PLAXIS

3D TUNNEL - version 2

Edited by

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PREFACE

PLAXIS 3D TUNNEL is a three-dimensional PLAXIS program, developed for the analysis of tunnels and underground constructions. It is part of the PLAXIS product range, a suite of finite element programs that are used worldwide for geotechnical engineering and design. The development of PLAXIS began in 1987 at Delft University of Technology as an initiative of the Dutch Ministry of Public Works and Water Management (Rijkswaterstaat). The initial purpose 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, the PLAXIS company (PLAXIS bv) was formed in 1993. In 1998, the first PLAXIS 2D deformation and stress analysis program for Windows was released. In the meantime a calculation kernel for 3D finite element calculations was developed which resulted in the release of the PLAXIS 3D TUNNEL program in 2001. In 2003 PLAXIS 3D FOUNDATION was released as the second three-dimensional PLAXIS program, focused on the analysis of foundation constructions including raft foundations and offshore structures.

Main goals and objectives: PLAXIS is intended to provide a practical analysis tool for use by geotechnical engineers who are not necessarily numerical specialists. It is often the case that practical engineers consider non-linear finite element computations cumbersome and too time-consuming for regular analyses. 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 are using the code in practical applications.

CUR consortium / PDC / Sounding Groups: Research and development of the PLAXIS software is supported by the Centre for Civil Engineering Research and Codes (CUR), in which a consortium of more than 30 companies participate. This consortium is currently known as the PLAXIS Development Community (PDC). The consortium contributes financially to the PLAXIS developments and the CUR committee checks the efficiency and quality of the resulting software products. The consortium provides a valuable link with engineering practice. Moreover, future developments are discussed within Sounding Groups of specialists and feedback is provided from these groups after new releases.

Scientific support: The development of PLAXIS would not be possible without world-wide research at many universities. In order to ensure that the high technical standard of PLAXIS is maintained, the development team conducts regular surveys of publications within the wide field of geomechanics and numerical methods. In addition, direct support is obtained from the following centres of research:

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Norwegian Geotechnical Institute (N)	Dr. L. Andresen
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The editors

COMPLETE SET OF MANUALS

General information

Disclaimer:

PLAXIS 3D TUNNEL is a finite element program for geotechnical applications and applications in underground construction in which models are used to simulate the soil behaviour. The program code and soil models have been developed with great care. Although a lot of testing and validation has been performed, it cannot be guaranteed that the PLAXIS 3D TUNNEL code is free of errors. Moreover, the simulation of geotechnical problems by means of the finite element method implicitly involves some inevitable numerical and modelling 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 3D TUNNEL 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 or tunnel design purposes. The PLAXIS organisation cannot be held responsible for design errors that are based on the output of PLAXIS calculations.

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 projects may be analysed using this high capacity Version. It is possible to use finite element meshes consisting of thousands of elements. The 2D 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. It is possible to analyse the influence of vibrations on soil and structures. Excess pore pressures can be included, liquefaction, however, is not considered due to the complexity of the involved models. Future Versions may have models that can handle liquefaction.

2D Demo Version: A Demo Version of PLAXIS 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.

PLAXFLOW: The PLAXIS Groundwater flow program is an independent program for the analysis of steady-state and transient groundwater flow. PLAXFLOW incorporates sophisticated models for saturated/unsaturated groundwater flow, using the well-known "Van Genuchten" relations between pore pressure, saturation and permeability. PLAXFLOW provides state-of-the-art facilities to incorporate time-dependant boundary conditions. It also enables the user to combine results with the PLAXIS 2D professional version for deformation and stability analysis.

3D Tunnel Program: This powerful 3D program is especially designed for the analysis of tunnel projects, but it can also analyse a large range of other geotechnical projects. It is possible to use finite element meshes consisting of thousands of elements. The 3D Tunnel Program is supplied as an extended package, including static elastoplastic deformation, advanced soil models, consolidation and safety analysis.

3D Foundation Program: This program is designed for the analysis of raft foundations, but it also enables the analysis of simple 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.

Trial Version: On special request, PLAXIS programs that are not available as a Demo Version can be ordered as a Trial Version for a limited period of time at highly reduced licence cost.

Educational Version: For universities and education centres, where the programs will be used for non-commercial projects, 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 given on a regular basis in several countries, with support from the scientific network. In these courses, application 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 the computer programs. 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 bulletin, the internet site *http://www.plaxis.nl* contains more general information about PLAXIS, including 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 users services, contact:

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SHORT REVIEW OF FEATURES

The PLAXIS 3D Tunnel program is a geotechnical finite element package specifically intended for the three-dimensional analysis of deformation and stability in tunnel projects. Geotechnical applications require advanced constitutive models for the simulation of the non-linear, time-dependent and anisotropic behaviour of soils and 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. The PLAXIS 3D Tunnel is equipped with special features to deal with the numerous aspects of complex geotechnical structures. A brief summary of the important features of the program is given below.

Graphical input of cross-section 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 and accurate modelling of the major geometry cross-section. From this cross-section model a 3D finite element mesh is easily generated.

Automatic mesh generation: The PLAXIS 3D Tunnel program allows for an 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]. From this 2D mesh, a 3D mesh is generated by a linear extension in the third dimension.

Volume elements: Quadratic 15-node wedge elements are available to model the deformations and stresses in the soil.

Plates: Special plate elements are used to model the bending of tunnel linings, shells, retaining walls 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 may be used together with interfaces to perform realistic analyses of tunnel projects and other geotechnical applications.

Interfaces: These joint elements are needed for calculations involving soil-structure interaction. They may be used to simulate, for example, 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 that are not necessarily the same as the friction angle and cohesion of the surrounding soil may be assigned to these elements.

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.

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

Geogrids: Geogrids (or geotextiles) are often used in practice for the construction of reinforced embankments or retaining soil structures. They can be simulated in the Tunnel program 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 3D Tunnel program offers a convenient option to create circular and non-circular tunnels composed of arcs and lines. Plates and interfaces may be added 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 practical methods have been implemented to analyse the deformations that occur due to the construction of the tunnel.

Mohr-Coulomb model: This robust and simple non-linear model is based on soil parameters that are known in most practical situations. 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: The PLAXIS 3D Tunnel program offers a variety of soil models in addition to the Mohr-Coulomb model. As a general second-order model, an elastoplastic type of hyperbolic model is available, which is called the Hardening Soil model. To analyse 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. More detailed information on these models can be found in the Material Models Manual.

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 almost 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 3D Tunnel 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 by themselves 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 the excavation of a tunnel or an underground construction.

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 structures 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. The PLAXIS 3D TUNNEL program can be used to compute this factor of safety using a 'phi-c reduction' procedure.

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 3D TUNNEL. This option is available for all types of calculations.

Presentation of results: The PLAXIS postprocessor has enhanced graphical features for displaying computational results. Exact values of displacements, stresses, strains and structural forces can be obtained from the output tables. Plots and tables can be send 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 paths and stress-strain diagrams. Particularly the visualization of stress paths provides a valuable insight into local soil behaviour and enables a detailed analysis of the results of a PLAXIS 3D Tunnel calculation.

HARDWARE SPECIFICATIONS

System requirements: The PLAXIS 3D Tunnel program runs on Pentium PC's using Windows®NT 4.0 with at least Service Pack 4, Windows® 2000 or Windows® XP, but preferably it should use Windows® 2000.

External drives: For installation purposes a CD-ROM compatible drive is required.

Hard disk: To install the PLAXIS 3D Tunnel program, at least 60 Mb of hard disk space must be available. In addition, a minimum workspace of 100 Mb is recommended, but for large projects more disk space will be required.

Random Access Memory (RAM): The minimum recommended amount of RAM installed in the computer is 256 Mb in Windows® NT or 2000 environments, or 512 Mb in Windows® XP. 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 3D Tunnel program requires a minimum screen resolution of 800 x 600 pixels and a 256 colour palette. A video card with at least 1 Mb video memory must be installed. The best performance is obtained using a screen resolution of 1024 x 768 pixels and a 16 bit colour palette. This is only possible when at least 2 Mb video memory is available on the video card.

Mouse: A graphical pointing device (mouse) with two or three buttons is required.

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 the PLAXIS 3D Tunnel program 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 3D Tunnel program 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 is automatically created in which the program icons appear. 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 please:
  - Click on the Windows® <Start> button and select *Run...* from the *Start* menu.
  - In the *Open* edit field type "R:\AUTORUN\AUTORUN3DT.EXE" (assuming that the installation is executed from CD-ROM drive R).
  - Press the <OK> button to start the introduction screen.
- Choose the option “Install 3D Tunnel Version XX”.
- Follow the instructions on the screen.
- Before starting the PLAXIS program, make sure that the hardlock key is correctly installed.

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 the parallel port of the computer. Alternatively, a USB-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 *Support* section of the PLAXIS website: http://www.plaxis.nl/.

The latest version of the hardlock driver can always be downloaded from this location. The hardlock key drivers are downwards compatible, which means that they can also be used successfully in combination with older PLAXIS versions.

Network Installation

The installation of a network license hardlock on a server requires a manual install of the hardlock drivers on the server. This process is described in detail in the document *network.pdf* that can be found on the installation CD.

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 rerun 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 INSTALLATION

In some exceptional cases the installation program fails to successfully install the PLAXIS 3D Tunnel program. Some possible error messages during the execution of the program can be:

- The program starts with the message "*No Hardlock found.*" and closes immediately.
- The program starts with the message "*The procedure entry point HLM_CHECKEXPDATE could not be located in the dynamic link library HLVDD.DLL.*"

The appropriate actions to be taken on these messages are described on the PLAXIS website: http://www.plaxis.nl/ in the *Support* section.