PLAXIS

2D - Version 8

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PREFACE

Development of PLAXIS began in 1987 at the Technical University of Delft as an initiative of the Dutch Department of Public Works and Water Management. The initial goal was to develop an easy-to-use 2D finite element code for the analysis of river embankments on the soft soils of the lowlands of Holland. In subsequent years, PLAXIS was extended to cover most other areas of geotechnical engineering. Because of continuously growing activities, a company named PLAXIS b.v. was formed in 1993. In 1998, the first PLAXIS version for Windows was released. In the mean time a calculation kernel for 3D calculations was being developed. After several years of development the PLAXIS 3D Tunnel program was released in 2001.

Main goals and objectives: PLAXIS is intended to provide a tool for practical analysis to be used by geotechnical engineers who are not necessarily numerical specialists. Quite often practising engineers consider non-linear finite element computations cumbersome and time-consuming. The PLAXIS research and development team has addressed this issue by designing robust and theoretically sound computational procedures, which are encapsulated in a logical and easy-to-use shell. As a result, many geotechnical engineers world-wide have adopted the product and are using it for engineering purposes.

CUR consortium: Research and development is supported by the Center for Civil Engineering Research and Codes (CUR). A consortium of more than 30 European companies contribute financially to these developments and a CUR committee checks the efficiency and quality of the resulting software. The CUR consortium also provides a valuable link with engineering practice. Future developments are discussed within the CUR consortium and feedback is provided after new releases of the code.

Scientific network: The development of PLAXIS would not be possible without world-wide research at universities and research institutes. To ensure that the high technical standard of PLAXIS is maintained, the development team is in contact with a large network of researchers in the field of geomechanics and numerical methods. Direct support is obtained from a series of research centres:

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National University of Singapore	Prof. H. Tan
Parahyangan Catholic University (ID)	Prof. P. Rahardjo

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The editors

Disclaimer:

PLAXIS is a finite element program for geotechnical applications in which soil models are used to simulate the soil behaviour. The PLAXIS code and its soil models have been developed with great care. Although a lot of testing and validation have been performed, it cannot be guaranteed that the PLAXIS code is free of errors. Moreover, the simulation of geotechnical problems by means of the finite element method implicitly involves some inevitable numerical and modeling errors. The accuracy at which reality is approximated depends highly on the expertise of the user regarding the modelling of the problem, the understanding of the soil models and their limitations, the selection of model parameters, and the ability to judge the reliability of the computational results. Hence, PLAXIS may only be used by professionals that possess the aforementioned expertise. The user must be aware of his/her responsibility when he/she uses the computational results for geotechnical design purposes. The PLAXIS organisation cannot be held responsible or liable for design errors that are based on the output of PLAXIS calculations.

Overview of the full manual

General information

PLAXIS VERSIONS, COURSES AND USER SERVICES

Update Versions and new releases of PLAXIS, containing various new features, are generally released annually. In addition, courses and user meetings are organised on a regular basis. Registered users receive detailed information about new developments and other PLAXIS activities. Valuable user information is provided by means of the PLAXIS bulletin and the Internet site *www.plaxis.nl*.

2D Professional Version: A large range of geotechnical problems may be analysed using this high capacity version. It is possible to use extensive 2D finite element meshes. The Professional Version is supplied as an extended package, including static elastoplastic deformation, advanced soil models, consolidation, updated mesh and steady-state groundwater flow.

2D Dynamics module: The PLAXIS Dynamics module is an add-on module to the PLAXIS 2D Professional Version. This module may be used to analyse vibrations in the soil and their influence on nearby structures. Excess pore pressures can be analysed. Liquefaction, however, is not considered due to the complexity of the physical processes involved and the limitations of the PLAXIS models in this respect. Future versions are intended to handle liquefaction in more detail.

3D Tunnel Program: This program is especially designed for the analysis of tunnel projects, but it also enables the analysis of a larger range of other geotechnical problems. 3D finite element meshes with a reasonable accuracy can be generated. The 3D Tunnel Program is supplied as an extended package, including static elastoplastic deformation and advanced soil models.

3D Foundation Program: This program is designed for the analysis of raft foundations, but it also enables the analysis of pile-raft foundations and offshore foundations. Large 3D finite element meshes can be generated. The 3D Foundation Program is supplied as an extended package, including static elastoplastic deformation and advanced soil models.

Demo Version: A Demo Version of PLAXIS Version 8, PLAXIS 3D FOUNDATION and PLAXIS 3D TUNNEL is available for interested persons who wish to learn about the program features and capabilities before ordering the Educational Version or the Professional Version. The Demo Version is based on the pre- and postprocessor of the Professional Version, but is limited in functionality as only a single soil material data set can be defined and only a limited number of construction stages can be calculated for each problem. The postprocessor is fully functional, except for the printing capabilities, which have been disabled.

Educational Version: For universities and education centres, an Educational Version of the listed PLAXIS programs is available at a reduced price.

Courses on Computational Geotechnics: Courses dealing with both theoretical and practical aspects of computer modelling in geotechnical engineering are provided on a regular basis in several countries, with support from the scientific network. In these courses, applications exercises and case studies are included during which participants have the opportunity to carry out various types of computer analyses. Although PLAXIS

is intensively used, the courses are not primarily intended to teach the details of this particular computer program. The main aim of these courses is to teach finite element modelling in geotechnical engineering, with direct applications to practical problems.

Bulletin: An international bulletin, issued twice a year, is provided to all registered PLAXIS users. This bulletin contains descriptions of practical projects in which PLAXIS has been used, backgrounds on the use of advanced soil models, information on new developments, hints for optimised usage of the program and a diary of activities.

Internet site: In addition to the information provided in the magazine, the internet site *http://www.plaxis.nl* contains more general information about PLAXIS, information on courses and meetings, answers to frequently asked questions and a discussion group for users.

User support: Limited free technical support is provided by e-mail. A professional helpdesk is available for clients who wish to obtain prompt and extensive technical and scientific support. This support is provided on the basis of a support contract.

For more information on products and users services, contact:

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SHORT REVIEW OF FEATURES

PLAXIS Version 8 is a finite element package intended for the two-dimensional analysis of deformation and stability in geotechnical engineering. Geotechnical applications require advanced constitutive models for the simulation of the non-linear, time-dependent and anisotropic behaviour of soils and/or rock. In addition, since soil is a multi-phase material, special procedures are required to deal with hydrostatic and non-hydrostatic pore pressures in the soil. Although the modelling of the soil itself is an important issue, many tunnel projects involve the modelling of structures and the interaction between the structures and the soil. PLAXIS is equipped with features to deal with various aspects of complex geotechnical structures. A brief summary of the important features of the program is given below.

Graphical input of geometry models: The input of soil layers, structures, construction stages, loads and boundary conditions is based on convenient CAD drawing procedures, which allows for a detailed modelling of the geometry cross-section. From this geometry model, a 2D finite element mesh is easily generated.

Automatic mesh generation: PLAXIS allows for automatic generation of unstructured 2D finite element meshes with options for global and local mesh refinement. The 2D mesh generator is a special version of the Triangle generator, which was developed by Sepra[1].

High-order elements: Quadratic 6-node and 4th order 15-node triangular elements are available to model the deformations and stresses in the soil.

Plates: Special beam elements are used to model the bending of retaining walls, tunnel linings, shells, and other slender structures. The behaviour of these elements is defined using a flexural rigidity, a normal stiffness and an ultimate bending moment. A plastic hinge may develop for elastoplastic plates, as soon as the ultimate moment is mobilised. Plates with interfaces may be used to perform realistic analyses of geotechnical structures.

Interfaces: Joint elements are available to model soil-structure interaction. For example, these elements may be used to simulate the thin zone of intensely shearing material at the contact between a tunnel lining and the surrounding soil. Values of interface friction angle and adhesion are generally not the same as the friction angle and cohesion of the surrounding soil.

Anchors: Elastoplastic spring elements are used to model anchors and struts. The behaviour of these elements is defined using a normal stiffness and a maximum force. A special option exists for the analyses of prestressed ground anchors and excavation supports.

Geogrids: Geogrids (or geotextiles) are often used in practice for the construction of reinforced embankments or soil retaining structures. These elements can be simulated in

[1] Ingenieursbureau Sepra, Park Nabij 3, 2267 AX Leidschendam (NL)

PLAXIS by the use of special tension elements. It is often convenient to combine these elements with interfaces to model the interaction with the surrounding soil.

Tunnels: The PLAXIS program offers a convenient option to create circular and non-circular tunnels using arcs and lines. Plates and interfaces may be used to model the tunnel lining and the interaction with the surrounding soil. Fully isoparametric elements are used to model the curved boundaries within the mesh. Various methods have been implemented to analyse the deformations that occur as a result of various methods of tunnel construction.

Mohr-Coulomb model: This robust and simple non-linear model is based on soil parameters that are well-known in engineering practice. Not all non-linear features of soil behaviour are included in this model, however. The Mohr-Coulomb model may be used to compute realistic support pressures for tunnel faces, ultimate loads for footings, etc. It may also be used to calculate a safety factor using a 'phi-c reduction' approach.

Advanced soil models: In addition to the Mohr-Coulomb model, PLAXIS offers a variety of advanced soil models. As a general second-order model, an elastoplastic type of hyperbolic model, called the Hardening Soil model, is available. To model accurately the time-dependent and logarithmic compression behaviour of normally consolidated soft soils, a Creep model is available, which is referred to as the Soft Soil Creep model. In addition to these soil models, a special model is available to analyse the anisotropic behaviour of jointed rock. Detailed information on these models can be found in the Material Models Manual.

User-defined soil models: A special feature in PLAXIS Version 8 is the user-defined soil models option. This feature enables users to include self-programmed soil models in the calculations. This option is primarily of interest for researchers and scientists at universities and research institutes, but it may also be useful for practising engineers. In coming years, validated and well-documented user-defined soil models may become available via the internet.

Soil tests: The soil test option in PLAXIS is a convenient procedure to check the behaviour of the selected soil material model with the given material parameters. After entering the model parameters, the user can quickly simulate several standard soil tests and compare the results against the results from actual laboratory tests.

Steady state pore pressure: Complex pore pressure distributions may be generated on the basis of a combination of phreatic levels or direct input of water pressures. As an alternative, a steady-state groundwater flow calculation can be performed to calculate the pore pressure distribution in problems that involve steady flow or seepage.

Excess pore pressures: PLAXIS distinguishes between drained and undrained soils to model permeable sands as well as nearly impermeable clays. Excess pore pressures are computed during plastic calculations when undrained soil layers are subjected to loads. Undrained loading situations are often decisive for the stability of geotechnical structures.

Automatic load stepping: The PLAXIS program can be run in an automatic step size and automatic time step selection mode. This avoids the need for users to select suitable

load increments for plastic calculations and it guarantees an efficient and robust calculation process.

Arc-length control: This feature enables accurate computations of collapse loads and failure mechanisms to be carried out. In conventional load-controlled calculations the iterative procedure breaks down as soon as the load is increased beyond the peak load. With arc-length control, however, the applied load is scaled down to capture the peak load and any residual loads.

Staged construction: This powerful PLAXIS feature enables a realistic simulation of construction and excavation processes by activating and deactivating clusters of elements, application of loads, changing of water tables, etc. This procedure allows for a realistic assessment of stresses and displacements as caused, for example, by soil excavation during an underground construction project.

Consolidation analysis: The decay of excess pore pressures with time can be computed using a consolidation analysis. A consolidation analysis requires the input of permeability coefficients in the various soil layers. Automatic time stepping procedures make the analysis robust and easy-to-use.

Safety factors: The factor of safety is usually defined as the ratio of the failure load to the working load. This definition is suitable for foundation structures, but not for sheet-pile walls or embankments. For this latter type of structure it is more appropriate to use the soil mechanics definition of a safety factor, which is the ratio of the available shear strength to the minimum shear strength needed for equilibrium. PLAXIS can be used to compute this factor of safety using a 'phi-c reduction' procedure.

Parameter variation: This feature assists the user in checking the sensitivity of the calculation results to variations in the material parameters. Based on a given range of possible values for the material data input parameters Plaxis will automatically calculate the resulting variation in selected output values, such as displacements, stresses or structural forces.

Updated Lagrangian analysis: Using this option, the finite element mesh is continuously updated during the calculation. For some situations, a conventional small strain analysis may show a significant change of geometry. In these situations it is advisable to perform a more accurate Updated Lagrangian calculation, which is called *Updated Mesh* in PLAXIS. This option is available for all types of calculations.

Presentation of results: The PLAXIS postprocessor has enhanced graphical features for displaying computational results. Values of displacements, stresses, strains and structural forces can be obtained from the output tables. Plots and tables can be sent to output devices or to the Windows® clipboard to export them to other software.

Stress paths: A special tool is available for drawing load-displacement curves, stress and strain paths, stress-strain diagrams and time-settlement curves. The visualisation of stress paths provides a valuable insight into local soil behaviour and allows a detailed analysis of the results of a PLAXIS calculation.

NEW FEATURES IN VERSION 8

PLAXIS Version 8 has several new features compared to its 2D predecessor, Version 7. In general, the extensions involve new modelling options, calculation facilities, output features and a general improvement of 'user friendliness' and consistency. Some of the new features are described below.

Modelling options: The modelling of tunnels in the Tunnel Designer has been extended. In addition, the Hinge option for plates has been extended with rotation springs to model plate connections that are neither pinned nor fully fixed. Regarding the modelling of geomaterials, the anisotropic Jointed Rock model, as introduced in the PLAXIS 3D Tunnel program, is also made available in Version 8. With the HSsmall model a Hardening Soil like material model including small-strain hardening has become available. For undrained materials, the input of Skempton's B-parameter is used to model partially undrained behaviour. Other new features in Version 8 are the user-defined soil models option and the soil tests option (see page viii).

Calculation facilities: The staged construction facility has been extended to allow for the activation and change of external loadings. Load multipliers are still available to increase globally load systems, but the general procedure is now to change the input values of the loads in the staged construction mode and to keep the multipliers at unity. This system improves the possibilities of varying external loads and combining individual loads with excavation or construction stages. In addition, a new and more robust calculation kernel has been implemented for steady-state groundwater flow calculations. Consolidation calculations have been extended to allow for staged construction in time and also for large deformation effects (Updated Mesh). Structural elements have been improved by the inclusion of an enhanced plasticity formulation for plates and anchors.

Output features: Animations are now a standard option within Version 8. The animations include displacements and forces in structural elements. Output for stresses and strains has been extended to all Cartesian components, and a selection can be made from total and effective stresses. In cross-section plots, normal stress components are automatically integrated to provide a total force. In addition to structural forces for each phase, envelopes of structural forces over multiple calculation phases are available for plates and geogrids. A report generator has been implemented to provide a report of input data and output results that can be further edited in Word.

HARDWARE SPECIFICATIONS

System requirements: The PLAXIS program runs on Pentium PC's using Windows®NT 4.0 with at least Service Pack 4, Windows® 2000 or Windows® XP Professional (32 bits) as the operating system.

Hard disk: To install the PLAXIS package, at least 60 Mb of hard disk space must be available. In addition, a minimum workspace of 500 Mb is recommended, but for large projects more disk space may be required.

Random Access Memory (RAM): The minimum recommended amount of RAM installed in the computer is 512 Mb in all Windows® environments. The use of extra memory in addition to the minimum requirements results in a faster operation of the program and/or a larger maximum number of elements that can be used in finite element models.

Video modes: The PLAXIS program requires a minimum screen resolution of 800 x 600 pixels and a 256 colour palette. However, it is advisable to use a screen resolution of at least 1024 x 768 pixels and a 16 bit colour palette.

Mouse: A graphical pointing device (mouse) with two or three buttons is required. A 'wheel mouse' is not required, but can be useful to view tables of output data.

Output devices: Graphical and tabulated output can be printed on all modern types of laser or inkjet printers (including colour printers). Printing is fully controlled by the Windows® operating system. For more information on the installation of output devices reference should be made to the respective manuals.

PC network: A single version of PLAXIS may be installed on a PC network. However, single versions can only be run on one workstation at a time using a local hardlock key. A multiple licence network version is available upon special request. This requires the installation of a multiple licence hardlock key on the network server and additional network software.

INSTALLATION

The PLAXIS package is installed by using an easy-to-use installation program. The program acts like a wizard and guides the user through the installation settings. During installation the files from the installation CD are decompressed and copied to the appropriate locations on the hard disk. At the end of the installation procedure, a new program group *Plaxis 8.x* is automatically created in the *Programs* sub-menu of the *Start* menu. The installation of PLAXIS Version 8 does not affect other PLAXIS products. Installation under the various Windows® versions as mentioned in the system requirements is similar. Make sure that you have the *Administrator* rights to be able to update the Windows registry.

Program installation

- Insert the PLAXIS installation CD in the CD-ROM drive. Within 10-20 seconds an introduction screen should appear. If this is not the case, then:
  - Click on the Windows® <Start> button and select *Run...* from the *Start* menu.
  - In the *Open* edit field type "D:\AUTORUN.EXE" (assuming that the installation is executed from CD-ROM drive D).
  - Press the <OK> button to start the introduction screen.
- Choose the option “Install PLAXIS Version XX”.
- Follow the instructions on the screen.
- Before starting the PLAXIS program, make sure that the hardlock key is correctly installed.

Local Hardlock key installation

PLAXIS continuously checks for the presence of the hardlock key that is included in the package. This key must be inserted in a USB port of the computer. Alternatively, a parallel key is available. Normally a device driver for the hardlock key is installed during the setup. If, for some reason, the installation of the hardlock key driver fails the user can install it manually as described in the section troubleshooting on page xiv.

Network Hardlock key installation

Alternatively it is possible to use a shared hardlock over the network. This needs a specical hardlock as well as a special driver to be installed which is not done automatically by the the setup. The document “network.pdf” that can be found on the Plaxis installation CD describes what procedure to follow in order to install the network hardlock key. Please note that a network hardlock key can be installed on any computer in the network with Windows® 2000, XP or 2003 as the operating system.

PROGRAM UNINSTALL AND REINSTALL

Should you wish to uninstall or reinstall PLAXIS you can either use the Windows' Add/Remove programs utility from the Control Panel or re-run the installation from the PLAXIS Installation CD. You can now choose whether to remove the program from your computer, repair a currently installed version or modify the currently installed version.

TROUBLESHOOTING

In exceptional cases the installation program fails to install the PLAXIS package. Some possible error messages during the execution of the program are:

- The program starts with the message "*No Hardlock found.*" and closes immediately.
- The program starts with a message related to the dynamic link library HLVDD.DLL.
- During installation the message "*IDAPI configuration cannot be merged.*" occurs.
- When importing a PLAXIS version 7.x project the message "*An error occurred while attempting to initialize the Borland Database Engine*" occurs.

Additionally the following problems may occur under Windows 2000:

- The mesh generator fails to generate a mesh though all the possible solutions have been applied.
- The calculation hangs directly after starting. In the bottom left corner of the calculation window the status of the calculation shows "Profile…".

The appropriate actions to be taken on these messages are described below:

No Hardlock found

For some reason the automatic hardlock installation has failed. In this case, the user has to install the hardlock drivers manually.

Manual hardlock key driver installation:

- Open a Command Prompt box and go to the sub-directory "Hardlock" of the directory where the PLAXIS package was installed (by default C:\Program Files\Plaxis8x).
- If a PLAXIS hardlock key was installed before, it should be de-installed before installing the new key. Therefore type the command: "HLDINST -remove".
- To install the new hardlock, type the command: "HLDINST -install".
- All options of the manual hardlock installation program can be viewed by typing the command "HLDINST –help".

The new hardlock key drivers are downwards compatible, which means that they can also be used successfully in combination with old PLAXIS versions.

The program starts with a message related to the dynamic link library HLVDD.DLL

The program finds an old hardlock key driver before it finds the newly installed driver. Most likely there is still a hardlock key driver of PLAXIS version 7.x on the system.

The best solution would be to manually remove all files called HLVDD.DLL from your computer and manually reinstall the hardlock key driver as described in the previous troubleshooting topic.

An error occurred while attempting to initialize the Borland Database Engine

The Borland Database Engine (BDE) could not be found. Most likely its files have been previously deleted using, for example, the Windows Explorer instead of the Add/Remove Programs option of Windows. In this case the BDE could not be re-installed and the user needs to make some changes in the Windows Registry to overcome this problem. It should be noticed that this procedure is for Windows experts only and that PLAXIS b.v. does not take any responsibility for side effects that may be caused by a manual uninstall procedure.

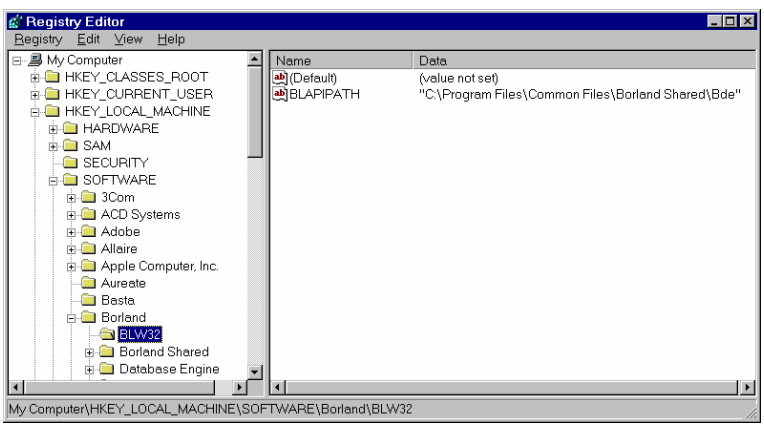

Figure I Registry editor

To be able to re-install the Borland Database Engine, the following steps should be taken.

- Click on the <Start> button on the status bar and select *Run...* from the *Start* menu.
- In the *Open* edit field type "REGEDIT" to start the Registry Editor program.
- In the tree view at the left double-click the "HKEY_LOCAL_MACHINE"; it will expand.
- In the newly expanded sub keys double-click the "Software" key to expand it.
- In the newly expanded sub keys double-click the "Borland" key to expand once more.
- Select the key "BLW32" and delete it.
- Select the key "Database Engine" and delete it as well.

- Close the Registry Editor program by choosing the *Exit* option from the Registry menu.

PLAXIS must now be re-installed. This should also install the BDE normally.

Windows 2000 or higher: Mesh generation fails or calculation hangs directly after starting

Both problems are related to the Windows' temporary directory stored in the TEMP environment variable. By default, under Windows 2000, this TEMP variable contains a rather long path ("C:\Documents and Settings\<username>\Local Settings\Temp" for the case where Windows has been installed on drive "C") causing the problem.

The solution is to set the TEMP variable to a shorter, existing, path. To do this:

- Go to the Windows Start Menu and successively select "Settings", "Control Panel" and "System".
- In the "System Properties" window that has now appeared choose the last tab sheet called "Advanced".
- From this tab sheet choose the middle option "Environment variables"
- In the "Environment variables" window choose from the uppermost list the variable called TEMP and select the "Edit" button in order to change its value.
- Set the TEMP variable's value to, for example, "C:\TEMP".
- Close all windows.
- Make sure the newly defined temporary directory exists. If this is not the case, then create the directory using the Windows Explorer.

Note that the above procedure may have to be repeated after installing a Windows Service Pack.