BULLETIN

PLAXIS

Nº 13 - JANUARI 2003

Bulletin of the PLAXIS Users Association (NL)

Plaxis bulletin
Plaxis B.V.
P.O. Box 572
2600 AN Delft
The Netherlands
E-mail:
bulletin@plaxis.nl

IN THIS ISSUE:

Editorial	1
Column Vermeer	2
New developments	3
Plaxis Team	4
Benchmarking I	5
Benchmarking II	8
Recent Activities	9
Plaxis practice I	10
Plaxis practice II	15
Users forum	19
Activities	20

Editorial

To inform the Plaxis users we aim to release two issues of this bulleting each year and it seems that we are improving and adhere to a more regular schedule. As always we plan to send the bulletin just before summer and around New Year and since this issue, the 13th bulletin, is sent in January we like to wish you all a happy new year.

The last period has been quite moving for Plaxis. The release of Plaxis V8, the European users meeting and a course in Brazil were some of the major events. Next to that Plaxis has moved up the hill to a newly built office block, though not far from the old office. In fact we only have to change the number on the door from Delftechpark 26 to Delftechpark 19. From this new location the Plaxis team expects to be better facilitated to serve the Plaxis users.

In this bulletin we have again collected some interesting subjects. Moreover, as mentioned in the previous bulletin, we will introduce the members of the Plaxis team. Some of the members will be already known to you from their participatation in user meetings or because you followed courses on Computational Geotechnics, or maybe you have met them during a geotechnical conference. Anyhow, we believe it will be interesting for all the Plaxis users to know a little more about the Plaxis team.

In addition, there are some new contributions to the standard categories in the Plaxis bulletin:

- Column Vermeer: Announces an upcoming workshop on soft soil modeling
- New developments: Introduces a new program for transient groundwater flow. This program, developed in cooperation with GeoDelft, will offer a serious alternative and will set a new standard in groundwater flow computations.
- Benchmarks: Shows the results of the previous benchmark and sets the conditions for the next benchmark, which is an excavation problem. We do encourage you to actively participate in the benchmark problems and send in your results. It is shown from the last benchmark that personal preferences in modeling may lead to significant differences in results.
- Plaxis Practice: In this part an article is presented about parameter determination. It contains suggestions for the determination of stiffness parameters for sand, derived from both, in-situ and laboratory tests.
- User's forum: A comprehensive explanation is given on the use of the application of loads in the new Plaxis V8. Furthermore significant information regarding the manual and some errata is presented.

In January we will organize our regular International Course on Computational Geotechnics. This course is renewed to meet with the Plaxis V8 additions. Furthermore the Schedule is again filled with new Plaxis courses and other interesting events. We trust that you find interesting information in this new bulletin and we are always interested to hear your remarks and comments.

Editorial staff:
Marco Hutteman, Plaxis Users Assocation (NL)
Dr. Wout Broere, Plaxis B.V.

Scientific Committee:
Prof. Pieter Vermeer, Stuttgart University
Dr. Ronald Brinkgreve, Plaxis B.V.

PLAXIS

Column Vermeer

On the Soft Soil Workshop

During my studies in the sixties Soil Mechanics was based on a limited amount of theory and empirical knowledge. Constitutive modelling had hardly been applied to granular materials, the experimental techniques consisted of fairly simple tests and computer facilities were not available. But times have changed. Experimental techniques have improved tremendously and lab testing as well as in situ testing have become highly specialised subjects within geotechnical engineering. Similarly, significant progress has been made in constitutive modelling and there is a growing number of numerical experts.
Within an European Commission funded Research Training Network named "Soft Clay Modelling for Engineering Practice" we are aware of the growing specialisation within geotechnical engineering and we try to bring all various different "professionals" together in the

International Workshop on
GEOTECHNICS OF SOFT SOILS
Theory and Practice

This three-days workshop will be held near Amsterdam at Noordwijkerhout,
17th to 19th September 2003. We will cover a wide range of soft-soil topics like

1. Constitutive modelling
2. Numerical modelling
3. Laboratory testing
4. In situ testing and sampling
5. Ground improvement
6. Case studies

The response of the geotechnical community is far beyond my expectation. We received about a hundred abstracts from potential contributors. Moreover, the abstracts cover the topics extremely well. It is only on in situ testing and sampling that we received a relatively small number of abstracts. Hence, we have not been able to mobilise practicioners and researchers working in this area to the extent we anticipated. Therefore we would like to get more contributions in that area, as in situ testing is of growing interest to geotechnical engineering. Thus we would make an exception and still accept abstracts on this particular topic although the deadline for submission has passed.

The workshop focuses both on theory and practice and I do hope that this workshop will help us to narrow the gap between theory and practice. At present research activities on geotechnical engineering are growing, particularly in the field of theoretical Soil Mechanics. In recent years many universities have emphasized fundamental research and it is often much easier to get funding for a theoretical study than for a practical application. In chemical, electronical or mechanical engineering this is no problem, as here we have large companies that are able to test new theories. In geotechnical engineering, on the other hand, companies are relatively small and find it financially non-attractive to absorb the impressive amount of new very high-level research output from universities. As a consequence much excellent analytical, laboratory and field testing research does not easily find its way into engineering practice. I am sure that our workshop will provide the highly needed interaction. Indeed, the abstracts reflect a nice mixture of authors from both universities and industry.

The style of the workshop will reflect the coupling between theory and practice. To this end the planning is as follows. The first day will focus on theory, the second day will be on testing and the third day will be devoted to practical ground improvement and case studies. We will thus begin with presentations on developments in modelling (1st day) and give the last word to practitioners (3rd day). The second day is mainly on the measurement of soft-soil properties and may as well include one or two sessions on special themes like creep and column-type ground improvement.

For further information on the workshop, the reader is referred to the website www.uni-stuttgart.de/igs/SCMEP.

P.A. Vermeer, Stuttgart University

New Developments

In the previous bulletin the release of Plaxis Version 8 was announced. Since the official release in August 2002 about 300 licences have found their way to clients. At the same time some small initial errors have been corrected so that new clients will obtain Version 8.1 (Service Pack 1). Early clients may download this Service Pack freely from our web side (www.plaxis.nl > Services > Updates).

The next product that we will release is a special 2D program for transient and (un)saturated groundwater flow (PlaxFlow). This program has been developed in cooperation with GeoDelft, the Dutch Geotechnical Institute. In this bulletin I like to mention some more details about this new product.

The PlaxFlow program can be used as a stand-alone program for time-dependent 2D flow (plane flow in a vertical section) or in combination with PLAXIS Version 8. After a transient groundwater flow calculation, the results (i.e. the water pressure distribution at different time steps) can be used in Version 8 to perform deformation and stability analyses for situations where the change of water conditions with time plays an important role. Examples of such situations include the stability of embankments in periods of high water levels, the influence of temporary pumping (for example to make an excavation) on the water level and the deformations in the surrounding area, etc.. There is no back-coupling from the deformation analysis to the groundwater flow analysis, but for most situations the current approach is very adequate.

Some characteristics of the PlaxFlow program are:

- Convenient geometry creation and mesh generation similar to PLAXIS Version 8.
- Relationships between permeability and pressure at one hand and degree-of-saturation and pressure at the other hand, based on the Van Genuchten model, the Approximated Van Genuchten model or user-defined relationships.
- A large number of pre-defined relationships are available for various types of soil.
- Pre-defined relationships can be easily selected using standardised soil classification systems.
- Boundary conditions for pressure (or head), closed boundary, discharge, seepage, precipitation and ponding conditions.
- Convenient generation of simple conditions on the basis of an external water level.
- Special conditions for impermeable screens, wells (sink or source) or drains.
- Multiple calculation phases with different conditions including staged construction.
- Time-dependent boundary conditions for external water level or precipitation (by means of linear transition, harmonic function or input table).
- Output of pore pressures, groundwater head, phreatic level, degree of saturation, specific discharge (Darcy flux), discharge through a cross section, time-pressure, time-head or time-discharge curves.

The more complex part of transient and unsaturated groundwater flow involves the relationships between permeability and pressure at one hand and degree-of-saturation and pressure at the other hand. Parameters for these relationships are generally not easy to select for geotechnical engineers who are not specialised in unsaturated groundwater flow. However, for this large group of users we have simplified the selection of parameters by pre-defining data sets for various types of soil on the basis of common standardised soil classification systems. On the other hand, experts in unsaturated groundwater flow may select the Van Genuchten parameters

PLAXIS

themselves or may create user-defined relationships. In this way, the groundwater flow program is applicable for a wide range of users. The PlaxFlow program will be released in the first quarter of 2003.

Ronald Brinkgreve
Plaxis BV

Plaxis Team

In this bulletin we like to introduce the members of the Plaxis team and tell something about their position and role in the Plaxis organisation.

Ronald Brinkgreve
Leader of the Research & Development team. After taking his doctorate at Delft University in 1994 he continued to work for Plaxis. He is one of the main developers of the Soft-Soil model. Apart from giving direction to the other members in his development team, Ronald is a regular lecturer at one or the other Plaxis course. The meeting and discussion with the Plaxis users is a source for the development of further Plaxis projects. Ronald represents Plaxis in the CUR development committee. Besides that Ronald is a part-time lecturer at Delft University on Material Modelling for Geotechnical Materials.

Paul Bonnier
Senior scientist. Paul is mainly involved in the further development and improvement calculation kernel of the Plaxis software. Paul is one of the problem solvers in the team and the inventor of new features.
After taking his doctorate at Delft University in 1993 on the topic of Numerical Modelling and Analysis of the Behaviour of Bituminous Concrete, Paul continued to work on the further development of Plaxis. Paul spent much effort on the development of the 3D version of the Plaxis software.

Grzegorz Soltys
Programmer and assistant scientific co-worker. Grzegorz is working on both the calculation kernel as well as the user interface. The last year he has been working on the development of the Plax Flow Groundwater flow program in cooperation with Geodelft. Grzegorz received a doctorate of the Technical University of Gdansk and has been working with the Plaxis group since 2000. Grzegorz likes to go to the theatre and is a photographer.

Rafid Al-Khoury
Scientific co-worker. Rafid is a relatively new team worker although he has been acquainted with the Plaxis group for a long time. Before he joined Plaxis Rafid worked with Prof. Blaauwendraad, of Structural Mechanics of TU-Delft, chain between 1998 and 2002. His main task was the development of computational tools for parameter identification of layered systems. He defended his thesis on December last year. Rafid likes listening to classical music and reading non-fiction books.

Wim Bomhof
Scientific co-worker. Wim is mathematician, and working on the Plaxis solvers. He is a graduate of Twente University and received a doctorate of Utrecht University. Wim was asked to join the Plaxis team to improve the performance of the solvers for the 3D Tunnel program, in which he succeeded. Now Wim is working on a new concept for our 3D Tunnel program. Wim travels by train to Delft and he lives on the Veluwe.

Ed Hartman
User-interface programmer. Ed is one of the co-workers responsible for the user interface of Plaxis software. His effort is important for the user friendliness and accuracy of the user interface. The last year Ed has been working on the development of the 3D Foundation program. He has been working on the problem of spatial modelling of the sub-soil in such a way that this leads to a user-friendly, easy to learn and to use 3D model for foundations. Ed has been programmer since 1988 and came to work for Plaxis in 2000. Ed runs the marathon and plays the guitar.

PLAXIS

Wout Broere
Courses and user-support. Wout lectures at some of the Plaxis courses that are organised all over the world. In order to have a smooth running course, the course organization starts one year before the actual event takes place. Courses are an essential part of user-developer interaction and contribute to the quality both of the Plaxis product and of the practical engineering feedback.
Wout has obtained a doctorate at Deft University in 2001, and continues as part-time researcher for physical modelling at the Geotechnical Laboratory of Delft University. He is involved in several large tunnel boring projects as well.

Dennis Waterman
User-support and programming. Dennis has been working for Plaxis since 1996. Dennis started with Plaxis programming the user interface. Later on he became, more or less involuntarily, responsible for the computer network of Plaxis. This year Dennis' attention shifted towards user support, and also lecturing in Plaxs courses. Dennis rides the bicycle and does not limit this activity to the Netherlands.

Dereyl Wazir
Computer, network and data management. Dereyl works for Plaxis since September 2002. He took over the network maintenance from Dennis. His other obligation is to organize a new data management system for Plaxis. The new data management system is mainly intended for the Plaxis Marketing and Sales section. Besides his work Dereyl, is doing some serious studying both at Delft University and the Erasmus University on the topic of Public Management. To relax Dereyl plays the guitar.

Sacha Born
Works with Plaxis since 1996. She is involved with marketing and sales and besides that with about everything that comes along, such as brochures, mailings and the Plaxis Bulletin. She organizes Plaxis related events.
Sacha's hobby is horses and she teaches horesriding classes after hours.

Annelies Vogelezang
Works for Plaxis part time, as besides Plaxis she is also managing a family. Annelies works at sales and handles deliveries to clients. Related to that she handles the Email communication with clients and keeps the clients database information up to date. Annelies likes to read and she does like to go out.

Klaas Jan Bakker
Director. Manages the Plaxis team. Klaas Jan works also works part-time for Delft University where he lectures on Hydraulic Structures, in paticular tunnels. Klaas Jan was involved in the development of structural elements in the computer code and developed on earlier version of the groundwaterflow kernel.
Before he entered the Plaxis company he worked for the Dutch Public Works department for 16 years. Among other things he was project leader for the research on the first large diameter bored tunnel in the Netherlands. He is a Dutch delegate for TC28: Underground Construction in Soft Ground.
Klaas Jan likes to go camping and sailing during his holidays and he plays the trombone.

Benchmarking I

PLAXIS BENCHMARK NO.2: EXCAVATION
1 - RESULTS

Introduction

The response of the Plaxis community to the call for solutions for the second Plaxis benchmark example, a deep excavation problem specified in bulletin No. 12, was reasonable but I would still like to see more Plaxis users taking part in this exercises.

Although the specifications of these benchmark examples are quite rigorous, some modelling details remain unspecified and thus the personal experience of the user comes into play. Sharing these experiences with other users and assessing the differences in the results caused by these "personal" assumptions

is the main goal of this section. In the long term this should contribute to more reliable and consistent results. The fact that these "minor" modelling details can lead to significant differences in calculated results in some cases will be proven once more by discussing the results of the benchmark exercise No.2.
According to the rules set when this section of the bulletin was introduced no names of authors will be disclosed and all entries are labelled E1 to E14. If two different analyses have been submitted by one institution the second one is named e.g. E14a.
The specification of Benchmark No.2 is not repeated here, please refer to the Bulletin No.12.

Remarks on submitted analyses

In the specification for the problem the constitutive model (HS-model) and the parameters to be used have been given, also the geometry as far as the construction steps are concerned. However, the overall dimensions of the computational model, element types, tolerance settings and the way how the groundwater lowering should be modelled, have deliberately not been prescribed. Therefore some variation in assumptions of these modelling details could be expected, and indeed some users employed 6-noded elements, some 15-noded ones, some used the standard tolerance settings (Version 7 was mainly used), but some set the tolerated error to 1% (standard in Version 8 now, which has been used by some analysts). Most users extended the interface elements below the wall as advocated in Plaxis courses but only a few set the interface behaviour to "rigid" as suggested by Plaxis. The main differences were observed in modelling the groundwater lowering, where the full range of possibilities was exploited to arrive at the pore pressure distribution after the groundwater lowering. These included "interpolation between clusters", no interpolation with a jump in pore pressures at the base of the wall and a groundwater flow calculation (boundary conditions assumed were also chosen differently).

Comparison of results for final construction stage

Figure 1 plots calculated horizontal dis-

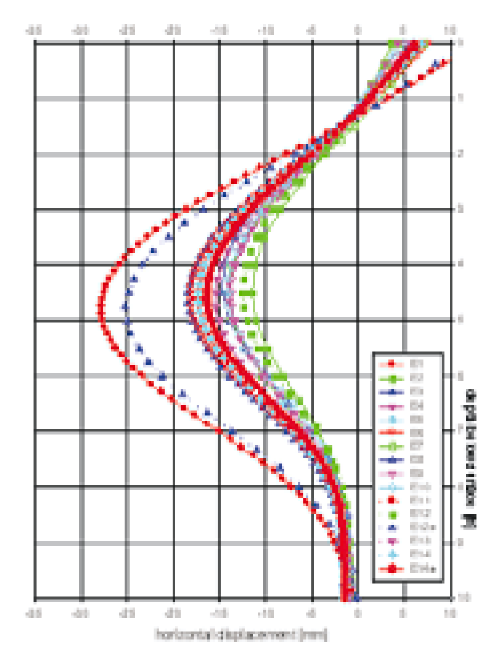


Figure 1 Horizontal wall displacements

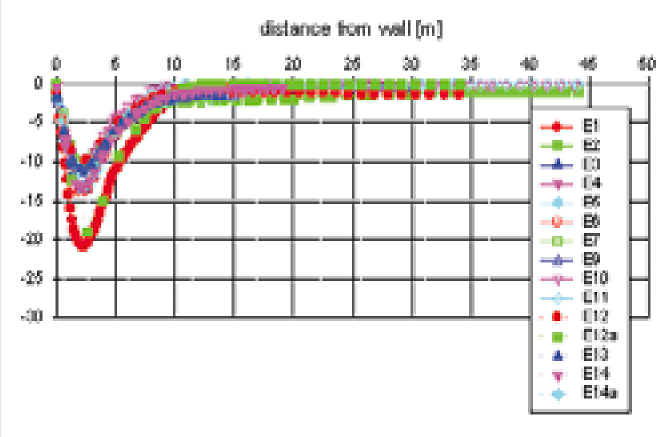


Figure 2 Settlements behind wall

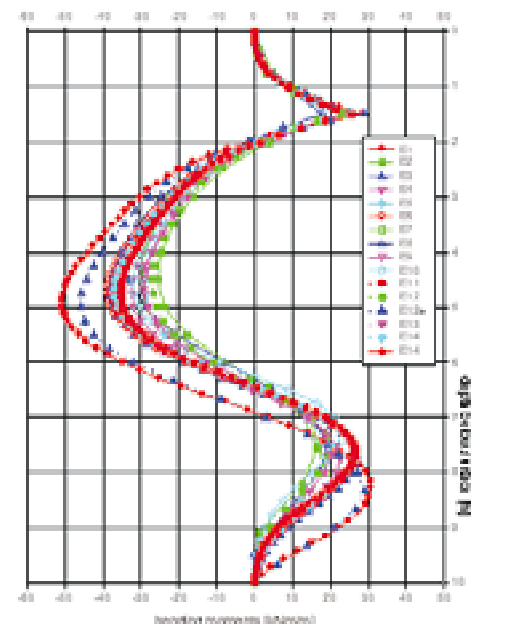


Figure 3 Bending moments

placements of the wall and most of the analyses obtain a maximum value between 14 and 18 mm, some however indicate more than 25 mm, some are below 13 mm. Accordingly the settlements behind the wall vary between 10 and 20 mm (Figure 2). Maximum bending moments are in the range between 26 and 38 kNm/m for most of the analyses, the maximum being 51 kNm/m (Figure 3). Calculated strut forces scatter slightly around a value of 106 kN/m with the minimum and maximum value being 84 and 124 kN/m respectively (Figure 4).

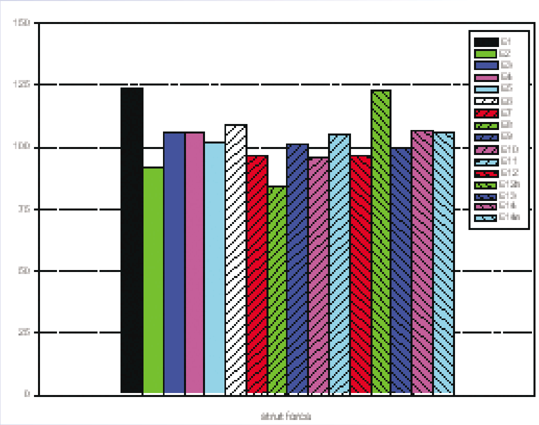


Figure 4
Calculated strut forces

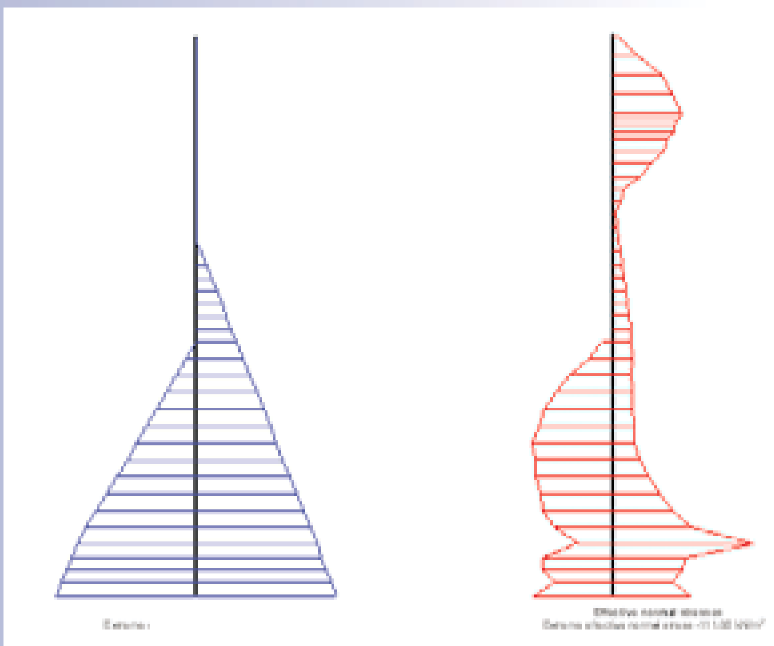


Figure 5 Calculated pore pressures and effective stress in interface in final excavation stage resulting from option "interpolate between clusters" for lowering the groundwater table

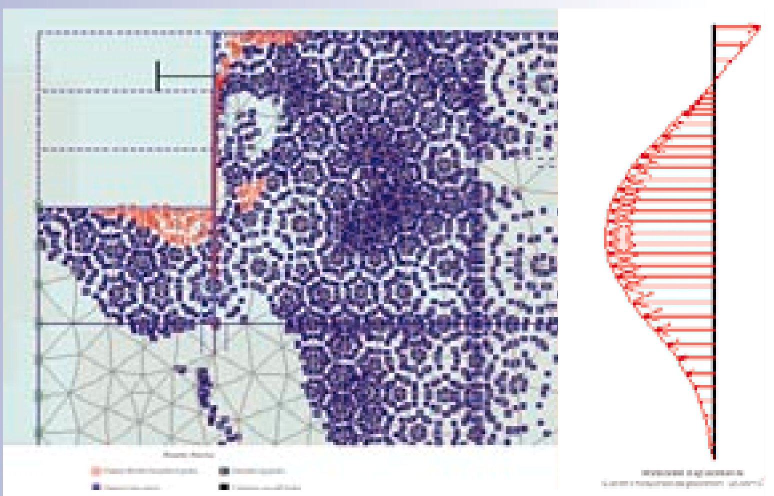


Figure 6 Plastic points and horizontal wall displacements in final excavation stage resulting from option "interpolate between clusters" for lowering the groundwater table

Although the scatter in the "mainstream" of the results is basically acceptable and can be attributed to mesh configuration in combination with element type and more importantly tolerance settings, the maximum values shown need some explanation. It turns out that the assumptions with respect to the modelling of the groundwater lowering are decisive. If a groundwater flow analysis is performed or if the pore pressure distribution with the "phreatic line option without interpolation between adjacent clusters" is chosen, displacements are significantly smaller compared to cases where the option "phreatic line with interpolation between adjacent clusters" has been adopted. This has been shown by "user E12" (E12 is groundwater flow option and E12a is interpolation option) and has been verified by separate internal studies. The reasons for these relatively large differences in this particular case are not only the different water pressures calculated by the different methods itself but as a consequence of this the differences in effective stresses in the interfaces in the lower part of the wall. These determine obviously whether the shear strength of the interface is exceeded or not and this in turn governs the overall behaviour at the base of the wall and influences the horizontal displacements of the entire wall because the deflection curve has a significantly different gradient at the base (Figures 5 to 8). This is also reflected in the distribution of bending moments at the lower part of the wall (Figure 3).

Comparison of obtained factors of safety

Figure 9 plots the factors of safety for all entries and this variation is not acceptable. Without having the details of all analyses, the differences can be most probably attributed to the choice of elements but even more importantly to the number of steps allowed for the phi-c-reduction (some used far to less steps) and tolerance settings (E12 pointed out that significant differences are obtained if a high number of steps (more than 1000) and/or very tight tolerances are set (0.001). These results strongly emphasize that phi-c-reduction analyses have to be checked very carefully in order to avoid highly erroneous results due to various modelling assumptions and numerical problems.

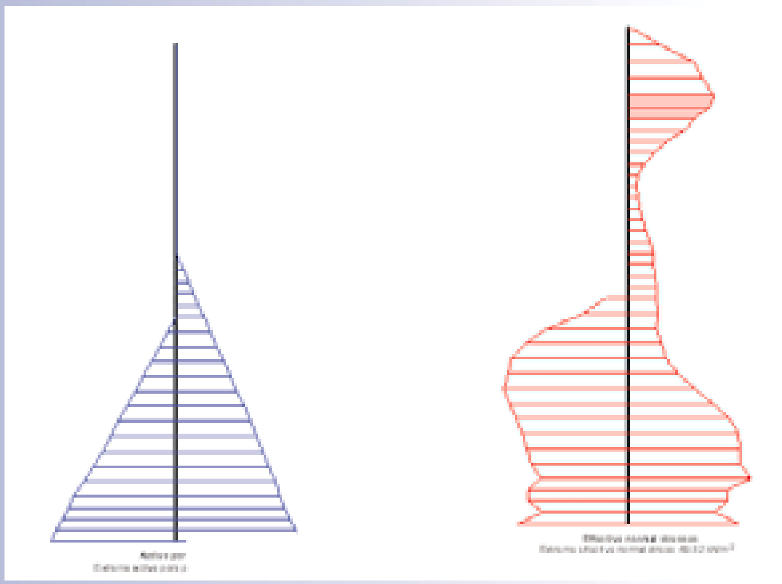


Figure 7
Calculated pore pressures and effective stress in interface in final excavation stage resulting from option "groundwater flow" for lowering the groundwater table

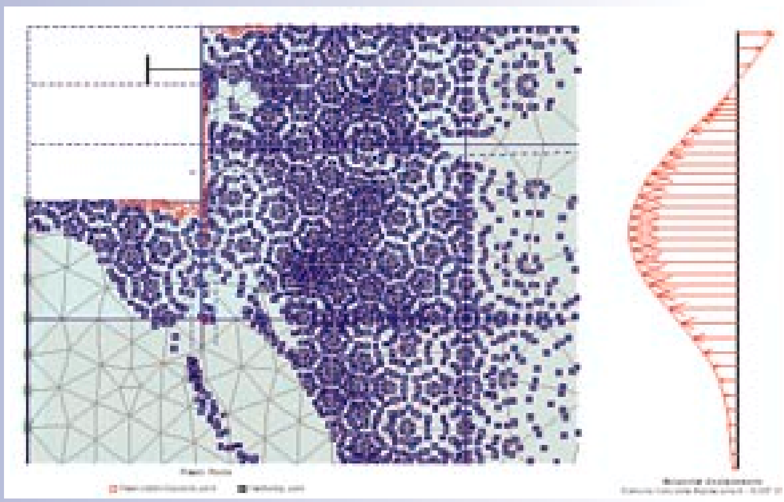


Figure 8
Plastic points and horizontal wall displacements in final excavation stage resulting from option "groundwater flow" for lowering the groundwater table

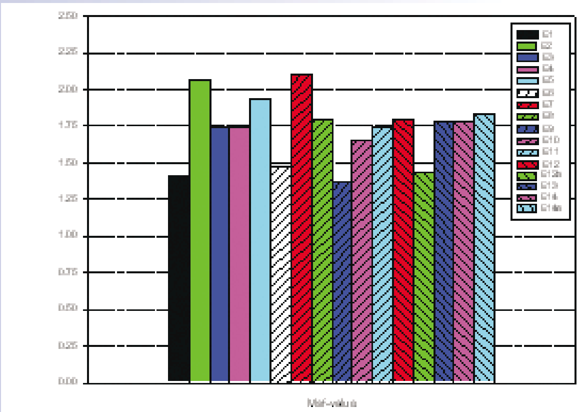


Figure 9
Calculated Msf-values

Conclusion

It has been shown once more that "personal" preferences in modelling assumptions can lead to significant differences in results obtained from a finite element analysis and although Plaxis is robust (if settings are chosen appropriately) and user-friendly, (fortunately) the user remains the key person in any analysis. It is therefore emphasized again that sufficient experience is necessary for obtaining reliable results from a finite element analysis.
The third PLAXIS Benchmark, published in this bulletin, is an embankment and I hope that the number of Plaxis users submitting solutions will increase again, indicating that the awareness for the necessity of validation procedures is growing.

Helmut F. Schweiger, Graz University of Technolgy

Benchmarking II

PLAXIS – BENCHMARKING NO. 3: EMBANKMENT 1

The geometry of the embankment example follows from Figure 1. Two layers of 1 m height each are to be constructed. The water table is assumed to be 1.0 m below the surface. For the first meter of the ground profile a gravel layer is assumed. The soft clay underneath is to be modelled with the Soft Soil model.

Analyses should be performed with the

PLAXIS

following boundary conditions for consolidation:

- lateral boundary closed, bottom boundary open

The following computational steps have to be performed:

- initial stresses, with
  $\sigma'_v = \gamma.y, \ \sigma'_h = K_0.\gamma.y \qquad (K_0 = 1\text{-}\sin\varphi)$
- apply both layers of the embankment under undrained conditions
- 100 years consolidation

Material parameters

Embankment: Mohr-Coulomb model

γ	E	φ	ψ	c	ν	Tensile-Strength
kN/m³	kPa	°	°	kPa	-	kPa
20.0	40 000	38	0	1.0	0.3	0.0

Top layer: Mohr-Coulomb model

γ	E	φ	ψ	c	ν	Tensile-Strength
kN/m³	kPa	°	°	kPa	-	kPa
20.0	40 000	38	0	1.0	0.3	0.0

Soft clay: Soft Soil model

κ	λ	φ	ψ	c	ν	γ_{sat}	e_0	k_f
-	-	°	°	kPa	-	kN/m³	-	m/s
0.028	0.15	27	0	0.1	0.2	18.5	1.1	$1*10^{-9}$

Results to be presented after construction of both layers and after consolidation, seperately:

- time settlement curve for point x = 0, y = 0
- surface settlement trough
- horizontal displacements at vertical profile at x = 8 m
- effective stresses sx and sy at vertical profile at x = 0 m
- effective stresses sx, sy and txy at vertical profile at x = 8 m
- effective stresses sx, txy at horizontal profile at y = 2.5 m

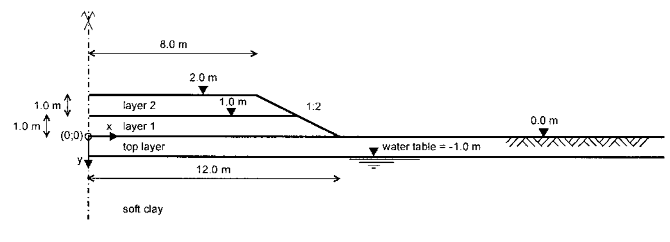


Fig. 1 Geometry of embankment benchmark

Fig. 1 Geometry of embankmen t benchmark

Results to be presented after construction only:

- excess pore pressures at vertical profiles at x = 0 m and x = 8 m
- excess pore pressures at horizontal profile at y = 2.5 m

Stress paths to be presented for applying both layers and consolidation phase:

- excess pore pressure and p'-q-stress path at the following locations (approximately):
  x = 0 > y = 0, 2.5, and 12
  x = 8 > y = 0, 2.5 and 12 m

All results have to be presented in Excel-sheets (Plaxis-project Files optional) and mailed to: helmut.schweiger@tugraz.at

RECENT ACTIVITIES

PLAXIS B.V. has crossed the road

Since July 1999 Plaxis bv occupied several rooms in the BTC I office complex in Delft. Over the last three years the Plaxis team has more than doubled in numbers, however, and the available office space became rather limited.

This prompted us to look for a more spacious office location, which we found nearby, on the other side of the road. Therefore, since October 21st, our address and telephone numbers have changed:

Plaxis BV

Delftechpark 19	PO Box
2628 XJ Delft	2600 AN Delft
The Netherlands	The Netherlands

Telephone: +31 15 2517720
Fax: +31 15 2573107

The new office has enough room to accommodate the continuous growth of the team over the next few years. We hope you will visit us when you are in the neighbourhood.

Plaxis Practice I

FE Analysis of Luz Station, São Paulo Underground

Introduction

One of the most challenging tunnel design ever faced by Themag Engineering was the Luz Underground Station. This is a part of the large project to start next year for the construction of the fourth line extension of the São Paulo Underground.

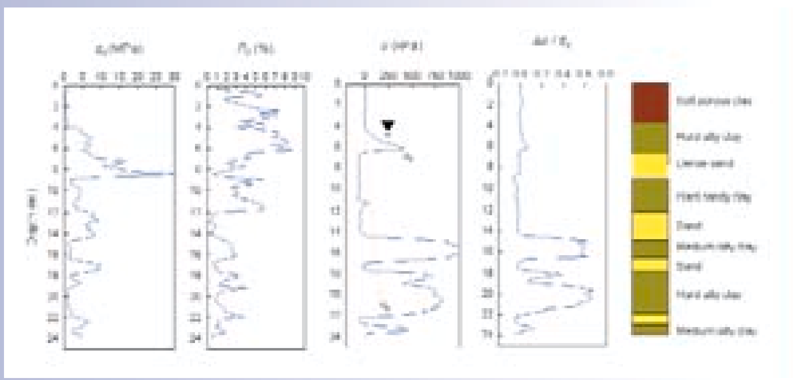
The proposed Luz Station will be an underground facility some 25 m deep, 20 m in equivalent diameter and 70 m long to be excavated in Tertiary soils in the city centre of São Paulo.

This article presents results of the Plaxis 2D and 3D analyses. The striking feature of the 3D analysis was to demonstrate the need of pre-treatment of the ground ahead of the excavation through jet grouting forepoling, which was not evidenced at the 2D analysis.

Site characteristics

The soils of the Tertiary basin of São Paulo consist of over consolidated hard clays and dense sands. The Luz Station site was investigated by means of several 63 mm diameter boreholes in which SPT was carried out at each metre along depth. Additionally, a few seismic piezocone tests gave the profile in Figure 1 and results of the low strain shear modulus (G0) profile versus depth in Figure 2. The results of this investigation identified a top layer of loose clayey fill followed by a series of interlayered over consolidated sands and clays. A few perched water levels can also be identified in the profile.

Figure 1
Results from seismic piezocone test



Construction method

The proposed construction method of such a large diameter section consists of shotcrete supported partial excavation with two side-drifts, followed by top heading excavation with a temporary invert and completion by excavation of the bench, followed by closing the inverted arch.

Two additional measures are considered in order to increase the safety factor: forepoling of the roof and also dewatering by means horizontal and vertical drains subjected to vacuum.

Geometry

Figure 3 presents the geometry model for the problem, consisting of a layer of fill followed by sand (pink) layers and clay (light blue layers). The analysed cross-section is 70 m wide and 43 m high.

Figure 4 shows the FE mesh which employed fifteen node isoparametric elements available in Plaxis. Lateral boundaries are free to move vertically and the mesh bottom is fixed. Beam elements were used to model the tunnel lining and internal walls. Interface elements were used around the tunnel.

Soil model

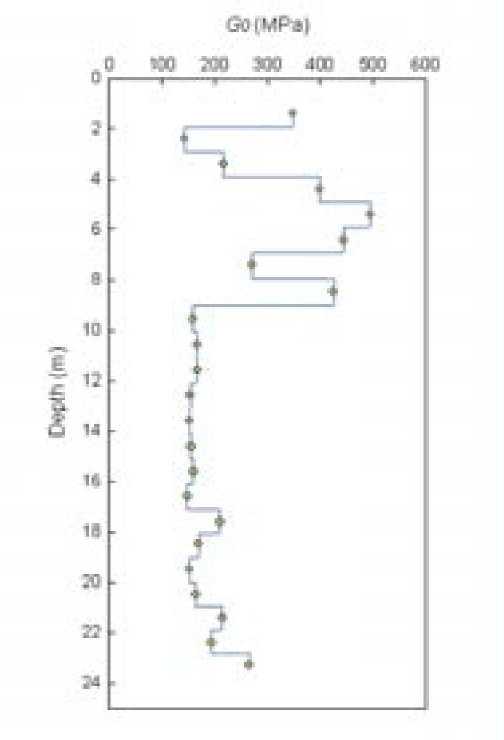


Figure 2
Low strain shear modulus profile from seismic piezocone

Plaxis offers a variety of elasto-plastic soil models including Mohr-Coulomb, Hardening Soil Model (HSM) and models for soft soils.
A preliminary analysis, not presented here, was carried out using the Mohr-Coulomb elastic, perfectly-plastic model. However, this model does not distinguish between primar loading and unloading and gave too high deformations when unloading takes place. Therefore, additional analyses employed the much more sophisticated Hardening Soil Model (HSM) which can be applied to hard and soft soils. When subjected to primary deviatory loading, soil shows a decreasing stiffness and simultaneously irreversible plastic strains develop. In the special case of a drained test, the relationship between deviatoric stresses and strains can be approximated by a hyperbolic formulation. The HSM, however, supersedes the hyperbolic model by using plasticity rather than elasticity and also by including dilatancy and a yield cap. Brinkgreve and Vermeer (1998) give details of this model..

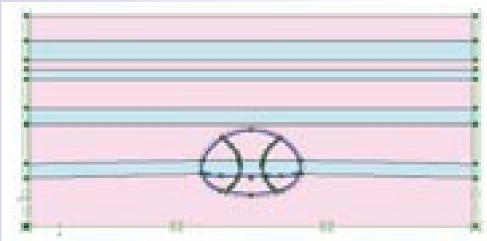


Figure 3 Geometry of the problem

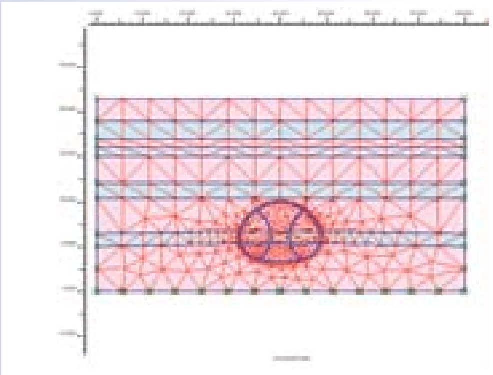


Figure 4 FE mesh

Parameter selection

Table 1 presents the selected parameters for the soil layers. The medium sand layers occur above the tunnel crown, corresponding to N values ranging from 5 to 15. However, the tunnel is located in much harder sands and clays, underneath these medium layers.

Modelling shotcrete lining and internal walls

The sprayed concrete lining and internal walls were considered elastic. The shotcrete lining is 500 mm thick and the internal walls 300 mm thick. Given concrete parameters were: Young's modulus 21 GPa and Poisson's ratio equal to 0.15.

Initial conditions

Initial stresses were obtained by means of the

Table 1 Soil parameters used in the Hardening Soil Model

Soil parameter	Symbol	Unit	Sand		Clay
			Medium	Dense	
	N (SPT)	Blows/30 cm	N= 5 –15	N = 15-45	N = 5-15
Young's modulus at 50% strain level	E_{50} (*)	MPa	60	70	50
Unloading-reloading Young's modulus	E_{ur} (*)	MPa	150	200	150
Oedometer modulus	E_{oed} (*)	MPa	50	60	50
Cohesion	c	kPa	10	10	60
Peak friction angle	ϕ	degrees	35	38	26
Dilatancy angle	ψ	degrees	5	5	2
Poisson's ratio	ν		0.2	0.2	0.2
Janbu's parameter relating	m		0.5	0.5	0.5
modulus to stress level					
Initial stress ratio	K_0		0.426	0.384	0.562
Tensile strength cut-off		kPa	0	0	0
Hyperbolic parameter	R_f		0.9	0.9	0.9

(*) related to reference stress pref = 100 kPa

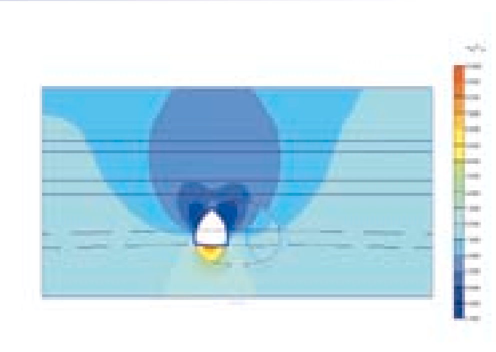


Figure 5
Vertical displacements, Excavation of right side-drift and closing temporary invert

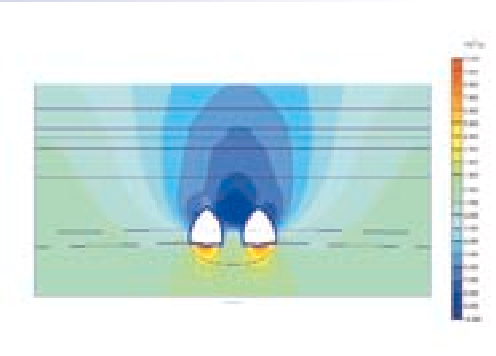


Figure 6
Vertical displacements, excavation of both side-drifts and closing temporary inverts

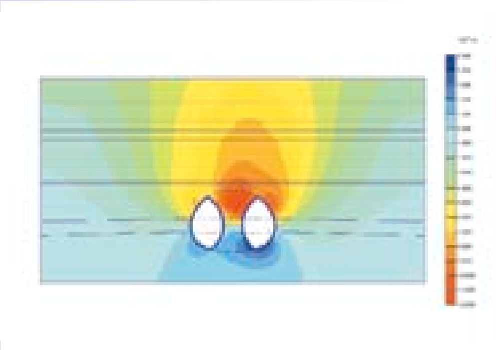


Figure 7
Vertical displacements, excavation of benches in both side-drifts and closing invert

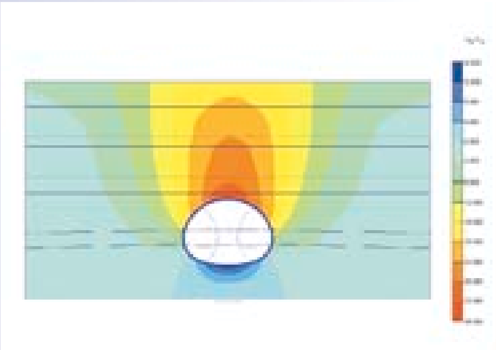


Figure 8
Vertical displacements, final stage

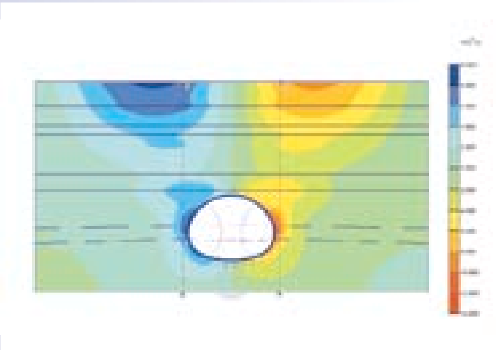


Figure 9
Horizontal displacements at the final construction stage

given initial stress ratio K_0. The groundwater level is assumed during construction to be below the inverted arch of the tunnel, due to effective dewatering.
After completion of the excavation the dewatering system will be turned off and the water level allowed to rise. This effect is evaluated later in this text.

Staged construction

The construction sequence includes the following stages:

1. Excavate the left side-drift first, apply the shotcrete lining and close the temporary invert;
2. Excavate the other side-drift, apply the shotcrete lining and close the temporary invert;
3. Excavate both temporary inverts of the side-drifts and excavate the bench, closing the vertical walls;
4. Excavate the top heading and shotcrete the tunnel crown and close the temporary invert;
5. Close the final inverted arch and demolish the internal walls
6. Apply the secondary concrete lining
7. Remove the dewatering system.

3D effects in the 2D analysis

To account for 3D effects in the 2D analysis, Plaxis enables the use of the so-called b method. This method reduces stresses by multiplying their values by a b coefficient less than unit, so that displacements would fit measurements before the face reaches a certain chainage. This process in Plaxis takes the following steps (Brinkgreve and Vermeer, 1998):

1. Generate initial stress field;
2. Deactivate the tunnel cluster (excavate) without activation of the tunnel lining and apply the stress coefficient: $\Sigma Mstage = 1 - \beta$
3. Activate the tunnel lining

The analyses covered in this report were carried out with $\beta = 0.6$, according to the designers' experience in similar cases.

PLAXIS

Horizontal displacements

Figure 9 and Figure 10 give maximum horizontal displacements that occur at the final construction stage. The maximum computed value is small as 14 mm.

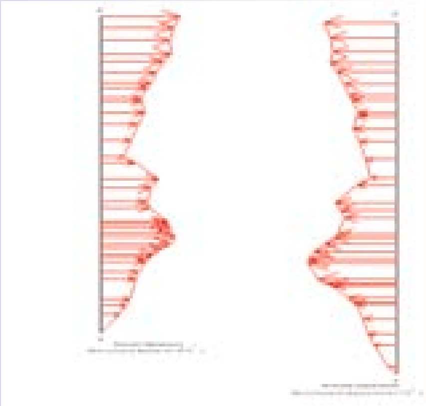


Figure 10
Horizontal displacements at both sides of the tunnel

Left side, section B', max displacement 7.6 mm (consistency in significant digits)

Right side, section A', max displacement 8.7 mm

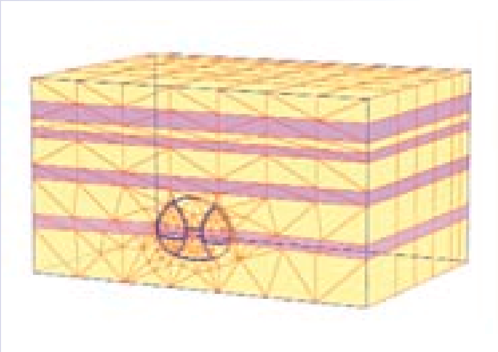
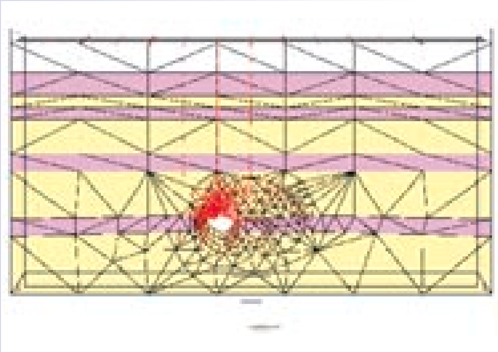


Figure 11
3D FE mesh



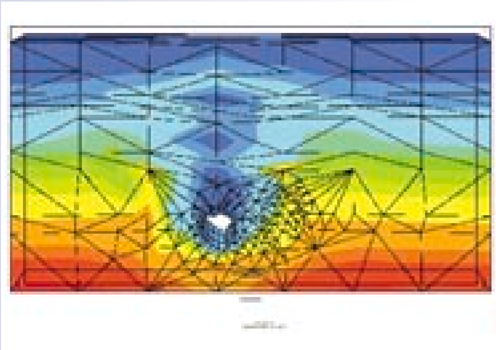


Figure 12
Total displacements side drift excavation, without forepoling

Figure 10 gives horizontal displacements profiles at both tunnel sides. Maximum values at these locations do not exceed 8 mm, and shall not affect nearby structures.

3D analysis

Plaxis 3D Tunnel was used for the first time by the authors to analyse face stability. Figure 11 shows the FE mesh using fifteen node isoparametric elements. Lateral boundaries are free to move vertically and the mesh bottom is fixed. Plate elements were used to model the tunnel lining and internal walls. Interface elements were used around the tunnel.

Geometry and computer time

The geometry of the mesh and the computer hardware has direct impact on computer time. The first attempt to carry out an analysis with all excavation stages in sequence in one single mesh resulted in an enormous stiffness matrix and processing time. The geometry and the FE mesh were reduced to fit in a suitable time and computer resources available. The 3D program requires much more memory and processing than the 2 D one. The first runs were carried out in Pentium II PC with 512 Mbytes of RAM and each excavation stage took four hours to run. As it was too long, the computer was replaced by a Pentium III 750 Mhz with 1 Mbyte of Ram and the processing time decreased to one hour for each excavation stage.

Tunnel face stability

The first stage of the 3D analysis lead to the collapse of the excavation (Figure 12). This was quite interesting because the 2D analysis was not able to predict this collapse. Therefore, it was decided to increase stability by pre-supporting the tunnel by means of a protection arch ahead of the excavation by means of forepoling. This forepoling consisted of two secant lines of 0.60 m diameter horizontal jet-grouting piles. This is a quite successful technique already used to stabilise several other tunnels in Brazil.

The pre-support was modelled by considering a 1 m thick layer of improved ground surrounding the tunnel-lining crown. Table 2 gives engineering parameters for this layer, according to previous Brazilian experience in similar cases.

Table 2 - Jet grouting engineering parameters

Young's modulus (MPa)	Cohesion (kPa)	Friction angle (°)
400	10	32

The stabilizing effect of this arch proved to be very good in further analysis, as it prevented the collapse of the tunnel.

Results

Vertical displacements

Figure 13 to Figure 15 give vertical displacements during excavation and the maximum obtained value was about 134 mm.

Conclusions

Plaxis 3D Tunnel analysis was capable to predict a tunnel collapse at the first side-drift excavation and the need of additional support to be installed ahead of the excavation. The pre-support consisted of horizontal jet-grouting piles, which lead to an improved arch that prevented collapse. The preliminary 2D analyses were not capable of predicting the need of the pre-support.

Reference

Brinkgreve, R.B.J. and Vermeer, P.A. Plaxis finite element code for soil and rock analysis, Version 7, Program Manual, 1998, Balkema, Rotterdam

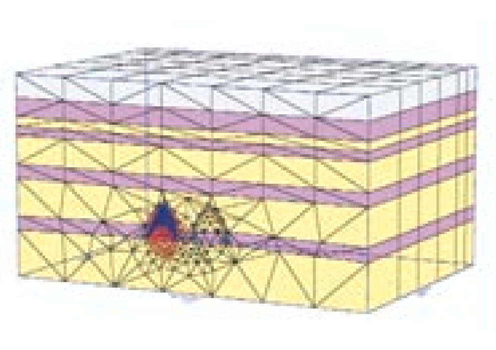
J.A.R, Ortiago, Federal University of Rio de Janeiro, Brazil

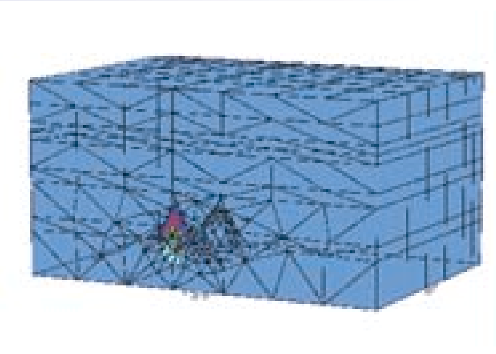
T.B. Celestino, University of São Paulo, São Carlos and Themag Engineering, Brazil

G. Re, Themag Engineering, São Paolo - Brazil

S.C. Luna, Terratek Ltd., Rio de Janeiro - Brazil

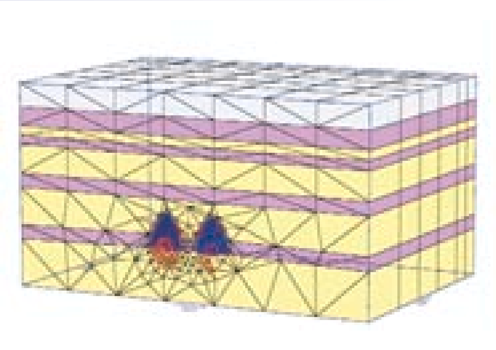
A.C. Sieira, Catholic University, Rio de Janeiro - Brazil

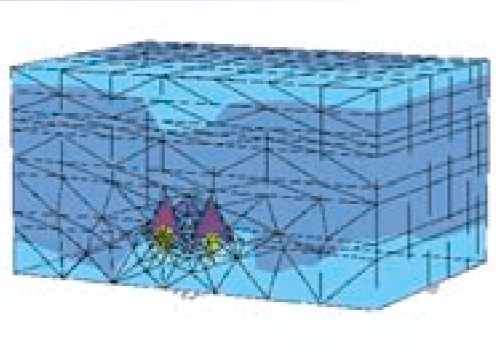




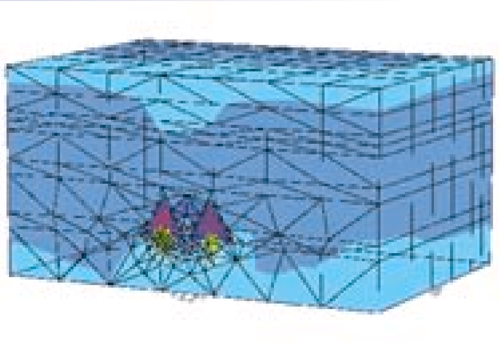
Extreme vertical displacement = 35,04 x 10-3m.

Figure 13 Vertical displacements, Phase 1. Left side drift excavation: (a) displacement vectors on top, (b) shaded areas at the bottom





Extreme vertical displacement = 36,45 x 10-3m



Extreme vertical displacement = 134,14 x 10-3m

Figure 15 - Vertical displacements, final construction stage

PLAXIS

Plaxis Practice II

Estimation of sand stiffness parameters from cone resistance

Introduction

This article discusses the estimation of stiffness parameters of silica sands from cone resistance for the use of Plaxis constitutive models. In the first part of this article correlation's are presented and formulae are proposed to estimate the stiffness for any combination of effective stress and cone resistance, which can be very helpfull if no laboratory test are available. In the second part of this article the relation between the relative density and the reference E_{50} is introduced. It is the authors opinion that this relation is directly proportional.

Use of Cone penetration Test

In the Cone penetration Test (CPT), a cone is pushed into the ground at a constant rate and continuos measurements are made of the resistance to penetration. Measurements are also made of the resistance of a surface sleeve. Additional sensors can be incorporated. The CPT has three main applications in the site investigation process:

- to determine sub-surface stratigraphy and to identify type of layers;
- to estimate geotechnical parameters;
- to provide results for direct geotechnical design.

This article discusses the second item above, focussed on the stiffness parameters of sandy soils. The correlations are generally based on tests on moderate compressible, normally consolidated (NC), unage and uncemented predominantly silica (quartz) sands.

Interpretation of CPT

Over the last decades there has been significant development in the use of CPT and this is reflected in the growth of the theoretical and experimental knowledge. Reference is made to one of the latest and most complete book on this subject from Lunne et al (1997). Most of the interpretation methods and correlation's are based on results of large laboratory calibration chamber test as well as field measurements. In general the estimated strength and deformation parameters of sand from CPT data is moderately reliable. Of coarse, there are still some aspects that influence the measured cone data and thus the interpretation. Regarding the nature of soil, the compressibility, cementation and particle size are of significant influence. Stiffness parameters in particular depend on uncertainties in situ such as, void ratio, effective stresses, stress history, drainage, and so on. Cone Penetration Testing in coarse grained material such as sand is generally drained. Under this condition there should be no generation and influence of excess pore pressures.

Stiffness parameters

The mechanical behaviour of soils can be modelled in Plaxis by different models at various degrees of accuracy. The Mohr-Coulomb (MC) model has a simple stress-strain relationship and involves only two input parameters, i.e. Young's modulus (E) and Poisson's ratio (ν). The Hardening-Soil (HS) model is an advanced model for simulation of soil behaviour. In contrast to the MC model, the HS model also accounts for stress-dependency of stiffness moduli. Stress-strain behaviour is described more accurately by using three different input stiffness':

- the triaxial loading stiffness: E_{50};
- the triaxial unloading stiffness: E_{ur};
- the oedometer loading stiffness: E_{oed}.

In the paragraphs below information is provided how to estimate the sand stiffness parameters from cone resistance for the MC model and HS model.

Estimation sand stiffness parameters from cone resistance

A reliable determination of sand stiffness parameters is of great practical interest in the view of the difficulties in obtaining deformation modulus from laboratory samples. Undisturbed samples are difficult to obtain using conventional techniques in cohesionless soils. Cone Penetration Testing have the advantage of time- and cost-effectiveness and provide information over the total depth.

Stiffness parameter: E_{50}

Research has shown that the drained Young's modulus in sand mainly depends on relative density, overconsolidation ratio and stress level. Figure 1 (Baldi 1989) presents a chart to estimate the secant Young's modulus (E'_s) of silica sands for an average axial strain of 0.1% for a range of stress histories and aging. This level of strain is reasonably representative for many well-designed foundations.

If we want tot make use of figure 1 we have to take a closer look at the relation between the $E'_s(\epsilon_{0.1\%})$ and de $E'_{50}(\epsilon_{50})$.

- The secant Young's modulus (E'_s) is derived from an average axial strain of 0.1%. This level of strain is in most cases lower than the strain at 50% of the mobilisation of deviator stress (ϵ_{50}) in a standard triaxial test. Triaxial tests on the Pleistocene quartz sand layers in Amsterdam show a e50 mostly in the range of 0.2% to 0.6%. The denser the sand the stiffer the response and the lower the ϵ_{50}.
- However, the results from standard triaxial test are often derived from disturbed and reconstituted samples. Where in situ a stiff response for all sands is expected during the first stage of shearing it is not in a triaxial test. Besides, recent improvements in small strain measurements indicate that stiffness derived from a standard triaxial test can be significantly underestimated by sources of error in external axial deformation measurements (Baldi 1988). In figure 2 the TA-test results of both conventional measurement and small strain measurement of a medium dense Pleistocene quartz sand are presented. The ϵ_{50} of the conventional measurement is 0.35% where the small strain measurement indicate a e50 of 0.15%.
- Given the discussion above the strain level (ϵ_{50}) is probably more than 0.1% and the E'_{50} might be overestimated.
- On the other hand most sands are slightly aged and overconsolidated while being considered as normally consolidated so the $E'50(\epsilon_{50})$ might be underestimated.
- Therefore it seems reasonable to assume that the above mentioned E's of recent NC sands can be compared to the E_{50} in de MC model and HS model.

Figure 1: Correlation between Young's modulus and (normalised) cone resistance.

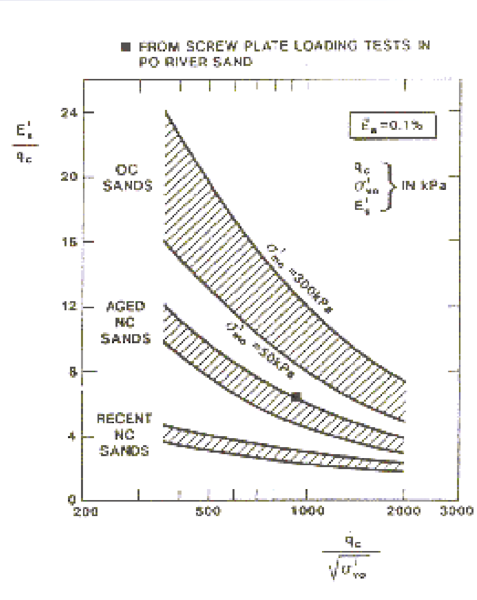
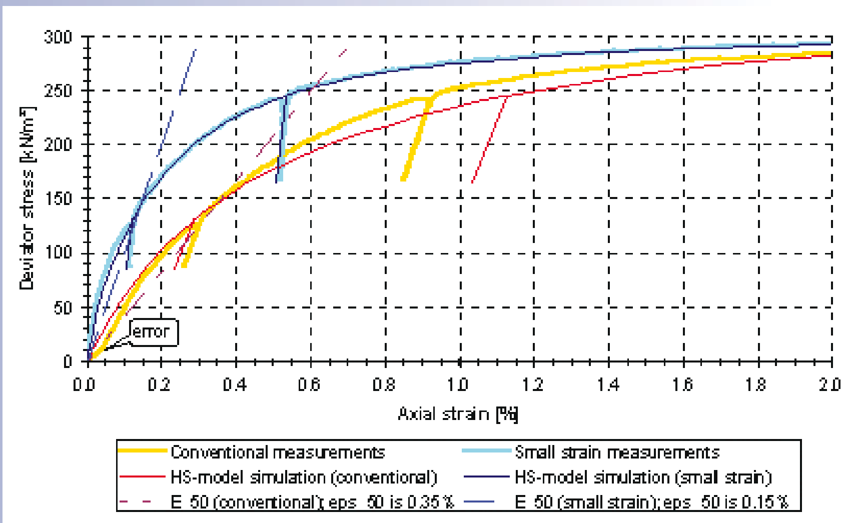


Figure 2: Standard triaxial test on medium dense pleistocene sand. The strains are measured both externally (on the loading ram) and locally by electrolevel inclinometer gauges on the sample. The results of the TA-test simulation with the HS-model are also presented in the figure.



It is also assumed that the E's of overconsolidated (OC) sands can be compared to the E_{ur} in the HS model. For many geotechnical constructions the level of strain in the subsoil due to unloading is less than 0.1%. The estimated value can be seen as an upper boundary. To derive the MC model and HS model parameters the following assumptions are made for all correlation's:

$\sigma'_1=\sigma'_v$

$\sigma'_3=\sigma'_h$

$k_{0;nc}=0.5$

$p^{ref}=100$

$mk_{0;nc}=0.5$

$\upsilon_{ur}=0.2$

The chart can be fitted by the following formula I. In this formula qc1 is the normalised cone resistance as presented in figure 1 and in formula II.

I): $\frac{E_s}{qc}\ \text{-}\propto (q_{c1})^{-0.5}$

II): $q_{C1}=\frac{q_c}{\sqrt{\sigma'_v}}$

III): $\frac{E_{ur}}{qc} \propto (qc_1)^{-0.75}$

Stiffness parameter: E_{oed}

Most correlation's between cone resistance and the stiffness refer to the drained constrained modulus, as found from the oedometer test. Figure 3 (Lunne 1983) presents a chart to estimate the tangent constrained modulus (M) of normally consolidated unaged and uncemented silica sands. Cementation is always a possibility in situ and is more likely in older sand deposits. Cementation reduces the compressibility and thereby increases the cone resistance.

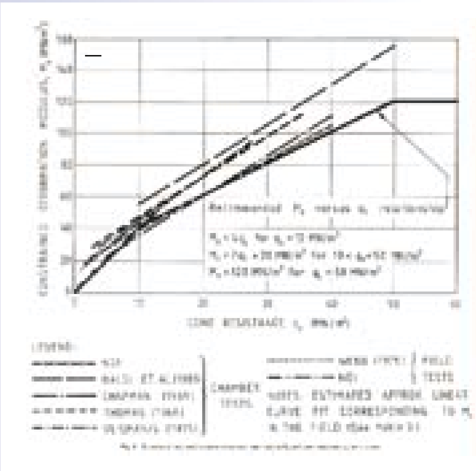


Figure 3: Correlation between constrained modulus and cone resistance.

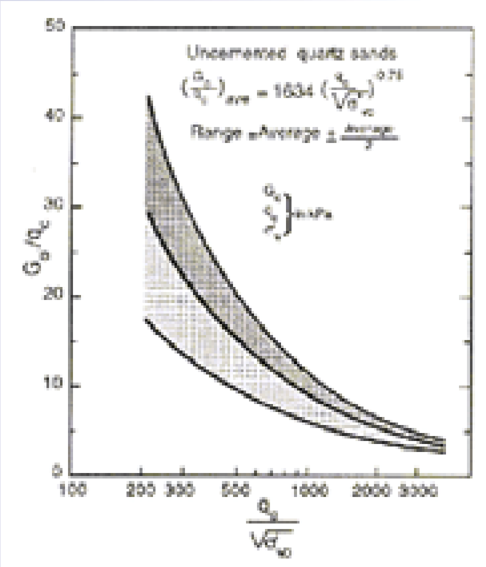


Figure 5.61 G_{max}/q_c (after Rix and Stokoe, 1992).

Figure 4: Correlation between small strain shear modulus and (normalised) cone resistance.

It is assumed that the above mentioned parameter M can be compared to the E_{oed} in the HS model. The well known formulae of the correlation with the cone resistance are presented below. In contrast to the other correlation's this parameter is only related to the cone resistance and not to the effective stress.

Stiffness parameter: E_{ur}

The small strain shear modulus (G_0) is related to the density and shear wave velocity and can also be estimated using empirical correlation's. The shear modulus is largest at very low strains and decreases with increasing strain level. It is generally been found that the maximum shear modulus is constant for shear strains less than 10^{-3}%. Figure 4 (Rix 1992) presents a chart to estimate the small strain modulus (G_0) for uncemented unaged cohesionless soils. Compressibility can have a significant influence on the correlation. More compressible sands appear to produce lower values of normalised cone resistance and hence higher values of G_0/qc.

From G_0 the E_0 can be determined assuming elastic behaviour and using Hooke's law. The E_0 is the small strain stiffness or dynamic stiffness and can be used as an upper boundary for the E_{ur} in the HS model. The chart can be fitted by formula III.

The stiffness parameters of sand for the MC model and HS model can be derived from the proposed analytical formulae from existing correlation charts as can be seen in figure 5. In

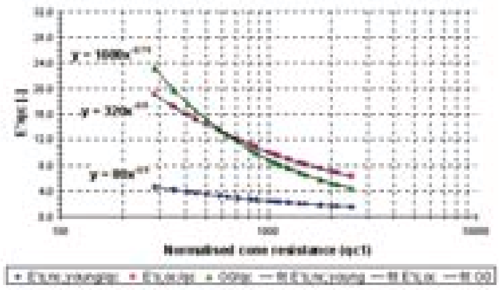


Figure 5: Proposed relation between stiffness parameters and (normalised) cone resistance.

table 1 some indicative (average) values are presented for several combinations of cone resistance and effective stress. These results can be compared to other tables with indicative values for the stiffness parameters (see for example chapter 12 from Lambe and Whitman (1979).

Proposed relation relative density and $E_{50;ref}$

For cohesionless material such as sand the relative density is often used as an intermediate soil parameter. The relative density (D_r) or density index (I_D) is defined as: $D_r=(e_{max}-e)/(e_{max}-e_{min})$, where: e_{max} and e_{min} are the maximum and minimum void ratios that can be determined in the laboratories using appropriate standards and parameter (e) is the in situ void ratio. Research on sand has shown that the cone resistance is controlled by the (relative) density, in situ stresses and compressibility. Compressibility can have a significant influence on the correlation. More compressible sands appear to have lower cone resistance than sands with low compressibility at the same relative density.

Several authors have suggested formulae to estimate the relative density from cone resistance. Kulhawy et al. (1990) suggested a formula for estimating the relative density which can be rewritten to formula IV. The same expression follows from substituting formula I and II into the general equation of the $E_{50;ref}$ in the HS model, see formula V. From these formulae can be concluded that the E_{50ref} is directly proportional to the relative density, see formula VI. The result from curve fitting (see figure 6) is a simple rule of thump as presented in formula VII. Note that the units of the constant and $E_{50;ref}$ should be the same because the relative density is dimensionless.

IV): $Dr \propto q_{c1}^{0.5} \propto qc^{0.5} \cdot \sigma'^{-0.25}_v$

V): $E_{50}^{ref} \propto E_{50} \cdot \sigma'^{-0.5}_v \propto q_c^{0.5} \cdot \sigma'^{-0.25}_v$

VI): $E_{50}^{ref} \propto D_r$

VII): $E_{50}^{ref} \approx 60 \cdot D_r$

Where:

Dr=relative density [-]

E_{50}^{ref}=HS-model references triaxial loading stiffness [MPa]

60 =constant [MPa]

Proportionality also applies to the other stiffness parameter as can be seen in figure 6.

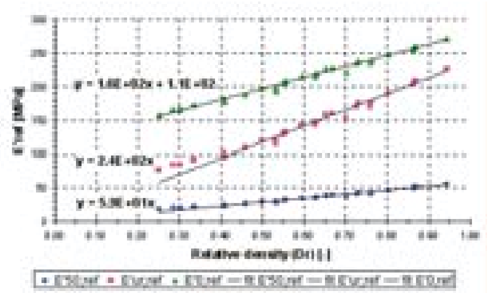


Figure 6:
Proportionality HS-model stiffness parameters and relative density.

Table 1: Indicative values sand stiffness parameters for MC-model and HS-model.

q_c [MPa]	σ'_v [kPa]	D_r (average) [-]	E_{50} MC-model [MPa]	E_{oed}	E_{ur}	E_0	$E_{50;ref}$ HS-model [MPa]	$E_{oed;ref}$	$E_{ur;ref}$	$E_{0;ref}$
5	20	0.70	12	20	48	99	38	45	151	222
5	50	0.53	15	20	60	140	30	28	120	198
5	**100**	**0.41**	**18**	**20**	**72**	**182**	**25**	**20**	**101**	**182**
15	50	0.90	26	50	104	184	52	71	208	261
15	**100**	**0.76**	**31**	**50**	**124**	**239**	**44**	**50**	**175**	**239**
15	200	0.63	37	50	147	310	37	35	147	219
25	**100**	**0.94**	**40**	**70**	**160**	**272**	**57**	**70**	**226**	**272**
25	200	0.80	48	70	190	352	48	49	190	249
25	400	0.67	57	70	226	457	40	35	160	228

PLAXIS

As a consequence it is also possible to select indicative values for classified sand based on the relative density, see table 2.

Conclusions

This article discussed the estimation of stiffness parameters of sand from cone resistance. The correlation's are generally based on tests on moderate compressible, normally consolidated, unage and uncemented predominantly silica sands. The main conclusions are summarised below:

- first, the stiffness parameters of sand for the MC and HS model can be derived from the analytical formulae based on existing correlation charts for any combination of effective stress and cone resistance;
- second, it can be concluded that the E50;ref is directly proportional to the relative density by a simple rule of thump, $E_{50;ref}=60 \cdot D_r$;
- third, it is possible to select indicative values for classified sand based on the relative density.

Literature:

- Baldi, G., Hight, D.W. and Thomas, G.E., "A Reevaluation of Conventional Triaxial Test Methods", Advanced Triaxial Testing of Soil and Rock, ASTM STP 977, ASTM, Philadelphia, 1988, pp. 219-263.
- Baldi, G., Bellotti, R., Chionna, V.N., Jamoilkowski, M. and Lo Presti, D.C.F. (1989) "Modulus of sands from CPT's and DMT's". Proceedings of the 12th International Conference on Soil Mechanics and Foundation Engineering, Rio de Janeiro, 1, 179-84, Balkema Pub., Rotterdam.
- Kulhawy, F.H. and Mayne, P.H. (1990) "Manual on estimating soil properties for foundation design". Electric Power Research Institute, EPRI, August, 1990.
- Lambe, T.W. and Whitman, R.V. (1979) "Soil Mechanics, SI version". John Wiley & Sons.
- Lunne, T., Robertson, P.K. and Powell, J.J.M. (1997) "Cone Penetration Testing in Geotechnical Practice". E & FN Spon.
- Lunne, T. and Christophersen, H.P. (1983) "Interpretation of cone penetrometer data for offshore sands". Proceedings of the Offshore Technology Conference, Richardson, Texas, Paper No.4464
- Rix, G.J. and Stokoe, K.H. (1992) "Correlation of initial tangent modulus and cone resistance". Proceedings of the international Symposium on Calibration Chamber Testing, Potsdam, New York, 1991, 351-62, Elsevier.

Table 2: Indicative HS-model reference stiffness for maximum relative density Conclusions

Description	$D_{r\,(min)}$ [-]	$D_{r\,(max)}$	$E_{50;ref}$ [MPa]	$E_{oed;ref}$	$E_{ur;ref}$	$E_{0;ref}$
very loose	0.00	0.15	16	8	66	146
loose	0.15	0.35	23	17	93	174
medium dense	0.35	0.65	35	37	138	212
dense	0.65	0.85	50	58	199	255
very dense	0.85	1.00	62	73	246	283

Contact: H.Lengkeek@witbo.nl

H.J. Lengkeek
Witteveen+Bos, The Netherlands

Users Forum

Applying loads in Version 8

The way loads are applied in Plaxis Version 8 is different from Version 7 and we have noticed that some users have difficulties to convert to the new system. In principle, the definition of the applied load has NOT changed:

Applied load = Load multiplier x Input value

In earlier versions the input values of loads were specified in the input program only and could not be changed during calculations, whereas load multipliers were used to apply or change loads when defining calculation phases. In Version 8 loads are still defined in the input program, but in the Initial Conditions they are automatically de-activated and the corresponding total multipliers are set to 1. When defining calculation phases, either the input values of the loads or the corresponding multipliers can be changed. This significantly enhances the flexibility of Plaxis, since it allows for many more combinations of loads that can be applied throughout an entire analysis. However, when converting Version 7 projects towards Version 8 users have to pay attention to the following:

PLAXIS

Since load are de-activated in the Initial Conditions, they have to be activated in the first calculation phase by means of Staged Construction, before they can be further applied using multipliers. Increasing multipliers directly in the first calculation phase results in zero loads, since the corresponding input values are still zero. In fact, it is better to adopt the new way of applying loads, i.e. keeping the multiplier at 1 and applying or changing loads using Staged Construction rather than using multipliers to apply or change loads.

Serious error in Material Models manual

In the early version of the Plaxis Version 8 manual there was a large misprint in the sense that all greek characters were missing. Meanwhile, our printer has corrected the misprint and has sent new manuals directly to clients. Users that have not yet obtained a new manual should ask the contact person in their company. If the new manual has not arrived at all, please send a message to info@plaxis.nl.

Apart from this misprint, there is a serious error in Eq. 5.14 on page 5.8. The stress-dependent oedometer stiffness is a function of σ_1 (major principal stress) rather than σ_3. The equation should read as follows:

$$E_{oed} = E_{oed}^{ref} \left[\frac{c\cos\varphi - \sigma'_1 \sin\varphi}{c\cos\varphi + p^{ref}\sin\varphi} \right]^m$$

Please correct this in your manual. The equations for E50 (5.2) and Eur (5.4) have correctly been written as a function of $\sigma 3$ in the manual.

We apologize for this error and hope that it did not cause too much confusion.

Update version 7.21 for version 8 users

Because the conversion from 7 to 8 is not very smooth and may cause some inconsistency, we have decided to make a special version 7 for Plaxis 8 users who like to finish existing projects with version 7. This special version (7.21) reads the new V8 hardlock key instead of the old V7 key. Version 7.21 can be downloaded freely from our internet site www.plaxis.nl (user service > downloads). V8 users that still have a V7 hardlock key are kindly requested to return their V7 key to Plaxis bv.

Ronald Brinkgreve

ACTIVITIES

6-9 January, 2003
Computational Geotechnics + Dynamics (English)
Berkeley, USA

19-22 January, 2003
Short course on Computational Geotechnics (English)
Noordwijkerhout, The Netherlands

19-21 February, 2003
Short course on Computational Geotechnics (English)
Seoul, Korea

10-12 March, 2003
Short course on Computational Geotechnics (German)
Stuttgart, Germany

23-26 March, 2003
International course for experienced Plaxis users (English)
Noordwijkerhout, The Netherlands

8-10 April, 2003
Short course on Computational Geotechnics (English)
Manchester, England

28-30 April, 2003
Short course on Computational Geotechnics (Italian)
Napoli, Italy

31 July–2 August, 2003
Experienced Plaxis users course (English)
Singapore

For more information on these activities please contact:

PLAXIS bv, P.O. Box 572
2600 AN DELFT, The Netherlands
Tel: +31 15 2517 720, Fax: +31 15 2573 107
E-mail: info@plaxis.nl