

Bulletin of the  
PLAXIS  
User Association (NL)

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## Editorial

*On April 6th, the new PLAXIS Version 7 for Windows 95 and Windows NT was released. Within two months after the release, over 250 Versions 7 installations are in use world wide and the number is increasing rapidly. We have received many compliments, especially on the new geometry input and fully automatic mesh generation.*

Despite our efforts to extensively test the new version, some users have reported errors and/or inconveniences. First of all we would like to thank these people for their time and effort to inform us about these problems. We highly appreciate such remarks so that we can quickly improve the program and further adapt it to the users' needs. Most errors could quickly be solved and have resulted in an updated version. As an extension to our user services, the updates are available on the Plaxis web-site (<http://www.plaxis.nl>) in the download area under user services. Version 7 users have received the password to access the download area.

In the past months the short courses in Stuttgart, Cairo, Boston and the Experienced users course in Noordwijk attracted over one hundred enthusiastic participants. For the coming months short courses are scheduled in Paris and Trondheim. Almost traditionally the 3rd week of January is reserved for the Standard international course in Noordwijk. This international course has been lectured for the past 11 years. Along

with the courses, the Plaxis program has enjoyed an increasing international exposure in the past 10 years. To celebrate this occasion a Symposium will be held on 18-20 March, 1999. In this bulletin you can find the call for papers, along with other related information.

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## Column Vermeer

Creep phenomena in soils are known, but nevertheless generally ignored in geotechnical engineering practice. For stiff soils creep rates tend to be very small, but in combination with high shear stresses they may become significant. For instance, many landslides in mountainous areas are triggered by creep in stiff soils. For soft soils creep phenomena are even significant both in shearing and in compression, especially when considering organic clays and peat. Apart from Bjerrum's 1967 Rankine lecture, however, little attention is paid to creep in the geotechnical literature.

Most textbooks do not even give a proper treatment of creep in standard one-dimensional compression tests. The standard oedometer test is a Multiple Stage Loading test with loading periods of precisely 24 hours. I will consider this so-called MSL-24 test in more detail to show that it is a creep test rather than a (primary) consolidation test. For each loading step,  $\Delta t$ , we obtain a new stress,  $\sigma_{new}^1 = \sigma_{old}^1 + \Delta\sigma^1$  and a new void ratio  $e_{new} = e_{old} + \Delta e$ . The relationship is well-described by the classical formula:

$$\Delta e = -C_r \log \frac{\sigma_{new}^1}{\sigma_{old}^1} - (C_c - C_r) \log \frac{p_{new}}{p_{old}} - C_\alpha \log \frac{\Delta t}{\tau}$$

Please note the minus signs in the equations, due to the fact that the void ratio decreases in compression ( $\Delta e = \text{negative}$ ).  $C_r$  is called the reloading index or the swelling index,  $C_c$  is the compression index and  $C_\alpha$  is the creep index for secondary compression. The preconsolidation stress is denoted as  $p$  and  $\tau$  is a reference time of 24 hours. Due to this particular choice of  $\tau$  the MSL-24 tests involve  $\Delta t = \tau$  and consequently  $\log(\Delta t / \tau) = 0$ . Hence it would seem that there is no creep in this standard oedometer test. Indeed, the above equation suggests that primary consolidation lasts for 24 hours, but this is entirely false. Even highly impermeable oedometer samples need less than one hour for consolidation. Then all excess pore pressures are zero and one observes pure creep for the other 23 hours of the day. This creep is simply contained in the second term of the above equation.

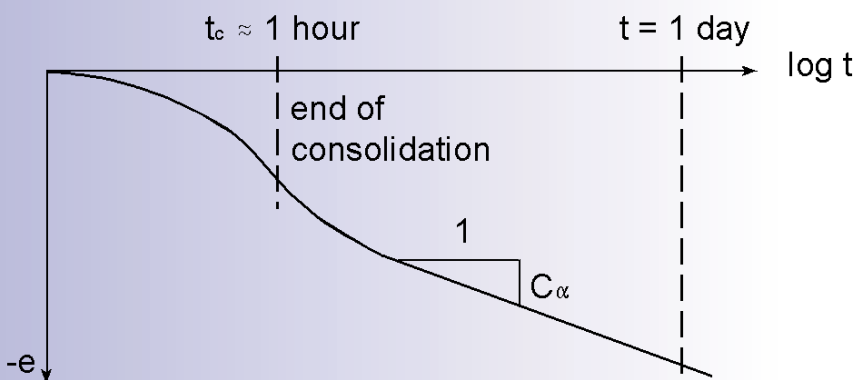


Figure 1 Results from MSL-24 test.

Apart from being misleading, another drawback of the above formula is that it cannot be used for general transient loading conditions. As a first step of a research project on creep at Stuttgart University, we therefore derived the differential equation:

$$\dot{e} = \dot{e}^e + \dot{e}^c = -C_r \frac{\dot{\sigma}^1}{\sigma^1} - \frac{C_\alpha}{\tau} \left( \frac{\sigma^1}{p} \right)^\alpha$$

where the a dot is used to denote a time derivative and

$$\alpha = \frac{C_c - C_r}{C_\alpha}; \quad p = p_{old} \exp\left(\frac{-\Delta e^c}{C_c - C_r}\right)$$

where  $\Delta e^c = \int \dot{e}^c dt$  starting with  $t = t_{old}$  and  $p = p_{old}$ .

Besides small elastic rates of volume change,  $\dot{e}^e = de^e / dt$  all deformation is considered to result from creep. The creep rate depends entirely on the ratio of the current stress and the preconsolidation stress. For normally consolidated samples where  $\sigma^1 = p$  we have high creep rates, whereas overconsolidated states with smaller values of  $\sigma^1 / p$  yield virtually no further creep. The new differential law looks different from the classical compression law, but it is a generalisation rather than a modification. The beauty of the new formulation is that it shows the effect of ageing as introduced by Bjerrum, i.e. an increase of the  $p$  over time due to creep.

Unfortunately, the idea of ageing is generally "forgotten" in geotechnical engineering, including in laboratory testing of clays. Consider for example the usual CU-triaxial testing of clay, where samples are consolidated under some pressure well beyond the initial preconsolidation pressure. Instead of the careful multi-staged loading as performed in an oedometer test, it is common practice to load in a single step up to the desired consolidation pressures. Near draining boundaries effective stresses are thus nearly instantaneously increased to the desired level. Hence boundary regions are rapidly compressed and then subject to a relatively long creep period. In the centre of the sample one

first of all gets excess pore pressure, which may last for several hours. In contrast to the boundary regions this centre point has little time to creep, at least if the undrained part of the test is started immediately after consolidation. Being a member of a committee on triaxial testing, I discovered that most labs would take half a day or at most one day for the consolidation stage of the test. In such cases one is bound to create non-uniform samples, as relative to the centre the boundaries have had time to “age” and thus obtain a higher degree of preconsolidation and a higher density than the centre part.

Calculations with the new Soft Soil Creep model show that the usual practice of one-step consolidation in CU-triaxial tests is very unsuitable. In order to obtain uniform samples one either needs multi-staged loading or a significant creep period in between the two phases of the tests. Unfortunately codes of practice only prescribe very short minimum periods of consolidation in triaxial testing, as ageing and other viscous phenomena tend to be neglected in the geotechnical engineering community.

**P.A. Vermeer, Stuttgart University**

## PLAXIS Practice

### MODELLING THE BUILDING PROCESS OF A DEEP UNDERGROUND STATION WITH FEM

*To keep the Amsterdam City Centre accessible, the underground network is to be*

*extended with the North/South Metro Line. The line, 9 km long, will connect the northern and southern parts of the city with the City Centre. Important preconditions for the design are that the North/South Line's construction should not result in any demolition of or significant damage to buildings, and that disruption of city life due to construction work is restricted to a minimum.*

For the North/South Line, and for the City Centre in particular, these preconditions result in the application of special construction techniques. For the line sections this will mean a bored tunnel that follows the street pattern as closely as possible. It was decided to lower the tunnel to a great depth to minimise the effects of the construction activities on surrounding buildings. Consequently the underground stations are at a great depth as well. Four underground stations will be built in the Amsterdam City Centre, see table 1.

The design of these stations is special in a number of ways:

- The stations will be constructed at extremely busy locations in Amsterdam;
- At excavation depths of well over 30 m, the building pits for the stations will be the deepest ever dug in The Netherlands;
- High water levels, moderate soil conditions;
- The building pits are locally very near (< 5m) to buildings of historical importance with relatively vulnerable wooden pile foundations.

These aspects combined make the design of these stations quite unique.

*Table 1 Deep underground stations*

Station	Top level of track	Excavation level (depth) building pit
1 Central station	NAP* -15.2 m	NAP -19 m (22 m)
2 Rokin	NAP -21.5 m	NAP -26 m (27 m)
3 Vijzelgracht	NAP -26 m	NAP -30.5 m (32 m)
4 Ceintuurbaan	NAP -16m/-26 m	NAP -30.5 m (32 m)

\* NAP = Amsterdam Ordnance Datum

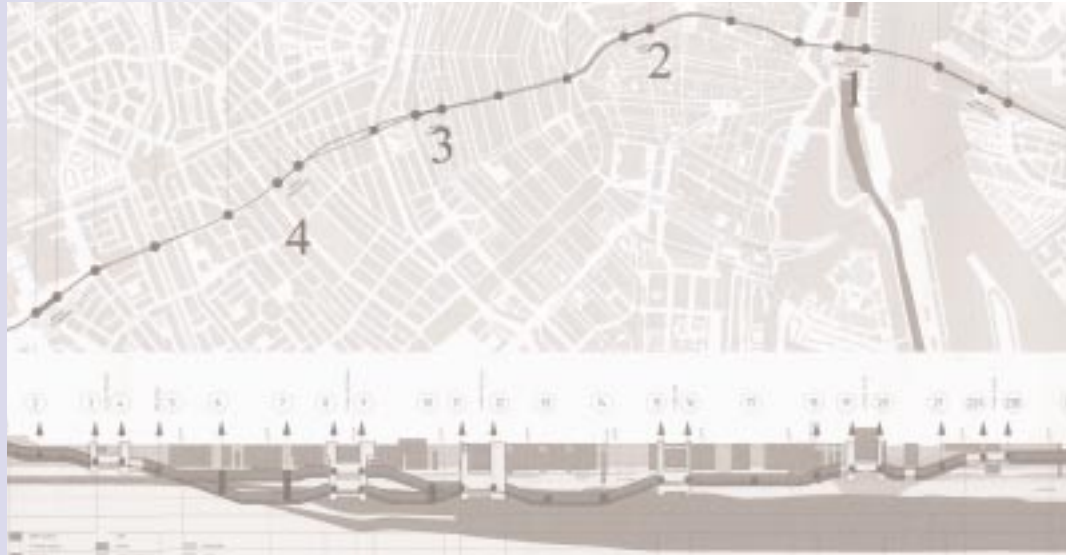


Figure 1 Plan of Amsterdam with plotted North/South Line.

**Soil characteristics:**

The characteristic soil profile for Amsterdam City centre is described in table 2.

Surface level in Amsterdam is at approximately NAP +1m. The groundwater level is NAP -0.4 m. The piezometric surface of the 1st and 2nd sand layer is approx. NAP -1.5 m. The piezometric surface of the 3rd sand layer is approx. NAP -3 m.

The historical buildings are usually founded on wooden piles on the 1st sand layer, while the more recent buildings tend to be founded on concrete or steel piles on the 2nd sand layer.

**Analysis of construction of a building pit with FEM:**

One of the most important aspects in the design of underground stations is the influence of the construction on the adjacent buildings and structures. This is of a main importance because there are historical buildings closeby along a large part of the building pit. The resistance of these buildings is often very limited. To get a good picture of deformations, it is necessary to use a FEM program, in which the full building sequence with time schedule is processed.

For the preliminary design the Finite Element Method (FEM) analyses are based on a ref-

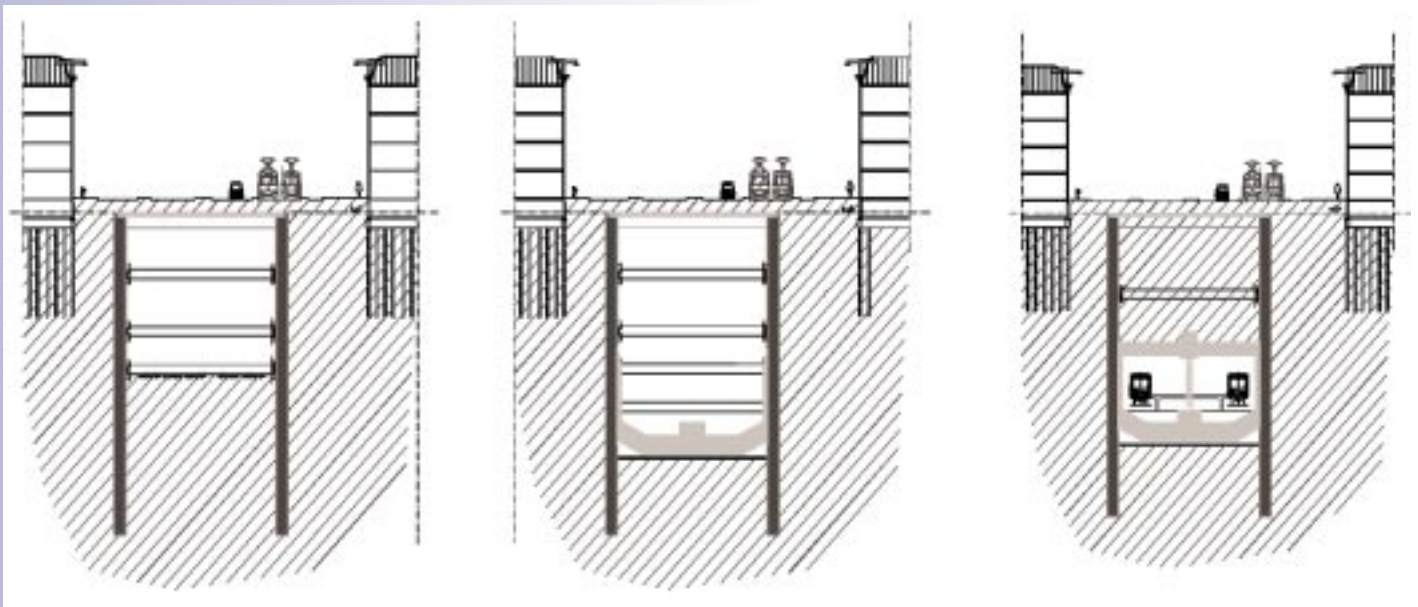
Table 2 Geotechnical profile

Approximate levels to NAP		Soil type
from	to	
surface level	- 2 m	fill
- 2 m	-12 m	holocene soil, clay, peat, sandy clay
-12 m	-15 m	1st sand layer
-15 m	-16/-20 m	sandy clay, clayey sand
- 16/-20 m	-26 m	2nd sand layer
-26 m	-52 m/ -58 m	Eem clay, Glacial clay
-52 m/-58 m	deeper	3rd sand layer

erence case, being Rokin Station. The following building sequence with time schedule is considered in the PLAXIS program.

- 1 Construction of diaphragm wall and building pit cover
  - Excavation to a level of NAP -2m
  - Construction of building pit cover (vertical load diaphragm wall)
  - Duration of this building stage 4 months
- 2 Phased excavation underneath building pit cover:
  - Lowering water table
  - Dry excavation
  - Placing steel struts c/c 5 m
  - Six excavation phases have been considered with an execution time of 2 months/phase (NAP -6.5m; NAP -11m; NAP -15m; NAP -18m; NAP -21m; NAP -25.5m)
- 3 Installation reinforced concrete floor at NAP -26m.
- 4 Construction reinforced concrete walls and roof structure
- 5 Backfilling space above roof structure with soil

- To include all stages of construction only one half of the building pit is modelled. In the PLAXIS 6.31 version the number of elements is limited to 800, six noded triangles. In figure 3 the FEM mesh is presented:
- The first excavation sequence is modelled as follows:
  - Calculation of initial stresses (KO-procedure followed by a staged construction analysis to simulate the pile loads of surrounding buildings)
  - Installation of diaphragm wall (staged construction analysis)
  - Lowering of groundwater table within the building pit
  - Excavation of subsoil (undrained staged construction analysis)
- The building pit cover is modelled as a fixed anchor
- Application of vertical load system on diaphragm wall (undrained ultimate level analysis.)
- Consolidation period of 4 months (consolidation analysis)



*Figure 2 Excavation sequence building pit*

The total FEM analysis comprises some 50 different calculation stages. About these different stages of construction as well as the FEM model the next remarks can be made;

- Within the current version it is not possible to perform a staged construction in time. Therefore an excavation sequence is modelled as follows:
  - lowering of groundwater table within the building pit (groundwater calculation combined with an ultimate level calculation to activate the new groundwater situation is activated)
  - excavation of subsoil (undrained staged construction analysis)
  - consolidation period of 2 months (consolidation analysis)

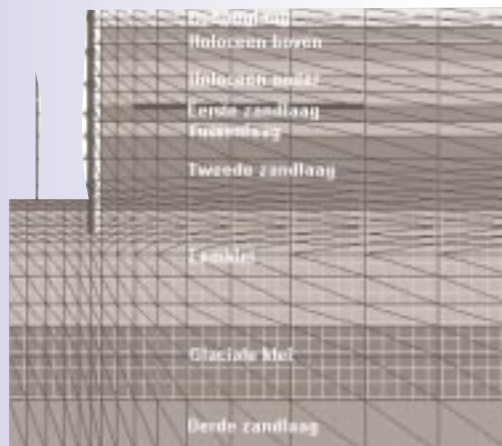


Figure 3 FEM mesh Rokin Station

- In the PLAXIS program it is recommended to use a plate to model a retaining wall. In this case the diaphragm wall is applied, that is vertically loaded (800 kN/m'). If this load is applied on the plate it will result in a point load on a single node, i.e. the bearing capacity of the wall is not modelled correctly,



Figure 5 Loaded retaining wall

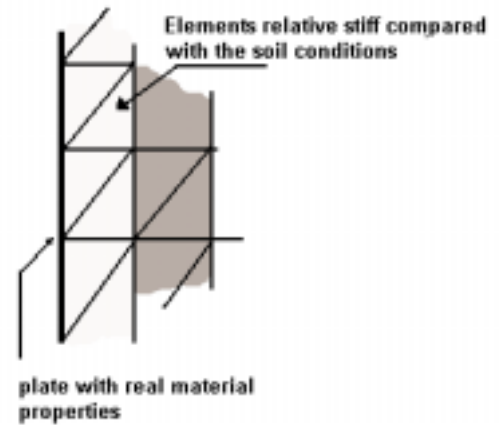


Figure 4 Close-up of model for diaphragm wall

figure 5. More over numerical problems are likely to occur. To solve this problem the diaphragm wall is modelled as follows figure 4 and 6:

- A plate with correct actual structural properties of the diaphragm wall
- A column of elements with the actual thickness of the diaphragm wall (1.4m). The material model is chosen as Non Porous, the E-modulus 1.106. The E-module of the soil elements does not have influence on the stresses in the plate.



Figure 6 Loaded diaphragm wall

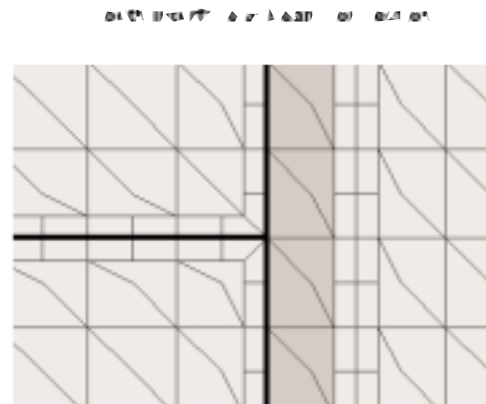
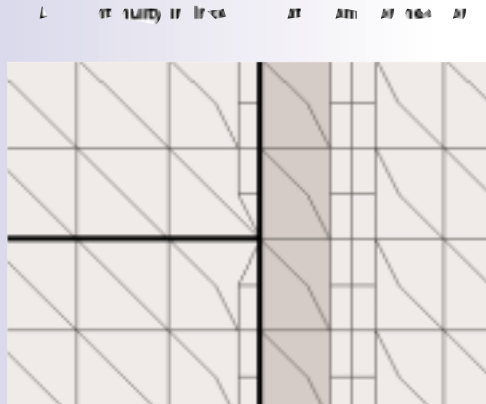


Figure 7 Different interface connections

### Bending moments Diaphragm wall

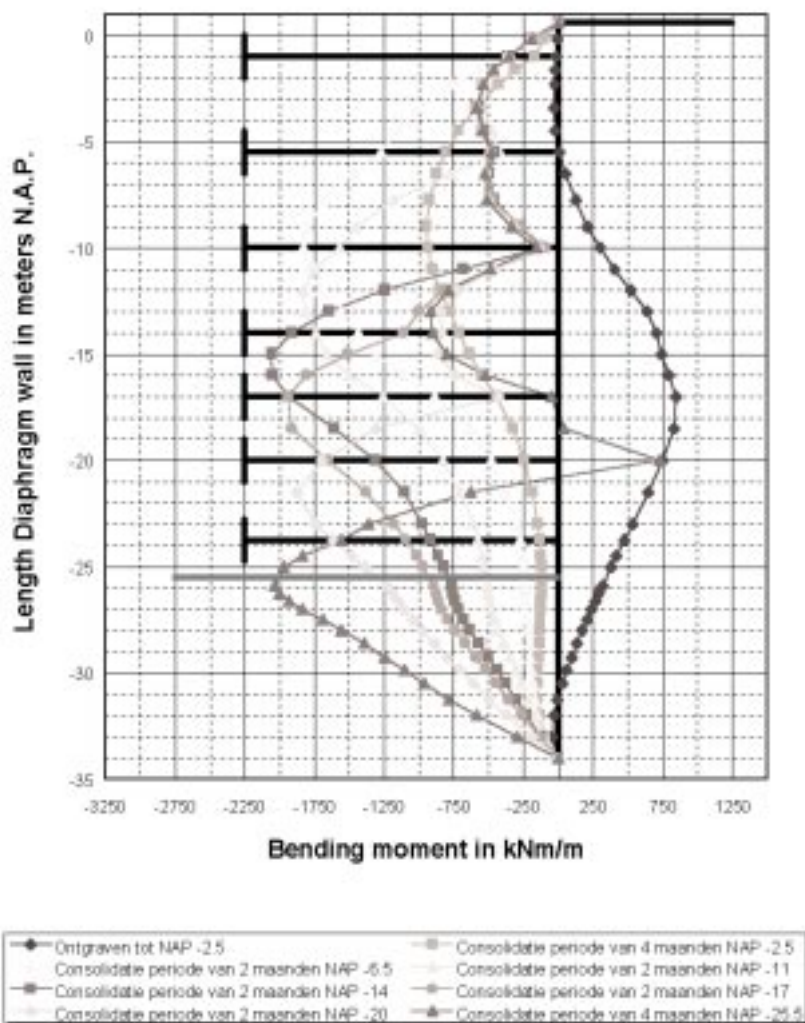


Figure 8

## Some first results:

IN THE GRAPHS BELOW SOME PRELIMINARY RESULTS ARE PRESENTED

- The material model used for the diaphragm wall is NON-POROUS. If this model is used in a groundwater calculation no convergence could be obtained. This problem can be overcome if the following procedure is used:
  - In the Input menu the material properties of the diaphragm wall have to be changed:
    - Drained behaviour
    - Very low permeability
    - Generate material properties: NO
    - Save data to disk : YES
  - Start the groundwater analysis
  - Change of material properties of the diaphragm wall to Non Porous and proceed with the other calculation stages.
- If interfaces are used at a connection of two plates the interface is discontinued at the connection point. This considerably affects the stress distribution in the soil. This problem is solved by adding two interfaces above and below the horizontal plate as shown in figure 7.

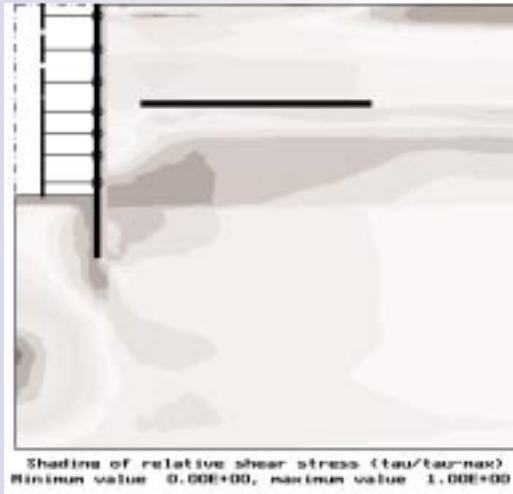


Figure 9

### Conclusions:

Modelling the deep underground station Rokin with the PLAXIS program, considering a combination of dry excavation, groundwater flow and consolidation, is challenging in many ways. The calculations are State of the Art. Although the results should be examined very closely, they seem to be very promising.

**ing. M. Hutteman & ir. J.C.W.M. de Wit Design Office North/South Line Amsterdam\*, De Weger Architects and Consulting Engineers**

\*The Design Office North/South Line is a group of consulting firms comprising:  
- Witteveen + Bos Consulting Engineers  
- De Weger Architects and Consulting Engineers  
- Ingenieursbureau Amsterdam (IBA)

## Plaxis symposium & experienced users course

It is about 10 years ago that PLAXIS found its way to the international market. Since that time PLAXIS has matured and has acquired over 1000 users worldwide. We would like to celebrate this achievement together with PLAXIS users and other geotechnical engineers in a three-day International Symposium:

### BEYOND 2000 IN COMPUTATIONAL GEOTECHNICS 10 years of PLAXIS International 18-20 March, 1999

The purpose of this Symposium is to bring PLAXIS users and developers together to exchange ideas and experiences and to address topics of advanced geotechnical engineering with a view to discussing computational methods and parameter determination. The symposium will focus on these interesting technical subjects, but some time will be reserved for social and cultural events, for which, Amsterdam is an ideal location. The Organising Committee looks forward to welcoming you at this first International PLAXIS Symposium in Amsterdam.

### Call for papers

Participants are invited to submit papers on subjects that relate to one of the session themes mentioned below:

- Tunnelling and deep excavations
- Dams and embankments
- Suburban and infrastructural works
- Education and research

Abstracts of papers, consisting of no more than 300 words, must be sent to the Secretary of the Scientific Committee before 30 July, 1998, at the address given below. Authors of abstracts accepted as a basis for lectures and/or poster presentations will be notified by 31 August, 1998. Final papers must reach the Scientific Committee by 31 October, 1998. Papers received after that date cannot be included in the Symposium proceedings. The proceedings will be available at the beginning of the Symposium. Their cost is included in the Symposium fee.

### International course Experienced users course

The International course for experienced Plaxis users is scheduled on 15-17 March, 1999, prior to the Symposium.

Regularly updated information on the Symposium can be found on the internet:

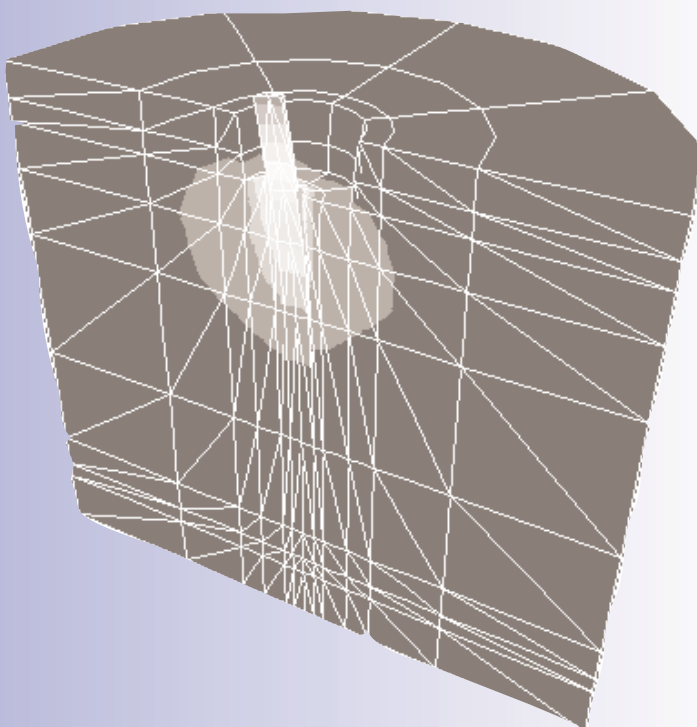
## New developments

Since two years the PLAXIS research and development team has been working on a new calculation module for three dimensional models. A limited model for laterally loaded piles and circular foundation structures has been made available within PLAXIS Version 6. Thereafter the module has been extended to allow for a 3D model composed of parallel cross sections. This year a new user interface will be developed for the 3D module based on the 2D windows user interface. In this article some preliminary 3D calculational results will be shown.

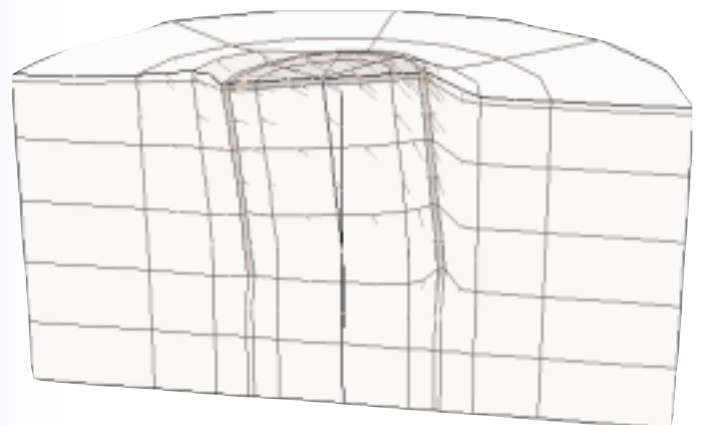
The first application is the horizontal loading of a 12.5 m long testing pile in cohesive soil.

Around the tip of the pile there is a small ditch. A 180 degrees circular mesh is used to model the situation. The pile itself is modelled with linear elastic volume elements. There are interface elements around the pile to model the pile-soil interaction. The deformed 3D mesh of the horizontally loaded pile is shown in Fig. 1. It can clearly be seen that there is an opening behind the pile due to cohesive soil and the tension cut-off in the interface elements.

The second application is a suction anchor in dense sand. This is a steel cylinder embedded in the see bottom to moor offshore constructions. The anchor has a height of 7 m and a diameter of 5 m and is loaded by a force at an angle of 30 degrees at 2/5 of its height. This situation is also modelled using a 180 degree mesh. The anchor itself is modelled with linear elastic volume elements. Instead of using interface elements along the anchor, there is a small row of volume elements with reduced friction properties compared to the surrounding soil. The displacement increments around the suction anchor at failure are shown in Fig. 2. This figure gives a good impression of the failure mechanism.



*Figure 1 Deformed mesh of a horizontally loaded pile*



*Figure 2 Displacement increments of a suction anchor at failure*

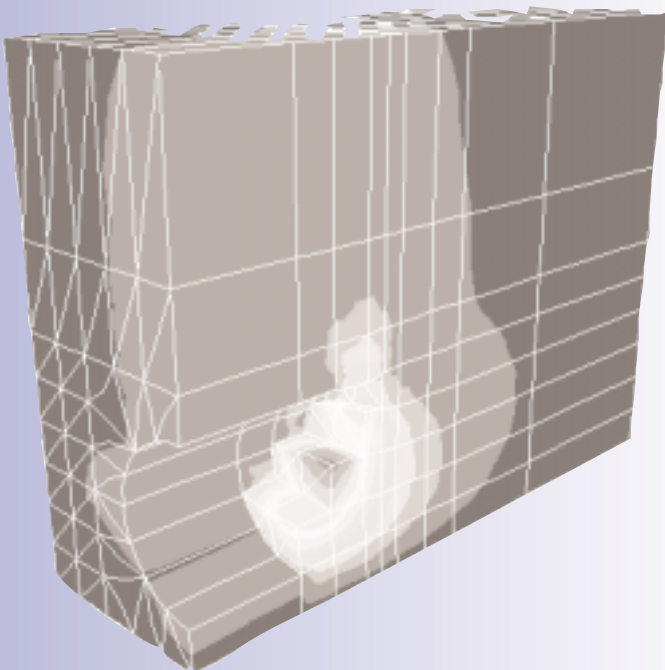
The third application is the excavation and construction of an NATM tunnel in soft rock. The front of the tunnel is unsupported and excavated in three parts (upper part, middle part, lower part) using the staged construction option. After a full cross section has been excavated, the tunnel opening is stabilised by means of a sprayed concrete lining. Since the situation is symmetric in a vertical plane in longitudinal direction, only half the geometry is modelled in a 3D mesh using similar parallel cross sections. Fig. 3 shows the deformed mesh of the NATM tunnel at a certain stage of construction. The deformations around the unsupported part of the tunnel are clearly visible.

The final application is an excavation supported by a sheet pile wall with struts at a certain distance. Such a situation may well be analysed using a 2D model, but a 3D model may give more insight in the variation of the deformations between the struts. The mesh includes plate elements to model the sheet pile wall, interface elements to model the

interaction between the pile and the wall and spring elements to model the struts. The excavation is analysed using the staged construction option. The contour lines of total displacements after full excavation are shown in Fig. 4. The plot indicates the small displacement variations between the struts.

These above results show that PLAXIS is ready for 3D calculations. Although the current possibilities are still limited, the 3D calculation module may be used for a large variety of geotechnical applications. With the development of the new Windows user interface the generation of 3D models will be almost as simple as creating 2D models. The release of the 3D module is planned for next year. A preliminary 3D module for laterally loaded piles and circular foundation structures (see Figs. 1 and 2) for PLAXIS Version 6.31 is already available on special request.

**Ronald Brinkgreve,**  
**Plaxis BV**



*Figure 3 Deformed mesh of an NATM tunnel at a certain stage of construction*



*Figure 4 Contour shadings of displacements increments for an excavation*

## Users Forum

**Question:**

Are there any "drawing aid's" I can use during the graphical input of geo-lines ?

**Answer:**

Yes, in addition to options like snap to grid, grid and grid spacing some additional procedures may be used to speed up the graphical input of the geometry:

- While pressing the <Shift> key, during a drawing action, the program can only create perfect vertical or horizontal lines.
- Another procedure is to use the command line input. If for example, the input of a "geometry line" is active, the user can specify geo-points, by entering coordinates numerically in the format: "x y" for absolute values and "r(x y)" for relative values. The command line is located at the left-hand bottom of the input screen. Please note that the decimal symbol used in Plaxis depends on the regional settings made in Windows control panel.

**Question:**

How can I enter more exact values for geo-point coordinates ? I have tried to increase the number of spacings per grid, but this does not provide sufficient accuracy.

**Answer:**

Coordinates of individual grid points can be specified by double clicking on geo-points. This will present a coordinate window, which may be used to change the coordinates. Alternatively, a table of coordinates is available in which coordinates may be edited. However, it is not possible to delete or insert geo-points in this table.

**Question:**

What is the quality of the meshes generated by Plaxis ?

**Answer:**

People that have been working with previous versions of Plaxis are used to structured meshes. The generation of the mesh in the new Version 7 is based on a robust triangulation procedure, which results in 'unstructured' meshes. These meshes may look disorderly, but the numerical performance of

such meshes is usually better than for regular (structured) meshes. It is hard to evaluate the quality of the mesh that is generated by Plaxis as this depends on the actual geometry being used. The mesh proposed by Plaxis may be refined in order to match the quality desired by the user. Some practical information on mesh generation and mesh refinement is given in the answer to the next question:

**Question:**

What steps can I take to enhance the meshes proposed by Plaxis ?

**Answer:**

To answer this question some background on the mesh generator is needed. The mesh generator requires a general meshing parameter which represents the average element size. In addition a local coarseness parameter is used in each geometry point. The former parameter is calculated by Plaxis and the latter parameter may be specified by the user. These parameters are used to distribute elements along user defined geometry lines. For more background on these parameters the reader is referred to the Reference manual page 3-48.

**Global coarseness:**

In Plaxis 5 different levels for the global coarseness can be used, ranging from very coarse to very fine. By default the global coarseness is set to "Course". In average this results in meshes with around 100 elements, but obviously this depends on the actual geometry used. The number of elements is not influenced by the "Type of elements" parameter, as set in the "General settings". Note that a mesh composed of 15-node elements gives a much finer distribution of nodes and thus much more accurate results than a similar mesh composed of the same number of 6-node elements. On the other hand, the use of 15-node elements is much more time consuming than using 6-node elements.

**Global refinement:**

The global refinement can be changed by the

user by selecting one of the global coarseness levels. This will result, after generation, in an overall change of coarseness.

#### **Local refinement:**

In areas where large stress concentrations or large deformation gradients are expected, it is desired to have a more accurate (finer) finite element mesh, whereas other parts of the geometry might not require a fine mesh. Such a situation often occurs when the geometry model includes edges or corners or structural objects. For these cases Plaxis uses local coarseness parameters in addition to the global coarseness parameter. Local refinement can be applied to individual clusters, geometry lines and geometry points. First the user needs to select one or more objects of the same category (clusters, lines or points). After the selection, the "Mesh" menu will reveal the appropriate local refinement options. In addition to the global

refinement levels, the local refinement options allows for further refinement.

#### **Advised mesh generation practice:**

In order to perform efficient finite element calculations a preliminary analysis should be performed using a coarse mesh. This analysis can be used to check whether the geometry model is large enough and to see where stress concentrations and large deformation gradients occur. This information should be used to create a more appropriate finite element model.

In order to create efficiently a detailed finite element mesh, one should first select the proper "Global coarseness" from the "Mesh" sub-menu. In addition, when local refinements are desired, one should start by refining clusters, then refining lines and finally refining points.

## **ACTIVITIES:**

### **NOVEMBER, 1998**

5th European Users meeting (English),  
Karlsruhe, Germany

### **4-6 NOVEMBER, 1998**

Short course on Computational Geotechnics (French), 'Pratique des éléments finis en Géotechnique', Paris, France

### **24-26 NOVEMBER, 1998**

Users meeting and Short course on Computational Geotechnics (Norwegian)  
Trondheim, Norway

### **18-20 JANUARY, 1999**

Standard course on Computational Geotechnics (English), Noordwijkerhout, the Netherlands

### **15-17 MARCH, 1999**

International course for experienced Plaxis users (English),  
Noordwijkerhout, the Netherlands (see also next activity)

### **18-20 MARCH, 1999**

"Beyond 2000 in Computational Geotechnics" Symposium to celebrate 10 years Plaxis international (English)

Amsterdam, the Netherlands (see also previous activity)

web-site:

<http://www.stw.nl/stw/plaxis/symposium.html>

### **APRIL, MAY, 1999**

Short course on Computational Geotechnics (German), 'Finite Elemente Anwendungen in der Grundbaupraxis',  
Stuttgart, Germany

### **7-10 JUNE, 1999**

XII European Conference SMGE

Amsterdam,

the Netherlands (see also next activity)

### **11-12 JUNE, 1999**

Short course on Computational Geotechnics (English),

Amsterdam, the Netherlands (see also previous activity)