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## Task report 2.2.d :

# Analysis of Horizontal Bearing Capacity of Caisson Breakwater

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In this task report the caisson breakwater structure, which has been tested in the centrifuge at Delft Geotechnics, is modelled in ABAQUS by means of the verified material model subroutine containing the Single Hardening Model. The response of the caisson is investigated under drained as well as undrained conditions. The results from the numerical analysis are compared to results obtained from the centrifuge test, which has been carried out with Eastern Scheldt Sand with e = 0,67 as the chosen model soil. Furthermore, an analytical bearing capacity analysis in the shape of an upper bound solution is put forward as a reference for the numerically obtained horizontal bearing capacity. Finally, reference numerical calculations based on the simpler Drucker-Prager Model are brought in for comparison. The performed analysis with the Single Hardening Model and have these analysis are compared, with analytical and the centrifuge test are schematic illustrated in Figure 1. This task report is a summary of the work reported in chapter. 8 /Andersen et all 1998.a/

## Analytical Bearing Capacity

On the basis of a kinematically admissible rupture Figure 2, the bearing capacity of the caisson when exposed to a static horizontal load has been determined. In order to account for the curvature of the failure envelope, different combinations of the cohesion and the friction angle have been used in order to obtain the minimum bearing *Figure* capacity. The friction angle used in the upper bound analysis is a reduced friction angle /Hansen, 1991/ introduced in order to account for the fact that the soil is governed by a non-associated flow rule.

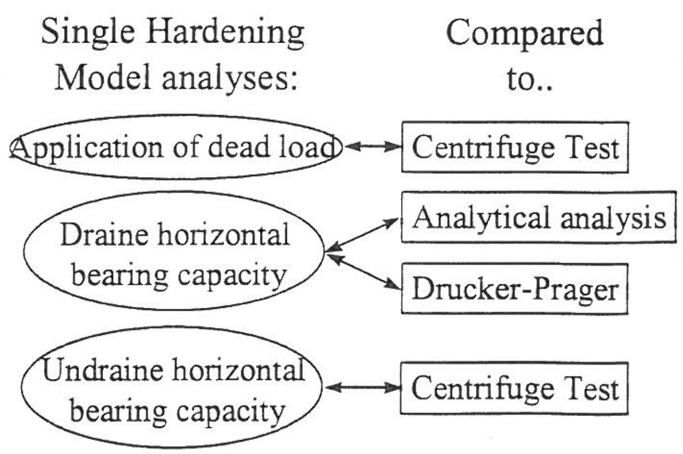
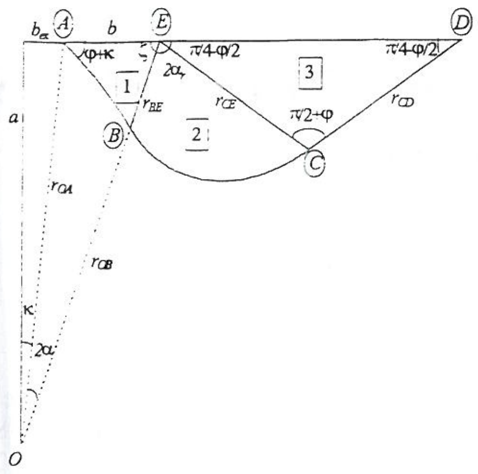



Figure 1. Schematic illustration of the performed analysis with the Single Hardening Model and have these ar the comparisons.




The Danish Code in geotechnique */DS 415. 1984/* prescribes the use of Terzaghi's method for bearing capacity calculations. In short, the method is outlined in chapter 8.1.2 /Andersen et all 1998.a/. In the following the obtained results from the analysis based on the kinematically admissible rupture figure as well as the method of Terzaghi will

*Figure 2. Rupture figure forming a rotation mechanism in frictional material*

be given.

As one out of several required input parameters for the respective programs, the volume weight of the soil has been determined. For Eastern Scheldt Sand, $e$ = 0,67, the effective volume weight has been determined to be:

- $\gamma'$ = 9,674 kN/m$^3$

The surface load on top of the soil layer is introduced in order to account for the loose gravel layer, which is placed adjacent to the caisson breakwater, as shown in Figure 3. On the basis of an estimated volume weight of this gravel layer, it is chosen to apply a surface load of $q$ = 20 kPa. The dead load of the caisson is 2420 kN/m. Furthermore, it is recalled that the width of the caisson is 13,5 m, and that the horizontal load is assumed to act at sea level, i.e.

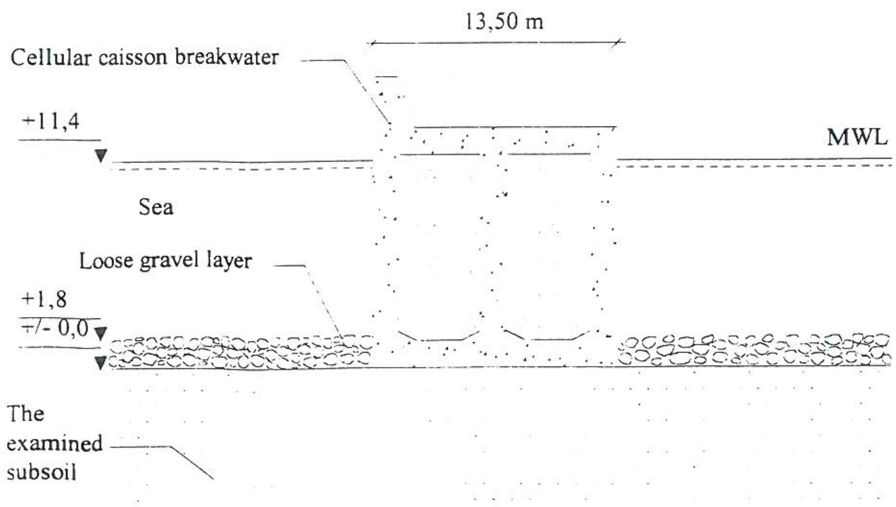



*Figure 3. Section with the prototype of the continuous cellar caisson breakwater.*

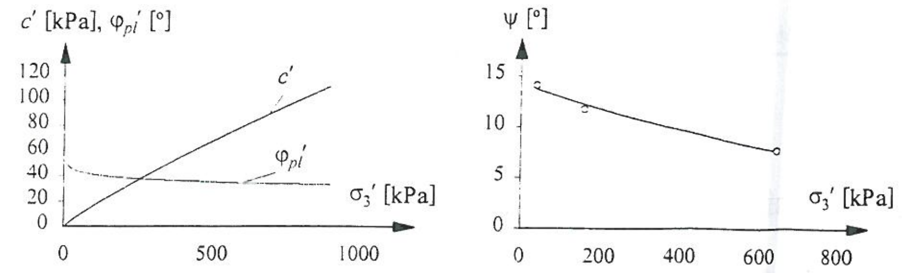



*Figure 4. Plane friction angle. cohesion and dilation angle as functions of* $\sigma_3'$ .

11,4 m above the sea bed.

The applied strength parameters are illustrated in Figure 4. Thus, for several values of the plane friction angle, the cohesion, and the dilation angle corresponding to different values of $\sigma_3'$ , have been applied.
It should be mentioned, however that for the calculations based on the bearing capacity formulation of Terzaghi, the plane friction angle obtained from is used directly, thus without applying equation for reducing the friction angle. The obtained results form the curves illustrated in Figure 5.

It shall be mentioned that the calculations have been continued at higher levels of $\sigma_3'$ and the tendency of increasing values of the bearing capacity in terms of higher values of $\sigma_3'$ continues. However, in order to get a clear picture of the location of the minimum, it is chosen to illustrate this particular section of the curves.

The data in connection with the determined minimum horizontal load according to the upper bound solution and the Danish Code are listed in Table 1.

Due to the fact that use has been made of the reduced friction angle in connection with the upper bound solution, it is seen in that a difference is present between the two curves. However, the shapes of the two curves are more or less identical, and for both analytical analyses, a bearing capacity in the range from 1120 - 1150 kN/m has been obtained.

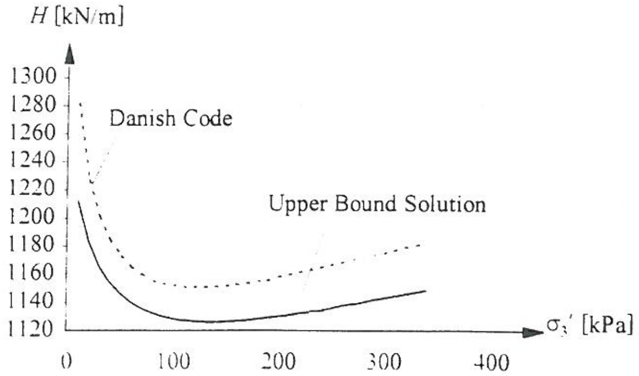



*Figure 5. Bearing capacity according to the Danish Code and an upper bound solution as a function of* $\sigma_3'$

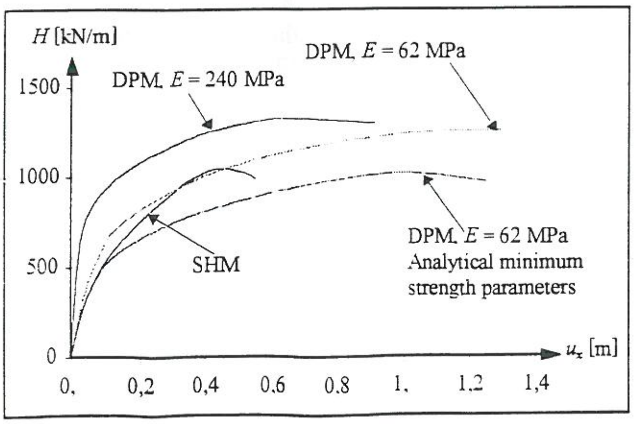
*Table 1. Data concerning the minimum of the horizontal lad according to the Danish Code and the upper bound solution.*

| | $\varphi_{pl}$ [°] | $\psi$ [°] | $\varphi_r$ [°] | $c'$ [kPa] | $b_{eff}$ [m] | $H$ [kN/m] |
|---|---|---|---|---|---|---|
| Danish Code | 40.1 | - | - | 19.9 | 2.67 | 1,151 |
| Upper bound solution | 39.7 | 12.4 | 35.9 | 22 | 2.9 | 1,127 |

## Numerical Analysis of the Caisson Breakwater

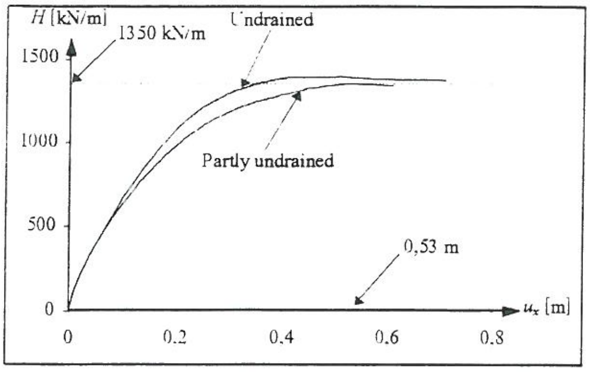
In the centrifuge test, the application of the caisson dead load is introduced by means of the acceleration of the centrifuge to the chosen level of gravitational acceleration. This phase has been modelled by means of the Single Hardening Model. It is concluded that the prediction by the Single Hardening Model differs from the test results. However, during the dead load application all deformations are very small, meaning that the uncertainty attached to the determined deformations is considered to be quite significant.

The horizontal loading of the caisson under drained conditions has been predicted by the Single Hardening Model as well as the Drucker-Prager Model, as shown in Figure 6. As input data for the Drucker-Prager Model, relevant combinations of strength- and deformation parameters have been introduced. By means of the Single Hardening Model, the horizontal bearing capacity is predicted to be slightly smaller than the value obtained by the analytical upper bound solution. The predictions based on the Drucker-Prager Model are seen to be very sensitive to the chosen input parameters. Thus, it is possible to obtain a bearing capacity similar to the Single Hardening Model prediction, but a value of around 20 - 25 % higher than the bearing capacity predicted by the Single Hardening Model is just as likely to occur, if another set of parameters is employed. In all cases, the Drucker-Prager Model estimates large deformations compared to the results from the Single Hardening Model analysis.
The response of the caisson when exposed to different load cycles has been analysed by the Single Hardening Model. Furthermore, the influence of the void ratio to the numerical predictions has been analysed. In both cases, reasonable results are obtained.




| | Bearing Capacity [kN/m] |
|---|---|
| SHM | 1,044 |
| DPM E=240 MPa | 1,324 |
| DPM E=62 MPa | 1,251 |
| DPM Min Strength Paramters | 1,017 |
| Upper bound solution | 1,127 |
| Terzaghi | 1,151 |

Figure 6. Predictions of the horizontal loading, performed by the Single Hardening Model and the Drucker Prager Model. These are compared by the analytical bearing capacity.




| | Bering Capacity [kN/m] | Horizonta displacement [kN/m] |
|---|---|---|
| Undrained | 1,394 | 0.51 |
| Partly Undrained | 1,350 | 0.53 |
| Centrifuge test | 1,440 | 0.76 |

Figure 7. Stress-strain curves for undrained and partly undrained analysis. The bearing capacities are compared with the results from the centrifuge test.

The caisson has been subjected to a partly undrained analysis. Thus, the behaviour of the pore water fluid during the horizontal load application has been included in the analysis. This analysis is performed by the Single Hardening Model. The bearing capacity obtained from the partly undrained analysis is compared to the maximum horizontal wave impact force, experienced during the centrifuge test, and a nice correspondence is observed, although the basis of comparison is not totally identical. This is due to the fact that in the centrifuge test, a large number of cycles have been performed before the maximum wave load is reached. Finally, it is observed that the partly undrained bearing capacity is higher than the drained bearing capacity, which is due to the negative pore pressure build-up, which occurs beneath the caisson during a rapid load application.

The rupture zones and the deformation mechanisms obtained from the respective numerical analyses have been investigated. In all cases, a close resemblance with the kinematically admissible rupture figure is present.

As a final remark, the computational consumption of the two investigated constitutive models should be mentioned, as a large difference has been experienced. Thus, an analysis performed by the Single Hardening Model has been found to be considerably more time consuming than the corresponding Drucker-Prager analysis.

## AAU Contribution before 1st August 1997

Ibsen L.B, Jacobsen K.P (1997). *Dynamic Bearing Capacity of Caisson Breakwaters Subjected to Impulsive Wave Loading.* 1st PROVERBS Workshop. Las Palmas, Spain 18-23 feb. 1997.

## AAU Contribution 1st August 1997 to 31 January 1998

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