding to a drum speed of 3 to 4 revolutions per hour.
The braking force exerted on the sheeting by the spiked drum during production of the mat varies between 450 and 600 kN. The horizontal movement of the mat on the platform is thereby adjusted to the rotary movement of the mat on the drum. The relationship between these movements is governed by the requirement that the mat must not sag between the sloping part of the production platform and the drum to such an extent as to cause a crack in the fixtone. A minimum radius of curvature of 4 m has accordingly been specified.
It takes about 10 hours to make and roll up a 17 x 200 m^2 fixtone mattress weighing 850,000 kg, 4 hours being required to make and spread the fixtone and 6 hours for incidental operations such as conveying materials and applying the edge ballast.

d. Mattress laying

The mattresses are laid at low water at about the turn of the tide. Then the variations in the direction and magnitude of pressures exerted on the mattresses by the current while they are being laid in position will not be too great. At least two hours before the tide turns at low water the "Jan Heijmans" (Fig.4) must therefore have been manoeuvred into the correct position, using the hauling system of anchors, wires and winches and the position-finding facilities, and the anchor beam must have been secured to the wire cables of the mattress. If at this moment the current velocity of the outgoing tide is not greater than 0.5 m per second and the set of the current is considered favourable, the mattress is unrolled. The correct position of the anchor beam must then be obtained by manipulating the winches and its position is checked with the echo-sounding equipment. When the anchor beam is in the correct position on the sea-bed, the mattress can be unwound; while this is being done, the vessel is pulled to the speed of unrolling, since at this stage of the work the radius of curvature of the mattress must not be too small and excessive force must not be exerted on it, because this might result in damage to the mattress or the anchor beam being dragged from its position on the sea-bed.
When the tail beam has reached the bottom, this beam is released pneumatically from the mattress and pulled up again.
The vessel is then hauled backwards until the forepart has been manoeuvred into a position more or less vertically above the anchor beam. The anchor beam is then disconnected from the mattress by means of a release cable after which the beam is pulled up. Depending on weather conditions, swell and waves, it takes about three hours to lay a fixtone mattress. The entire operation is monitored continuously by echo-sounding equipment.

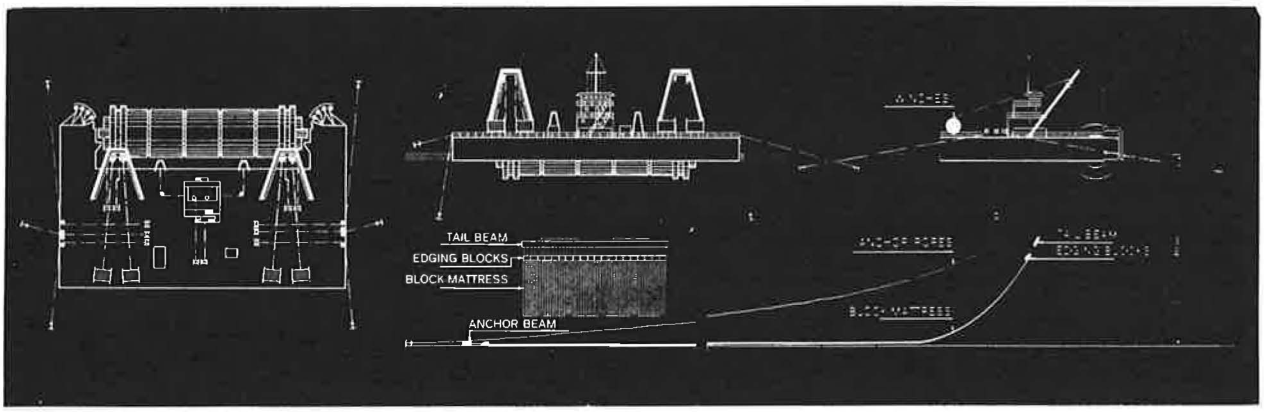
2.3.2 The block mattress

a. Mattress composition and manufacture

The base of the block mattress is formed by a geotextile (polypropylene) specially developed for the purpose. The geotextiles have been subjected to extensive tests and the result is a geotextile weighing about 1200 g/m^2 having a tensile strength of about 250 kN/m. In addition, this fabric satisfies all requirements as regards permeability to water, impermeability to sand ($O_{90} \leq 0.300$ mm) resistance to wear and biological and chemical resistance.
The block mattress factory was built at the Sophia workharbour, on the island of Noord-Beveland. At the beginning of the production line six rolls of the geotextile, adjacent to each other, are reeled off and immediately sewn together automatically, thus forming a strip 30 m wide. In the next phase plastic pins are forced into the material in a pre-arranged pattern. The pins serve to anchor the concrete blocks that are to be placed on the mattress at a later stage. Thus, each block mattress, with an area of 6,000 m^2 is produced with 72,000 pins. These operations are carried out in eight minutes.

The mattress is then moved a distance of 2 m and the production cycle starts all over again. The mattress - complete with pins - is passed underneath an array of block moulds 2 x 30 x 0.17 m^3, which are then lowered. At the same time the moving floor, made up of pallets, slides underneath the matting. The block mattress is supported by the moving floor for the duration of the manu facturing process. A pouring machine moves in transverse direction from the concrete mixing plant to fill the

Fig. 5 : Block-mattress laying.



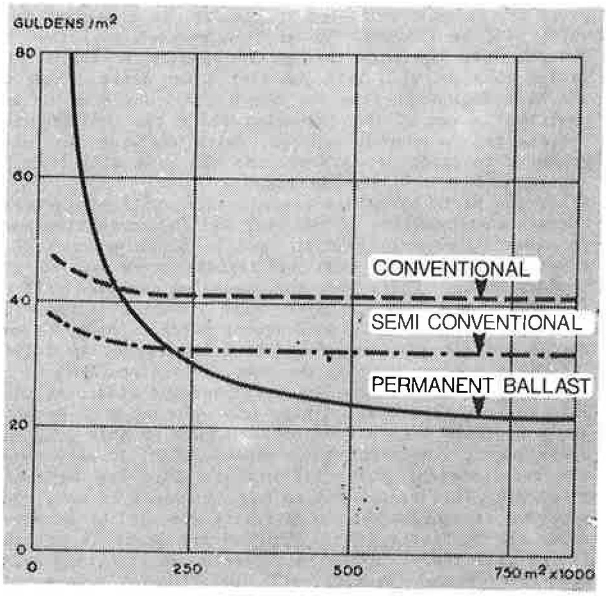


Fig. 6 : Scour protection.

moulds. High-frequency vibrators - placed in the moulds - ensure that the concrete acquires its proper density. As it moves back, the machine tops up the moulds. When all moulds have been raised the mattress is moved along another 2 m to a 60 m long steam room, where a temperature of between 50°C and 60°C and a very high humidity are maintained. It takes about four hours for the concrete to acquire the necessary strength.

After the block mattress has left the steam room, the moving floor is taken away. It takes 15 hours to make one mattress, 200 m long, 30 m wide, studded with 18 thousand concrete blocks and weighing 12 hundred tons in all. An expansion pit takes up the slack which forms due to the difference between the rate at which the mattress is manufactured and that at which it is wound onto the floating drum (measuring 10 m in diameter and about 42.50 m in length). Steel ropes are used to secure the heavy anchor beam to the end of the mattress. Supported by a hydraulically operated steel floor the mattress with the anchor beam attached, is wound onto the drum. After the anchor beam has been locked to the drum, the cylinder with block mattress is towed away and an empty cylinder takes its place. In this way a reasonable continuity is assured both in manufacture and in the sinking operations.

b. Mattress laying

A special method has been developed for sinking the mattresses on location and this can be used in depths of water down to about 40 m. The cylinder with the block mattress is towed to an accurately positioned pontoon and locked in a kind of trap. Immediately after the start of the ebb-tide the mattress is unwound from the cylinder in a direction parallel to the current. Initially the cylinder is rotated with the aid of winches. As soon as the mattress hangs down far enough, the lowering operation is commenced. At the same time the pontoon is shifted at a maximum speed of 4 m per minute in the same direction as the current. The actual sinking operation takes about an hour and a half. A heavy bar, accurately positioned on the bottom by means of anchors, ensures that the block mattress is placed on the bottom in the specified position.

During the sinking operation the position of the suspended part of the mattress between the roller and the seabed is constantly checked by means of a Profiling Sonar. In this way it is possible to correct any deviations from the required position that occur through the current striking at an angle or on account of the mattress being lowered either too slowly of too quickly. At the end of the block mattress a tail beam is fitted (Fig.5). If everything has proceeded according to plan, the anchor beam and tail beam are detached , secured on the empty cylinder and towed to the factory.

c. General

Quite a lot experience has been obtained in the manufacture of the block mattresses and from sinking operations. Results have come up to expectations, but research is being continued with unabated effort. For example, the technicians have recently succeeded in improving the geotextile even further by adding an extra non-woven geotextile. This has made it possible to control the sand permeability of the filter to an even higher degree of accuracy than hitherto, so that it can be adjusted to local conditions and specific requirements.

2.3.3 The gravel-sausage mattress

The gravel-sausage mattress has a geotextile base to which sausage-like geotextile tubes filled with gravel are attached. This mattress is easy to reshape and is therefore useful also on irregular bottom conditions. The geotextiles used are the same as those used in the fixtone mattress and the block matttress described above. For several reasons the gravel sausage mattress is not yet used in practice on a large scale.

2.3.4 Cost aspects of scour protection

Because of the very large areas of scour protection, required for the Oosterschelde Project the cost per square metre is very important. On Fig.6 you can see an indication for the price of several types of scour protection. For conventional and semi-conventional scour protection the starting costs are low and they can be used for small projects. But when more than about 250,000 m² are required permanent ballast scour protection is cheaper. This is because of the investments in special equipment, factory/s and vessels. On the Oosterschelde Project a total of about 5 million m² of scour protection was required and so the new permanent ballast scour protection provides a very economical solution.

3. SCOUR PROTECTION FOR THE STORM SURGE BARRIER

For the storm surge barrier in the Oosterschelde, the sandy bed must be protected to prevent it being washed away before, during or after placing of the piers and also during closure operations. About 4.5 million m² of block mattress scour protection are required. In the last 6 years new demands have arisen for the polypropylene geotextile of the block mattress, and it now has been developed with an expected lifetime of up to 200 years. More details about this subject are given in the paper "The long-term thermo-oxidative stability of polypropylene geotextiles in the Oosterschelde Project" (1). The strength must be garanteed and the quality also has to be to a high standard. Details on the mechanical research on geotextiles are given in the paper "Analysis and experimental testing of the load-distribution in the foundation mattress" (2). Over the past few years protective mats have been placed on either side of the axis of the barrier to form a strip between 450 and 650 m wide.

4. CONSTRUCTION IN THE MOUTH OF THE OOSTERSCHELDE

4.1 General

A storm surge barrier is to be built in the three channels Hammen, Schaar van Roggenplaat and Roompot at the mouth of the Oosterschelde. The best way to construct the barrier is to place concrete piers in the channels, the base of each pier being firmly embedded in rubble, and then to close off the remaining parts of the wet cross-section by means of sliding steel gates. Construction work has now begun: the piers and sill beams are being constructed in a special dock at the mouth of the Oosterschelde, from there they will be transported to their final positions in the three channels.

4.2 Foundations

The sea-bed beneath the storm surge barrier must have an enormous bearing capacity and therefore the materials of the sea-bed, fine sands, silts and muds which are poor foundation materials, are being removed by dredging and replaced by better quality sand. To further strengthen the sea-bed it must then be compacted to a depth of up to 15 m by a specially built vessel, the Mytilus (Mussel). The vessel has four steel vibrator tubes which compacts the loose sand and thus increases its bearing capacity. To make sure that the base on which the concrete piers rest, will withstand the ravages of time, an extra layer is to be added in the form of prefabricated filter mattresses, which are manufactured in the Roompot harbour and placed in position by a special pontoon, the Cardium (Cockle).

4.3 Function of the filter mattress

The mattresses consist of a filter construction of three graded layers and are impermeable to the sand of the sea-bed. They form a carefully composed transition from the sea-bed to the layers of rubble which will be placed around the base of the piers. The mattresses will hold the underlying sea-bed sand in position despite the pressures to which the barrier may be exposed, and at the same time they will provide sufficient drainage for water This latter function is of prime importance, ensuring that the upper layers of sand are not washed away should the barrier be exposed to severe current action or heavy waves. The mattresses, approximately 42 m wide and 200 m long, weigh about 5.5×10^6 kg each. In order to prevent the mats from being damaged before and during the installation of the piers, a second smaller mat, 31 x 60 m is used immediately below the base of the pier. In view of the very high standard of requirements regarding both quality and positioning of the filters, it was decided, after various ways of production had been considered, to prefabricate the mats and to transport them to their location.
The same procedure, used before when the block mattress were so successfully laid, will be followed. The filter mattresses will be assembled on shore and then wound on to a gigantic floating cylinder positioned in front of the assembly plant. A more detailed description of the filter mattress is given in the paper "The Oosterschelde filtermattress and gravel bag, two large-scale applications of geotextiles" (3) and on the mechanical requirement, in the paper "Analysis and experimental testing of the load-distribution in the foundation mattress"(2).

4.4 Laying filter mattresses on the Oosterschelde sea-bed

The filter mattress will be placed onto the sea-bed in water, with a maximum depth of 35 m, by the specially built rig, the Cardium. This vessel is also equipped with a dust-pan suction nozzle which will dredge and level-off the Oosterschelde sea-bed to the correct depth immediately prior to mattress laying.

4.5 Pier positioning and installation

A lifting pontoon, the Ostrea (Oyster), is being built to lift, transport and position the concrete piers. The piers are being constructed in the dry, in a special dock which will be flooded. The lifting pontoon will then be brought into the dock through an opening in the circularing dike and will lift the pier a few metres clear of the bed. Tugs will then tow the pontoon and pier to its position in one of the channels, where the pontoon will be attached to another pontoon, which has been carefully anchored in position. At low tide the pier will then be lowered onto the filter mattress.
After the piers have been placed, there will be cavities between the underside of the pier and the foundation bed. In order to ensure stability and to minimise pier displacement, the piers must be rigidly connected to the foundation bed. Therefore, any remaining cavities will be filled, from inside the pier, with a cement bonded filling material such as a sand-cement mortar. Since the cavities between pier and foundation bed cannot be filled immediately after placing the pier, provisions have to be made to prevent the settlement of sand and silt particles into the cavaties. In addition the cavities must be properly enclosed with a kind of form work so that grouting operations can be carried out successfully. To meet these two requirements, a special gravel-filled bag has been developed. This gravel filled bag (sausage) is made from a porous sand-tight synthetic fabric and will be attached along the perimeter of the foot of the pier. It will be filled with gravel in the construction dock. During transport the gravel sausage will be tied-up temporarily against the pier for protection. After placing the pier on the foundation bed, the fastenings will be released, causing the gravel bag to fall onto the foundation bed. In this way, the two functions of the bag, seal and form work are realised. This item is discussed further in the paper "The Oosterschelde filter mattress and gravel bag, two large-scale applications of geotextiles" (3).
Finally the pier base will be firmly embedded in several layers of rubble. Once all the piers are in position, the various parts of the bridge, the gates and the upper beams and girders will be added and the pier dam will be complete.

5. CONCLUSIONS

For the Delta Project and in particular the Oosterschelde Project a number of completely new scour protection methods have been developed and implemented, all using geotextiles. Two methods, the filter mattress and the gravel bag, are only possible because of new geotextiles. Much research has been carried out using both large scale and laboratory tests. Totally new design methods had to be developed because in most cases it was necessary to design the scour protection and other constructions from first principles based on the functional requirements. With this approach it was possible to meet the needs of the local requirements and the circumstances. In order to verify the quality of the geotextiles used and other products a new certification system was developed, based on an internal quality control system of the manufacturer. Good experience has been acquired on the use of this system.
On the basis of this approach to design, execution and quality control the use of the relatively cheap geotextiles will lead to effective constructions all over the world.

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