

# INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING



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ate the effectiveness of a densification of the subsoil and the influence of a granular material sill under the caisson. To this end, on a second location, the subsoil was densified to about 70 percent relative density while the test caisson itself was placed on a 1.2 metres high sill.

#### TEST SET UP

An already available 15 x 27.7 m<sup>2</sup> open caisson, with a height of 10 m and a dry mass of 1785 tons, was used as a test caisson. A test location was chosen in the working harbour Neeltje Jans in the middle of the Oosterschelde (Fig. 1). The caisson was placed in 7 metres deep water. The contact pressure was about 33 kN/m<sup>2</sup>.

Reaction forces were provided by placing a heavy 15 x 45 m<sup>2</sup> caisson behind the test caisson. Figure 2 shows the reaction caisson to the right and the test caisson to the left on the first test location. In the foreground the control room from which the whole test was controlled.



Figure 2 View of the test location

To decrease the influence of the reaction caisson on subsoil stresses underneath the test caisson, the reaction caisson was placed upon a sill. Figure 3 clearly shows that the reaction caisson freely protrudes over a distance of 15 metres.

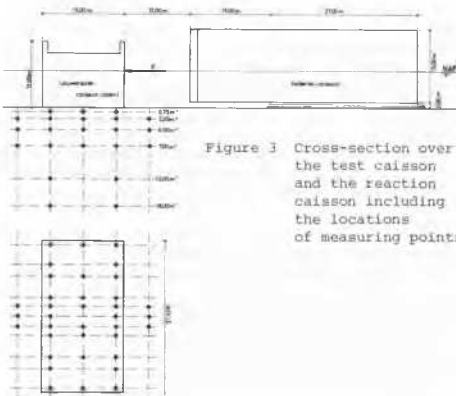


Figure 3 Cross-section over the test caisson and the reaction caisson including the locations of measuring points

Forces were exerted by means of 6 double working hydraulic jacks with a total capacity of 9000 kN in compression and 3000 kN in tension (Figure 4).



Figure 4 Between the test caisson on the left and the reaction caisson on the right the hydraulic jacks to provide the cyclic loading forces are clearly visible

Horizontal and vertical displacements of the test caisson were measured by means of laser and other optical methods. The subsoil was instrumented to measure pore pressures at 56 points, horizontal total pressures at 10 points, total pressures under a 45° inclination at 10 points and vertical contact pressures also at 10 points.

In 4 verticals vertical soil displacements were measured down to 16 metres depth by means of a series of inductive vertical displacement meters mounted in a flexible plastic tube. Horizontal soil displacements were measured to a depth of 17 metres with a series of 12 inclinometers mounted in a similar plastic tube.

The measuring points were chosen at locations where comparisons with the predicted values could be made and where the soil phenomena involved were expected to show a characteristic behaviour. In figure 3 some of the measuring points are shown. The majority of the sensors are concentrated in two cross-sections, over the middle part of the test caisson.

Measurements from 128 sensors were read every 200 milliseconds and stored on magnetic tape by a computer-controlled data acquisition system. Figure 5 shows the interior of the control room.



Figure 5 Interior of control room with function generators, analogue recorders, amplifiers, mag tape units and computer

The loading program is shown in figure 6. For convenience of analysis the program has been divided in a series of 6 parcels, each lasting 15 minutes.

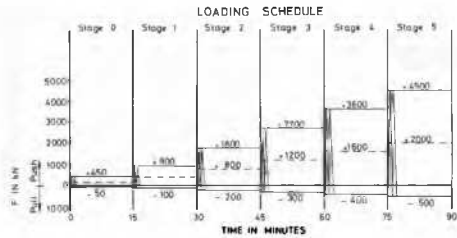


Figure 6 Loading program

In every next parcel the static force (representing the difference in mean waterlevel between the North Sea and the Oosterschelde) as well as the cyclic forces (representing the wave action) increase until at the last loading stage the total force varies between 500 kN pulling force and 4500 kN pushing force (2000 + 2500 kN). The cyclic loading frequency was chosen to be  $1/3$  Hz. The loading program was run four times with some variations in loads and frequency.

#### SCME TEST RESULTS

Practically all the instruments for these complicated tests were specially developed. The time schedule, however, was so limited that extensive testing of all the new devices, including the loading device, proved to be impossible.

To obtain an absolute minimum of insight in the response of the whole system when loaded, it was decided to test the loading device, before the proposed program was run, by applying a small total force of 250 kN. Due to an unexpected event the actual force was much greater during a very short time of about 2 seconds.

Fortunately the measurements were registered by the data acquisition system. Some of these results on the virgin situation are shown in figure 7 (left side). These results are compared with those of the last test of the program on the non-densified location, when also a high load acted on the caisson (figure 7 right-hand side).

The figure shows that while the unintended force amounts to 7500 kN, the programmed force at the end of the tests was 9000 kN. This difference in force was deliberate because the rate of application of the first force was so high that it appeared highly feasible that the exact maximum force was not recorded by the digital data acquisition system.

The horizontal caisson displacement amounted to about 50 mm, half of which was a plastic deformation. The vertical caisson displacement is a non-recovering 10 mm. It seems that the displacements due to the second shock-force have greatly reduced, the horizontal displacements being about 25 mm, 17 mm of which was recovered, while the vertical non-recovering displacement is only some 1 mm.

Whether the caisson displacements are only due to superficial sliding of the caisson over the bottom of the site could not yet be established.

Pore pressures are shown in location FV (situated at the side of the caisson where the force is applied) at depths from 0.75 till 18.00 metres. As expected

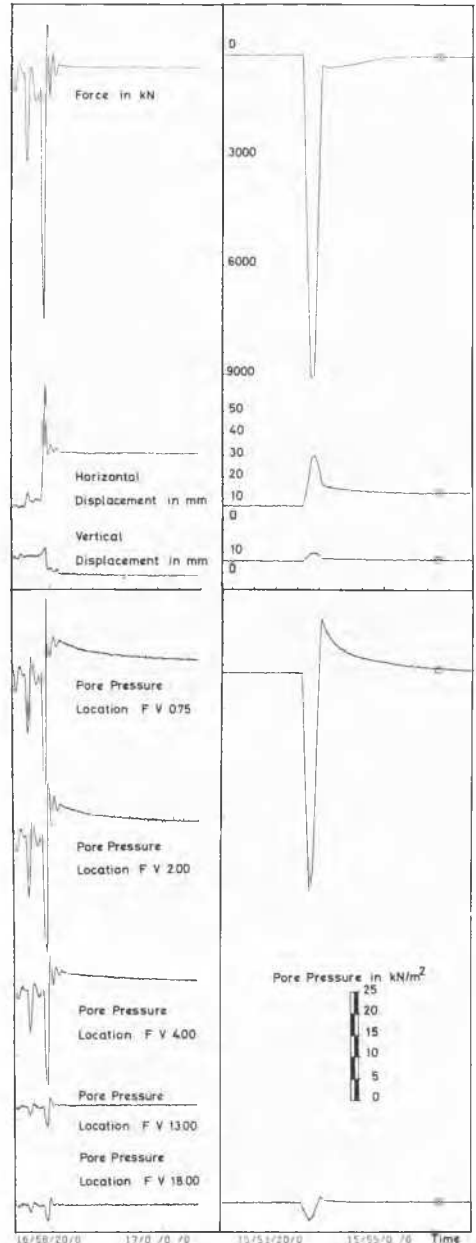


Figure 7 Some results of the unintended large force (left) and the intended large force (right)

the activated pore pressures slowly decrease with depth. (45 kN/m<sup>2</sup> - 40 kN/m<sup>2</sup> - 30 kN/m<sup>2</sup> - 7 kN/m<sup>2</sup> - 6 kN/m<sup>2</sup> at the respective depths of 0.75 m - 2.00 m - 4.00 m - 13.00 m - 18.00 m.)

Pore pressures after the test at the same location could only be measured at 0.75 and 18.00 metres depths. No significant difference in behaviour could be observed. The second force although generates a somewhat higher pore pressure that can be expected from a possible difference in applied force (viz. 65 kN/m<sup>2</sup> at a depth of 0.75 m), but this may be largely due to an increase in density by the preceding loading program.

At the second, densified location a similar loading program was run as at the first location. At the end of these tests it was decided to determine the force needed to push the caisson aside.

The static as well as the cyclic loads with a frequency of 1/3 Hz were raised gradually, as is shown in figure 8. No horizontal displacement occurred at a cyclic load varying between 4000 and 9000 kN (6500 ± 2500 kN).

While the loads were slowly raised to vary between about 6000 and 9000 kN (7500 ± 1500 kN), after some 40 cycles the caisson suddenly started to move and kept moving with an average of 6.6 mm per loading cycle. The ratio H/V varied between

$$\frac{6000}{14000} = 0.43 \text{ and } \frac{9000}{14000} = 0.64.$$

After 12 cycles the pore pressures at 0.75 m depth had dropped drastically from about 50 kN/m<sup>2</sup> down to 5 kN/m<sup>2</sup>. In the next 12 loading cycles an average caisson displacement of 15.5 mm per loading cycle was measured, while pore pressures kept constant 5 kN/m<sup>2</sup>.

As a consequence of this observation it was concluded that the displacement acts only in the surface layer. A further support for this conclusion is deduced by comparing the ratio of the pore pressure swing at loadings of 6500 ± 2500 kN with the same swing at loadings of 7500 ± 1500 kN.

This ratio is nearly constant for all pore pressure meters deeper than 0.75 metres. Only this last one shows a disproportionate large increase in pore pressure. Just at the moment the caisson starts moving the pore pressure swing at this depth drops till about 10% of the preceding value.

When the test was stopped, because the maximum stroke length of the jacks was reached, a sudden excess water pressure occurred that decreased in about 10 minutes. This excess water pressure also decreases with depth (22 kN/m<sup>2</sup> - 12 kN/m<sup>2</sup> - 10 kN/m<sup>2</sup> - 7 kN/m<sup>2</sup> and 3 kN/m<sup>2</sup> in succession).

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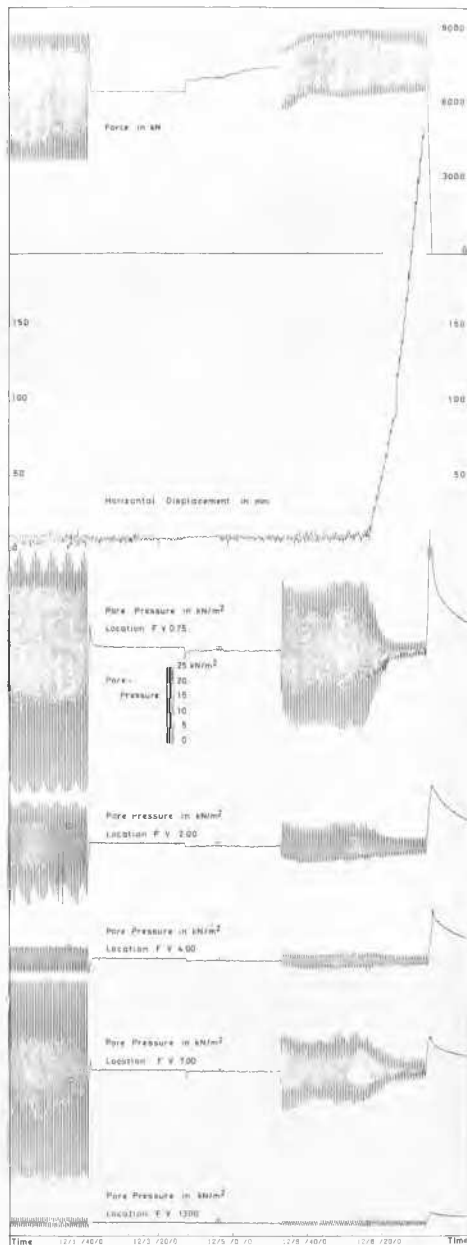


Figure 8 Some measuring results during a high level cyclic loading at the densified location