



## Piled embankments in PLAXIS 2D, 3DTunnel and PLAXIS 3D 2011

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In recent years, there is a growing interest in the use of piled embankments. This interest also initiated several investigations, the publication of for example the Dutch design guideline for piled embankments (CUR226, 2010) and the German EBGEO (2010). The slip road, containing a piled embankment, of the highway A12 in Woerden (25 km south of Amsterdam) was designed using CUR226. The reinforcement of the piles was, as prescribed in CUR226, designed using PLAXIS 2D (9.0). During the construction of the road several types of sensors were placed on the piles, pile caps and geogrids. In order to predict especially the moments in the piles, measured with optical fibres attached to the steel piles, a 3DTunnel model was build. Recently, this model was adapted and rebuild in PLAXIS 3D 2011. This paper compares the results of the models with PLAXIS 2D (9.0), 3DTunnel (2.4) and PLAXIS 3D 2011. The measurements are not yet available.

➤ The previous slip road in Woerden needed to be reconstructed. Without advanced construction methods, the soft soil on the location would have caused severe differential settlements. Usually, such soft soils are preloaded during a long time. However, the option of preloading was rejected in this case, because of required time span. Another option, the application of Styrofoam was rejected, because the road should remain available in case of flooding.

The option of a piled embankment was considered. The advantages of the piled embankment are the small settlement, the independence of heterogeneity of the subsoil, long lifetime, and short time between the start of the construction and time to take the slip road into service.

The construction contains about 900 concrete prefabricated piles, a geosynthetic reinforcement and a layer of construction aggregate. The piles have substantial differences in length, because the required bearing capacity can only be acquired in the deeper layer of sand that varies in height.

The representative cross section is located on a canting part of the road. The section contains an

old ditch that is filled with water. For the purpose of drainage a new ditch was required. The ditches are shown in the figures.

The original design of the reinforcement in the piles below the slip road was made in PLAXIS 2D 9.0. The embankment contains several sensors to monitor displacement, forces en bending moments in the piles in a test section of the road. In order to make an accurate prediction of these measurements, a model was made in 3DTunnel 2.4. Recently, the model was also rebuilt in PLAXIS 3D 2011.

The cross sections of all three different models are almost the same. The layers containing peat or soft clay are modelled with the Soft Soil Creep model, and the other layers are modelled with the Hardening Soil model. The model in 3DTunnel has the smallest depth that is allowed by symmetry rules; only half a pile and half of the space between the piles. This choice had to be made because of the limited calculation possibilities with 3DTunnel. The model in PLAXIS 3D 2011 contains two rows of piles and half of the space between the piles on both sides of the model.

The most interesting parts of the differences between the 3 models are the geogrid and the

piles. Except the piles, all material models are equal in the 3 PLAXIS versions. In the PLAXIS 2D model, plates are used with a hinge to model the piles. In the 3DTunnel model, a pile is constructed out of three parts. Two clusters (per layer) of concrete piles are used in combination with a plate. This plate has a bending stiffness of 1/1000 of the real pile. On top of the piles, there are two node-to-node anchors connected to the pile cap, in order to create a hinge. For the PLAXIS 3D 2011 model, an embedded pile with hinge was used.

The 2D-model only determines the tensile forces in the geogrids in the direction perpendicular to the road. The direction along the road is obviously not modelled. In the 3DTunnel and PLAXIS 3D 2011 models, the shape and density of the meshes are different. The PLAXIS 3D model has a finer mesh and the shapes of the elements in the geogrids are triangular.

For the situation without traffic load, all three PLAXIS models predict similar bending moments in the piles, (with no correction for the different phases) after 10 years of settlement (see figure 1). In this figure the bending moments of the fourth pile from the left is shown. Note that the model of PLAXIS 3D 2011 contains two rows of piles.



For the situation with traffic load, it appears that the bending moments in the 3DTunnel model are smaller than the two other predictions, and probably not realistic. This difference is initiated in the start of the phases with updated mesh. The updated mesh is required to properly model the membrane effect in the geogrid. During the excavation, the bottom of the excavation shows a heave. When the piles are activated, a pre-stress occurs. This is the main cause for the smaller bending moments. For the same reason, a large bending moment in the model of PLAXIS 2D is present at -19m, but for this model correction is possible. Since the piles consist of one type of linear elements.

Figures 1 and 2 show the tensile forces in the geogrids, in the directions perpendicular to the road. It should be noted that CUR226 predicts a maximum tensile force along the road of 96 kN/m, and across the road of 112 kN/m. This agrees very well with the 3D predictions.

The differences between the PLAXIS models do not increase when the load is applied. The plots of the forces in the geogrids show that all PLAXIS models, and especially PLAXIS 2D, give peaks at the sides of the pile caps (these peaks decrease when the element sizes are reduced further), but generally, the maximum forces are similar to the PLAXIS 3D model. The forces in the geogrids in the 3D models are similar, but the PLAXIS 3D 2011 version gives higher values, especially in the direction parallel to the road.

It can be concluded that PLAXIS 3D 2011 is better suitable for modelling piles than 3DTunnel and gives very promising results. The most important improvement in PLAXIS 3D 2011 is the embedded pile, since the bending moment and initial strain of the piles in the installation phase of the piles (with updated mesh) are less disturbed. The modelling in PLAXIS 3D 2011 is also easier and faster than the modelling in 3DTunnel.

In the near future, the calculations results of the calculations will be compared to the measured data.

#### References

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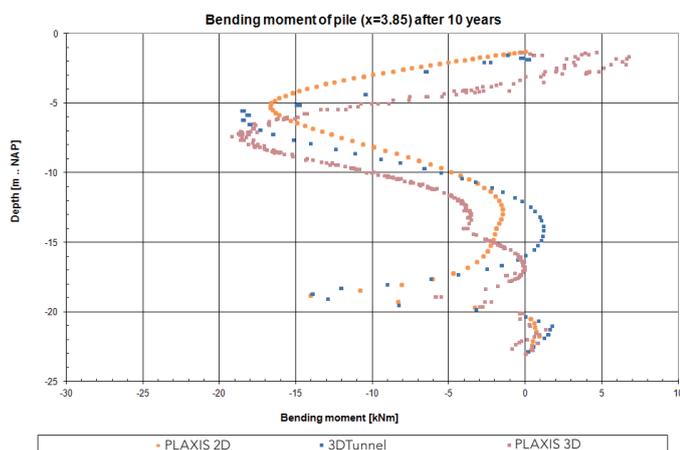


Figure 1: Bending moment in pile, without traffic loading

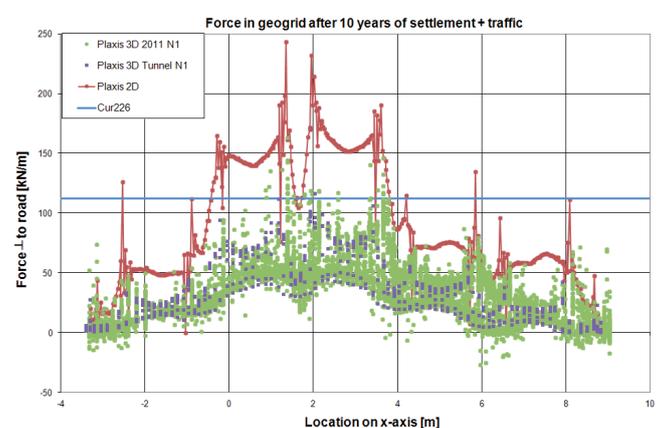


Figure 2: Force in geogrid, with traffic loading