Prediction the long-term behaviour of a bored tunnel in soft soil using a geotechnical centrifuge and numerical models

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3.2 Ground deformations associated by urban tunnelling

RandstadRail is a future light-rail link between Rotterdam, The Hague and Zoetermeer in the Netherlands. Building the Rotterdam section of RandstadRail involves the construction of 2 single-track shield tunnels in Rotterdam, each with an outer diameter of 6.5 m and a length of 2.4 km, using the tunnel boring technique.
The top part of the tunnel will be placed in very soft Holocene soil on several locations. The tunnel is founded in the stiff Pleistocene sand and will have an embedment of 135^0 in the sand as a minimum in these situations.
It is expected that the soft Holocene layers will settle 1.0 m due to consolidation and creep during the lifetime of the construction. The external stresses on the tunnel lining will increase during consolidation and become larger than the vertical overburden pressure as a result of this mechanism.
The time dependent additional stresses have been analysed analytically as well as numerically. Physical modelling, using the GeoDelft geotechnical centrifuge, was performed in order to verify the design approach and to determine a proper calculation method for the tender documents. In these test the normally consolidated clay was loaded with 2 sand layers. These sand layers were constructed during flight by poring sand from a hopper. Figure 1 shows the model tunnel and deformed clay stratum after a test. Figure 2 shows the pressure increase during various loading steps.

The paper presents a description of set-up and the results the centrifuge tests and of the used calculation methods and the findings of the back analysis using finite element techniques.

The centrifuge-test results indicate that long-term settlements lead to additional loads on the tunnel lining that need to be incorporated in the design.
As expected the negative skin friction affects the vertical effective stresses on the tunnel lining. The study revealed that a change of the horizontal stresses has to be accounted for as well.
The measured loading on the model tunnel was a 30% smaller than calculated using the purely elastic analytical approach. A more sophisticated soil model appeared necessary to simulate the centrifuge tests. With the finite element approach, using the Plaxis Hardening Soil model, the centrifuge test results can be simulated well.
However, the elastic approach has been adopted for the tender documents for reasons of his simplicity and safe calculation results. Furthermore, it appeared that the influence on the final calculation results was limited, due to the dominating effect of the angle of embedment.

The added value of the centrifuge tests was therefore in this situation that it was proven that the traditional calculation method results in sufficient safe results and that no further safety margin due to the uncertainty in the calculation method is necessary.

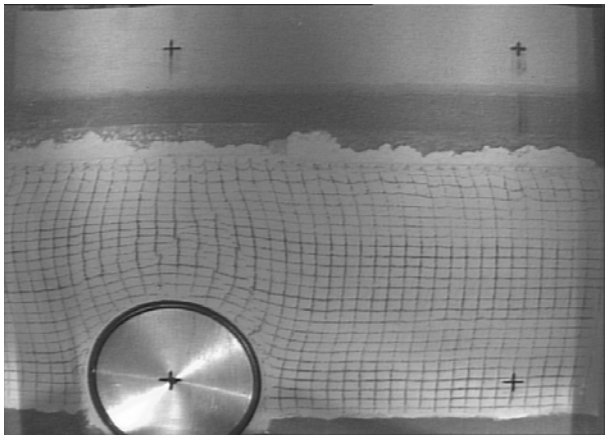

Figure 1. Deformed grid after test 2.

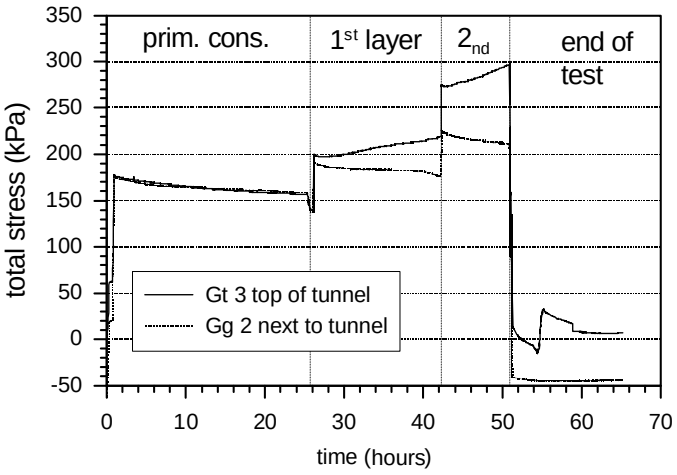

Figure 2. Test 2: Measured soil stresses on the tunnel and in the clay at 220 mm from the tunnel axis.

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