Development of the barrier's design

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2. Development of the barrier's design

Caisson design

Over the years, in the course of carrying out the Delta Project, experience has been gained in constructing, floating into position and installing caissons. At the same time, dams were being built using more gradual methods, so that two bodies of experience were gained: one, with techniques for using materials deposited from overhead cableways or by pumping up sand, and another, using caissons as prefabricated units to close flow channels and openings.

When, in 1974, the contractors Dijksbouw Oosterchelde (DOS) continued their study of the technical and financial aspects of a "porous" dam, they based their approach on the design principles already evolved for caisson. The DOS study came up with a number of technical solutions to the problem, the most promising of which was a storm surge barrier consisting of a row of caissons side by side. DOS proposed a caisson with a concrete box girder on top, thus fulfilling two design requirements: high torsional strength together with closure of the openings above AOD.

In addition to the box girder, the DOS caisson was to have a heavy concrete bottom slab and cross-walls. The entire structure would be built of prestressed concrete (Fig. 1).

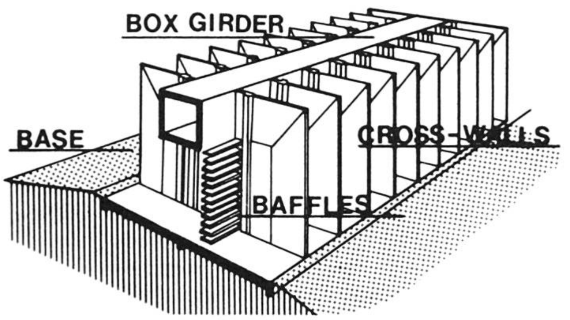

Fig. 1 DOS caisson

After the Government's decision, on 9 November 1974, to build a movable storm surge barrier (i.e. one with gates), attempts were made to establish the precise requirements that the structure would have to meet so that the design could be finalized.

Although the evidence of previous investigations suggested that a row of gated caissons would be best, from the outset other solutions which could have provided alternatives were examined.

At the request of the Rijkswaterstaad, the contractor set up a research department the Studiecommissie Oosterschelde (Stucos), which concentrated on devising barriers not based on the use of gated caissons. Thirty, more or less realistic ideas emerged, four of which, selected somewhat at random and differing considerably from one another, are illustrated in Figs. 2 to 5.

Fig. 2 shows a concrete floating unit which can be lowered or raised – to act as a gate which could be opened or closed – by pumping water into or out of its internal compartments. The piers (vertical columns) in such a structure can be spaced 20-25 m apart. The snag is that the buoyancy of the empty structure would make it difficult to control and it was accordingly decided not to proceed with this design.

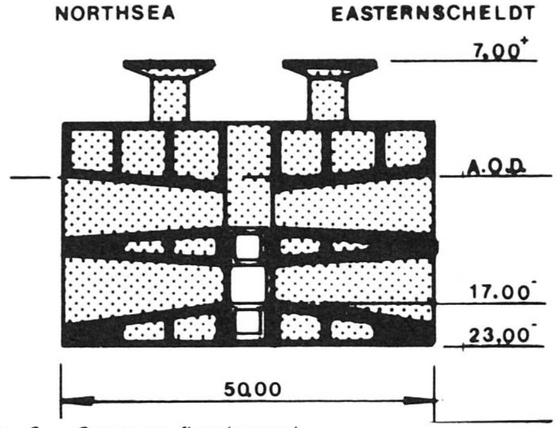

Fig. 2 Concrete floating unit

Fig. 3 illustrates and idea for a gate consisting of a huge concrete cylinder, or roller, which under normal conditions sits at the bottom of the caisson. When a surge tide is predicted, water is pumped out of the cylinder, which is then hauled up along an inclined plane by means of cables. The slope has toothlike projections to give the cylinder a secure grip. An advantage of this design is that the piers between which the cylinder is mounted can be spaced very wide apart. On the other hand, it presents so many difficulties of design and construction that it also had to be abandoned.

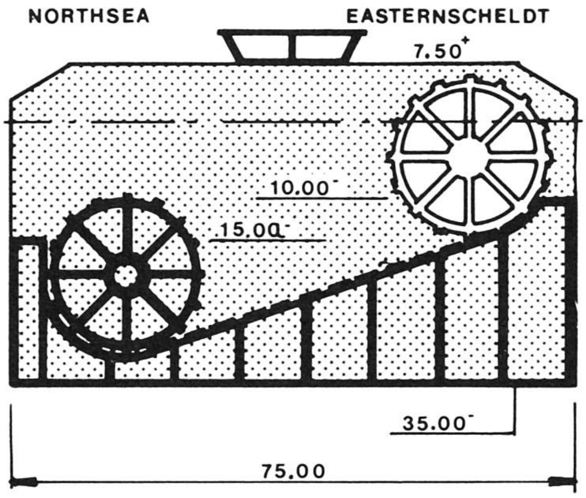

Fig. 3 Concrete cylinder

The principle of the "finger gate" is shown in Fig. 4. Normally it is sunk into the base of the barrier, which is in the open position. To close the gate, water is pumped out, causing the gate to rise by buoyancy. This form of construction would necessitate a deep slot and a correspondingly elaborate foundation structure all along the barrier, which, besides presenting many technical problems, would be prohibitively expensive.

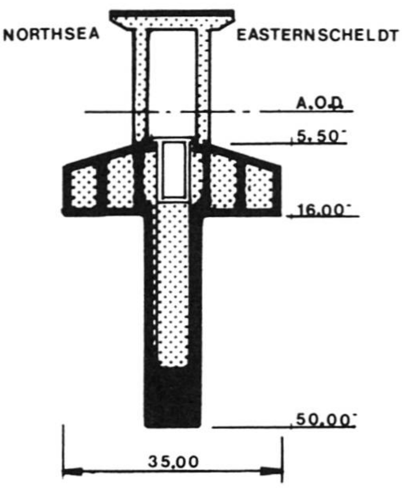

Fig. 4 Finger gate

Fig. 5 illustrates a solution based on the siphon principle. This design has a number of advantages: high functional reliability owing to the absence of gates and to the very modest mechanical equipment involved. Unfortunately, it is not possible to obtain the minimum flow cross-section, though it might admittedly have been possible to install continuous ducts or culverts in the base of the structure and thus increase the flow cross-section.

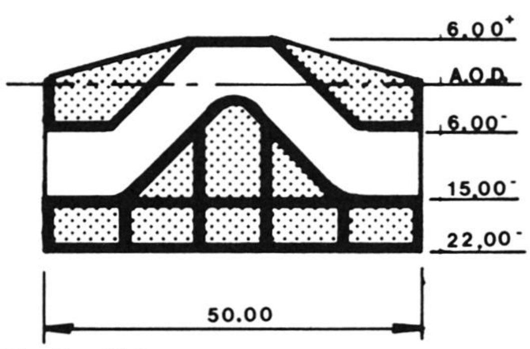

Fig. 5 Siphon

Other ideas envisaged caissons with wave reducers and float gates and special weir structures. All these alternatives had to be rejected, however, on account of their lack of robustness to stand up to the particularly rough conditions in the Eastern Scheldt.

After due evaluation of all the schemes it was decided to concentrate further design work on the principle of the gated caisson. Once a certain sill height had been established as a basic requirement for the design, it proved possible to reduce the number of types of caisson to three , providing different flow cross-sectional areas: the "open box" caisson, the "half box" caisson and the "venturi" caisson.

For several reasons the type finally chosen was the "half box" caisson. Three alternative designs were envisaged, differing both in the method of foundation and the choice of the main structure:

a) gated caissons on a rubble base;
b) gated caissons on a pile foundation;
c) piers on pneumatic caissons.

Evaluation of the chosen design

In June 1976 it was decided to adopt the principle of "piers on pneumatic caissons" for the storm barrier in the Eastern Scheldt. Once the decision had been made, a considerable amount of work had to be done finalizing details for which the planning time-table allowed from six to nine months. Attention was focused particularly on the foundations, supplementary hydraulic conditions, the sill, and the optimization of the design, while striving to reduce construction risks as far as possible.

a) The foundations

A detailed analysis has revealed that there are two kind of ways in which the barrier is likely to be affected: the pneumatic caissons may undergo horizontal displacements and they may overturn. The deeper these caissons are installed into the sea bed the more likely they will be to overturn rather than be displaced (Fig. 6).

The soil around and underneath caisson foundations has to have the necessary qualities to enable it to resist overturning or displacement. Since the soil under the caisson is structurally better than the soil next to it, the caisson derives most of its stability from its base. However, the deeper the caisson is installed in the ground, which increases the risk of overturning, the greater the pressure on the base. To compensate for this, the caisson has to rely more and more on the lateral support provided by the relatively weaker soil strata.

Contrary to what might be supposed, it emerges that the risks do not progressively decrease as the caisson is installed deeper in the ground. From an embedded depth of about 10-12 m onwards, the positive effect of lateral support is cancelled by the negative effect of the larger risk of overturning.

For depths of less than 10-12 m, on the other hand, the caisson has a greater tendency to shift horizontally than to overturn. In the light of these facts the maximum height of the caisson – originally envisaged as 26 m – was reduced to 16 m. In addition to the depth, to which the caisson is embedded, the area of its base has a considerable effect on stability which increases as the area of the base increases.

With a larger base, requirements regarding the strength of the subsoil can also be relaxed slightly which is especially important for less deeply embedded caissons in less densely packed upper strata.

On the basis of these considerations the diameter of the open caissons was increased from 16 m to 18 m. The original design of a caisson foundation system embedded at a relatively great depth in Pleistocene strata had evolved into a system comprising caissons with a larger base area and installed at less depth (Fig. 7).

b) Construction risks

The risks are bound up with the final closure of the opening in the main flow channels an important part of which is the construction of the pneumatic caissons and piers within the protection of a cofferdam. The work involves a gang of men at a depth of – 25 m AOD in the punped-out area who will take about three months to construct one complete caisson/pier combination.

Much of the work at this stage is at the mercy of the weather, so that particularly in the winter months progress is likely to be irregular and difficult to plan.

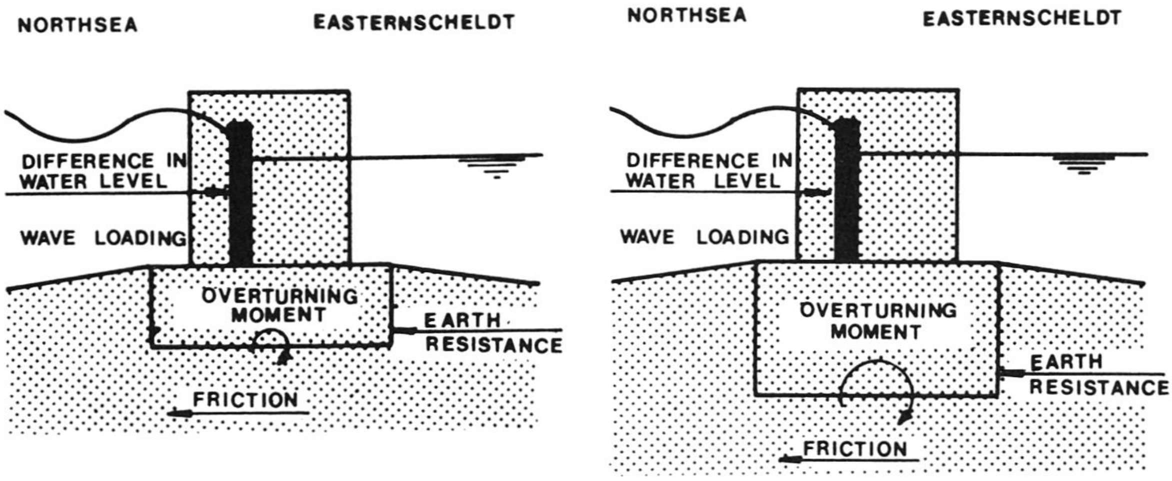

Fig. 6 The deeper the caissons are embedded, the greater the risk of overturning

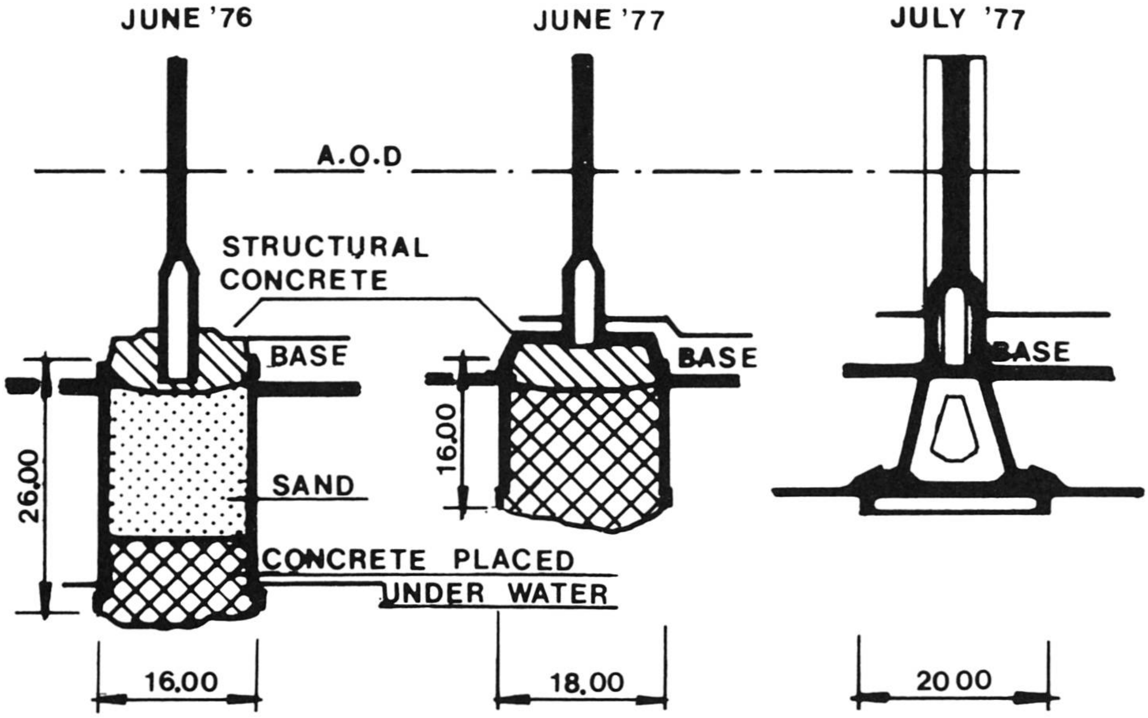

Fig. 7 Evolution of the design of the foundation

Optimization of caisson / pier

As a result of the evaluation of the caisson/pier design an entirely new design of the storm surge barrier eventually emerged; the risks in construction determined the direction in which optimization of the scheme was sought. An important improvement was achieved by deciding not to assemble the piers and caissons in situ in the openings but to construct complete caisson-cum-pier units, each constituting a prefabricated whole or monolithic pier, on a safe construction site protected from the weather. Installing the piers in their final position by means of this method is still a sensitive operation requiring good weather but it takes only two to three days. Finishing everything off then occupies a period of one to two weeks and is much less vulnerable to adverse weather conditions. The piers are transported from the construction site to their ultimate destination at the mouth of the Eastern Scheldt by means of a special lifting vessel. Each pier is lowered into a trench previously dredged in the sea bed in which a layer of supporting material has been put down.

The technique therefore differs from the method originally envisaged of positioning pneumatic caissons by sinking them into the ground by means of suction excavation.

When in position, the base of the pier is completely covered with coarse-grained fill material of high grade which is strengtened further by compaction.

In the absence of a cofferdam which is not needed in this modified scheme the load on these units is about 75 % less than that envisaged in the original design for "piers on pneumatic caissons". As a result, the risks during construction are less and the work is much safer, because now men do not have to work in a cofferdam more than 25 m below water level.

(W. Colenbrander)