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5. Foundation soil and revetments

Compaction of the sand subsoil in the Eastern Scheldt

Investigation of the soil in the Eastern Scheldt showed the existing subsoil generally to have a porosity of 40-43 %, which has for possible consequences:

- softening of the subsoil and unstability of the structure;
- differential settlement;
- liquefaction of the subsoil.

In order to improve the properties of the sandy soil, its porosity has to be reduced, which is done by compaction. The problem in the Eastern Scheldt is that compaction has to be done in open water of a depth of 15-28 m. Besides, the thickness of the layer of sand is anything up to 15 m, with an average of 8 m. As no appropriate equipment was available, a compaction barge has been developed. Its main dimensions are shown in Fig. 1, the equipment it carries will compact the sea bed along the centre-line and at the edges of the revetment of the barrier over a width of 78 m and 26 m, and a length of 3000 m and 6000 m, respectively.

Finally, it should be noted that the Eastern Scheldt contains sand with a high silt content which is highly sensitive to softening and incompactable. This will be removed and replaced by sand with a low packing density and probably a high porosity which will likewise have to be compacted by vibrators.

Foundation bed

The foundation bed supports the piers directly and is a continuation of their foundations. The lower boundary of the bed is formed by the Eastern Scheldt sand which is to be compacted along the centre-line of the barrier. The foundation bed has to perform a number of soil engineering and hydraulic functions, both during construction and when completed.

The soil engineering functions require adequate shearing strength to resist the large horizontal forces that occur when the barrier gates are closed. In resisting these forces horizontal and vertical deviations have to remain small. The principal hydraulic function of the foundation bed is to hold underlying sand in position despite the static and dynamic pressures which develop as a result of different water levels on either side of the gates. The requirements are more stringent under the piers than in between them where the base connects with the foundation bed.

No settlement due to any loss of material can be tolerated under the piers, whereas some settlement under the base – which is a "particulate" structure composed of numerous relatively small elements and therefore flexible – can be accepted. Concerning, the base its bottom layer must form a suitable transition to the top layer of the foundation bed and its particles which act as a filtering system must be graded accordingly.

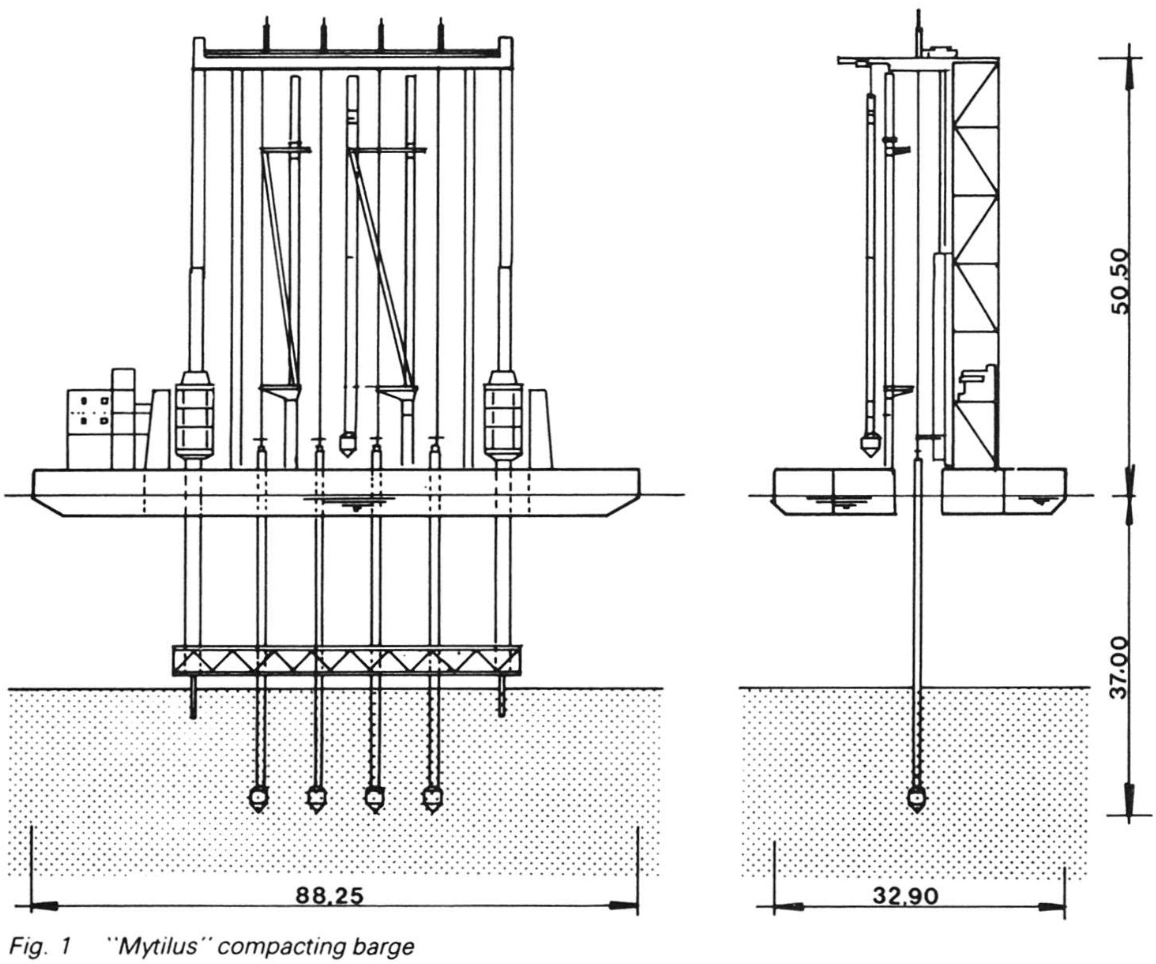

Fig. 1 "Mytilus" compacting barge

The bottom layer of the base is added after the piers have been installed and, for the sake of stability, must consist of pieces averaging about 10 cm in size.

Besides these two main functions, there are further requirements with regard to the evenness of the surface of the foundation bed and vertical tightness. All of these considerations have led us to devise a bed comprising three graded layers. From bottom to top they consist of a layer of coarse sand (d 50 1 mm), a layer of gravel sand (d 50 5 mm) and a layer of gravel (d 50 25 mm). The coarse sand is virtually impenetrable to the sand on the bed of the Eastern Scheldt, and the filter layers themselves are graded in such a way that no finer material from below will force itself into the layer above. For practical reasons it has been decided to enclose the layers in a huge mat, approximately 31 cm thick, 51 m wide and 200 m long, since this is the best way of installing filter material under the conditions liable to arise in the Eastern Scheldt. Layers built up from loose material are liable to be seriously influenced by the action of the current and the movement of sand along the bed of the estuary and this also affects grading, and therefore the quality of the completed "filter". The width of the mat is governed by the centre-to-centre spacing of the piers (45 m) plus an average overlap of 6 m. No overlaps are permissible under the piers because they constitute weak points and would not be compatible with forming a level surface for the foundation bed on which the piers rest. The length of the mat is determined by the fact that it must connect to the apron revetments on each side of the barrier.

The mat is assembled under "factory" conditions, rolled up on competion, and transported to the flow channel where the piers are to be installed. The mat is placed on the sea bed from a 90×60 m pontoon (Fig. 2), called the "Cardium", equipped with suction nozzles over a width of 45 m which make the bottom of the estuary even and of the right depth to receive the mat, which is then laid (in part simultaneously with the suction dredging and levelling operation). A good deal of experience has already been gained with rolling-up and laying mats – though not as heavy as the previous one – made of rubble and stone-filled asphalt on the Eastern Scheldt sea bed.

Work has also been done with suction dredgers equipped with 10 m nozzles, and further experience with these will shortly be gained in the Eastern Scheldt itself when underwater trenches are dredged to remove unsatisfactory subsoil and replace it with structurally superior material.

The mat is composed of:

- a supporting layer, made of plastic or of plastic-based fabric strengthened with steel cables; this forms the underside and can resist a load of 80 tons per metre; the respective layers of filter material (sand, gravel sand, gravel) are separated from one another by continuous interlays of plastic-based fabric in order to prevent any mixing of these layers (which would spoil their grading);
- within each layer of filter material partitions prevent the material sliding down and accumulating at the lower end while the mat is hanging vertically whilst it is being laid by the pontoon;
- vertical steel pins tie the mat together.

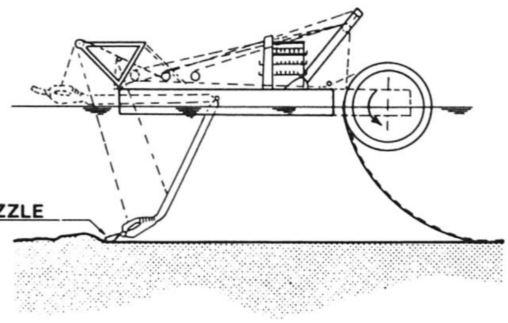

Fig. 2 "Cardium" pontoon for foundation mats

In order to prevent the mats from being damaged before and during the positioning of the piers, a second mat is used, 32 cm thick, measuring 32×60 m, and filled with gravel.

Its upper surface has concrete blocks covering 60% of its total area, ranging in thickness from 8 to 18 cm. The blocks compensate for unevenness in the undermat. Investigations are being conducted to see whether additional measures will be needed to ensure that the evenness tolerances of ± 10 cm which have been specified will be achieved. The absolute level of the top surface must be accurate to within 15 cm.

A second function of the concrete blocks is to provide a stacked arrangement with sufficient interstices to accommodate some sand during the time that elapses between cleaning up the surface of the top mat lowering the pier into position.

The "Cardium" is also equipped with a vertical suction system for removing sand that has settled on the undermat before the top mat into position.

Sill

The sill provides protection for the foundation bed and indirectly for the subsoil by preventing erosion by the current and waves.

The protective function has to be performed under everyday conditions when there is a surge tide and the gates are closed and also in emergencies when one or more gates fail. Particularly severe current action is then liable to occur in the affected channels and the upper layers of material forming the sill must be able to withstand this. Another function performed by the sill is that of providing some measure of horizontal and vertical support for the piers.

Two alternative ways of constructing the sill have been worked out:

a) A sill consists entirely of non-bonded "particulate" material

Broadly speaking, the top layers are formed of basalt blocks weighing 1-3 tons on the seaward and 6-10 tons on the Eastern Scheldt side, the thickness of the layer in each case being equal to twice the average diameter of the blocks (Fig. 3).

The space between the top layer and the foundation bed is filled with stone-like materials graded to conform to the filter laws (layers containing particles of different coarseness, so arranged that water flowing through one

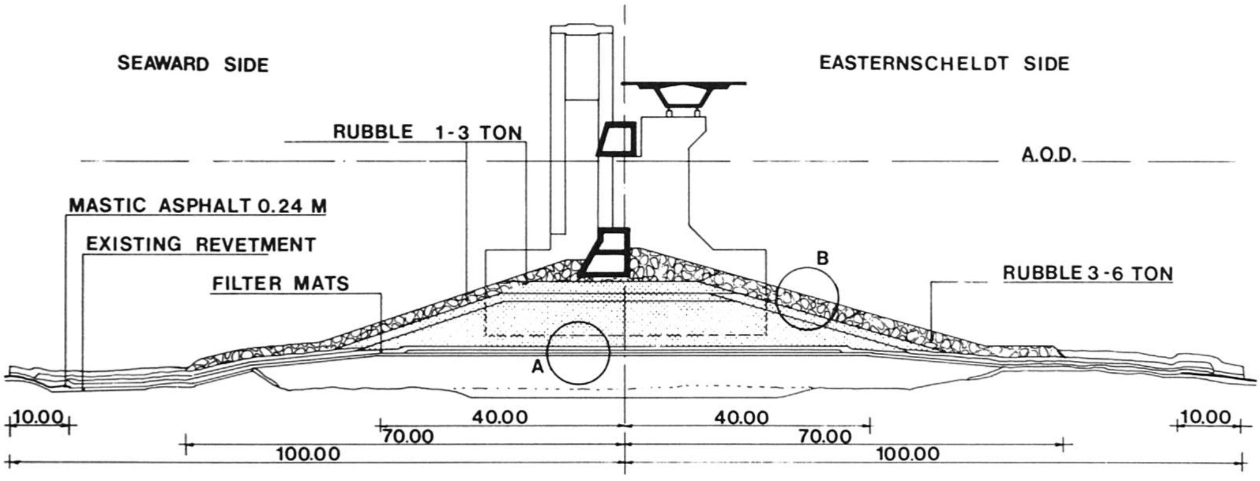

Fig. 3 Base with open top layer

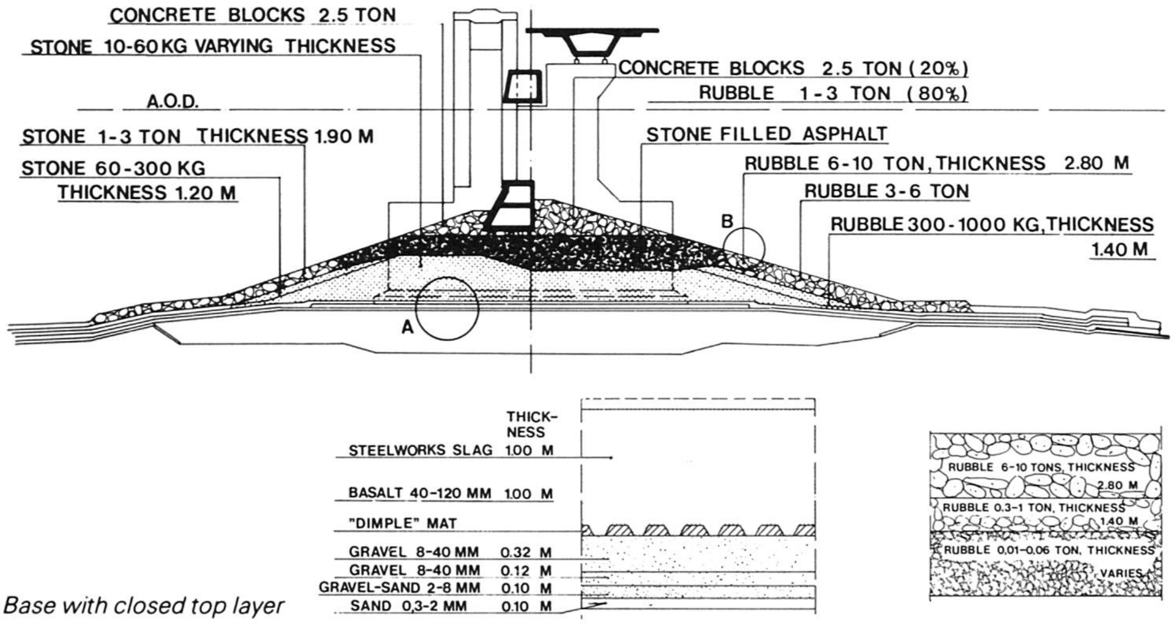

Fig. 4 Base with closed top layer

layer does not carry material from it into the next layer to clog it). The problem consists mainly in placing the large stones without damaging the pier and in obtaining the required degree of evenness to enable the sill beam to be installed. The choice of the size and specific gravity of these graded stones is governed more particularly by the need to ensure their stability against current action during the construction period. They would be brought into position by means of an end-dumping barge with an underwater chute, while stone-filled asphalt can be placed against the piers to give them extra protection. Stone also has to be placed against the sill beams to ensure adequate stability for those parts of the base which are directly under beams. A suitable profile for guiding the current has also to be provided.

b) The top layer of the sill consists of a composite asphalt casting with an average thickness of 4 m

The space between this and the foundation bed is packed with non-bonded "particulate" material graded to act as a filter with respect to the foundation bed and processing sufficient stability against current action during the construction period (Fig. 4). The problem consists, on the one hand, of the feasibility of constructing such a thick layer of asphalt under water without the instrusion of horizontal "lenses" (thin local inclusions) of sand into the mass. On the other hand, an asphalt structure of this kind is more susceptible to differences in permeability due to sand intrusion and growth of marine organisms. Such local permeability variations cause differences in water pressure under the asphalt. Against this must be set the advantages offered by an asphalt top layer: the need to place large stones in the immediate vicinity of the piers is obviated; the static head (pressure difference) across the foundation bed between the piers is reduced. Which of these two alternative construction methods is to be adopted will shortly be determined on the basis of a final analysis of the problems involved.

Apron revetments

As a result of the construction of the storm surge barrier the flow cross-section of the mouth of the Eastern Scheldt will be reduced. This in turn means that, under normal conditions, the current velocity on both sides of the barrier due to incoming and outgoing tides will increase. The existing sea bed on each side of the barrier, up to a certain distance, however, is not stable enough to withstand these higher velocities. In the absence of protection measures, soil erosion would occur, thus endangering the stability of the piers. In order, to protect the sea bed against the action of the current and waves, a bottom revetment or protective covering is to be installed over a distance of 550-650 m from the centre-line of the barrier.

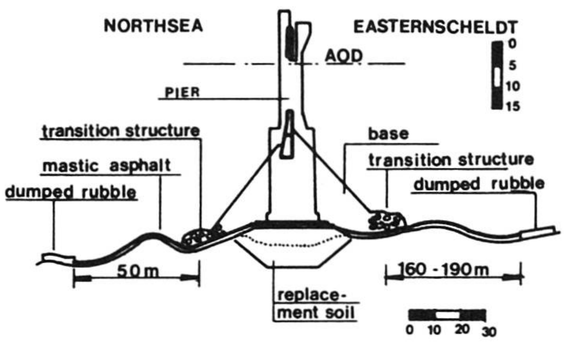

Fig. 5 Apron revetments

Besides having to cope with the higher current velocities due to a reduction of the flow cross-section, the revetment must also be designed to withstand the current that will result if one or more gates fail to function under extreme conditions when the barrier has to be closed. Investigations have shown that the revetment which can adequatly stand up to normal conditions is not entirely suitable in an abnormal situation. Certain parts of it, therefore, the aprons, have to be of special construction. They will in fact consist of a closed-texture mastic asphalt slab about 24-32 cm thick, in principle completely impervious to sand and, by virtue of its relatively smooth surface, highly resistant to the forces exerted by currents.

However, because it is impervious, overpressure and underpressure which may cause the slab to lift off the sill have to be taken into account. Pressure variations can be caused by:

- differences in water levels on either side of the closed barrier;
- flow conditions in the event of failure of a gate to close;
- wave motion, more particularly on the seaward side of the barrier.

In view of the relatively high overpressure which is expected to build up under the mastic asphalt layer when the barrier is closed, part of the revetment between the sill and the aprons is to be left "open", i.e. an open-texture transition structure will be introduced (Fig. 5). This offers the designer the choice between a (partly) closed or an open sill besides forming a good transition from the sill to the apron.

The behaviour of the overpressures and underpressures due to dynamic wave and current loading is a highly complex phenomenon.

Research has shown that under extreme conditions pressure fluctuations may be ranging about 0.5 m. Although investigations have not yet been completed, it appears likely that an asphalt slab of the above thickness will be strong enough to withstand loads of this magnitude. Should it, nevertheless, turn out to be insufficient, additional strength can be provided by increasing its thickness or by weighting it with rubble deposited on top of it. In the light of this, construction of the aprons has already started before the design has been finalized in every respect.

Meanwhile part of the apron in the Roompot channel has been installed on the Eastern Scheldt side of the barrier. This work has been carried out with the aid of the asphalt-laying vessel "Jan Heijmans", which was designed specially for underwater asphalting in deep water. It lays the mastic asphalt in layers 8 cm thick and 5 m wide.

A process analysis of the asphalting operations and thickness measurements performed in situ is being conducted to discover whether this procedure will have to be modified for installing the aprons in the future.

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