PLAXIS

3D FOUNDATION

Version 1.5

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PREFACE

PLAXIS 3D FOUNDATION is a three-dimensional PLAXIS program, developed for the analysis of foundation constructions including raft foundations and offshore structures. 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. PLAXIS 3D FOUNDATION is the second three-dimensional PLAXIS program and was developed in cooperation with TNO.

Goals and objectives: In 1999, the PLAXIS company and the Numerical Mechanics group of TNO decided to start a research cooperation project on foundations. Main cause to start such a project was the increasing interest for pile-raft foundations. This type of foundation may lead to significant economical benefits compared to classical pile or raft foundations. Pile-raft foundations require advanced deformation-based tools to analyse the individual contributions of the piles and the raft in the total bearing capacity of the full foundation. The complementary competences of TNO (structural mechanics and numerical methods) and PLAXIS bv (soil modelling and numerical methods for geotechnical engineering) were essential for such a project, since foundations form the interaction between buildings (structures) and the soil. As a part of the research project a special purpose finite element computer program was developed. The current PLAXIS 3D FOUNDATION program is the result of further elaboration and operationalisation of this research program. It is a first step to the analysis of pile-raft foundations, although the main aim of the current program is to model classical raft foundations and to a lesser extent offshore foundations. In the meantime, further research is performed on a more advanced modelling of piles and pile-raft foundations. Results of this further research will be implemented in future updates of the PLAXIS 3D FOUNDATION program.

Support: The research required to develop the PLAXIS 3D FOUNDATION program was performed in the framework of a BTS cooperation project, with financial support from the Dutch Ministry of Economic Affairs.

CUR consortium / PDC: 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. Future developments are discussed within the consortium and feedback is provided after new releases.

Scientific network: The development of PLAXIS and PLAXIS 3D FOUNDATION 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 geo-mechanics and numerical methods. Direct support is obtained from a series of research centres:

Delft University of Technology (NL)	Prof. F. Molenkamp
Institut für Geotechnik, Uni Stuttgart (D)	Prof. P.A. Vermeer
BundesAnstalt für Wasserbau (D)	Dr. M. Heibaum, Dr. R. Schwab
Geodelft (NL)	J.M. van Esch, M. Visschedijk
TNO (NL)	Dr. G.J. Schreppers
Technical University of Graz (A)	Prof. H.F. Schweiger
Laboratoire 3S, Univ. of Grenoble (F)	Prof. M. Boulon, Prof. C. Viggiani
University of Oxford (UK)	Dr. H.J. Burd
University of Glasgow (UK)	Prof. M. Karstunen, Prof. S. Wheeler
University of Colorado at Boulder (USA)	Prof. S. Sture
Massachusetts Institute of Technology (USA)	Prof. A.J. Whittle
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Norwegian Univ. of Science and Tech (N)	Prof. S. Nordal
Norwegian Geotechnical Institute (N)	Dr. L. Andresen
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The editors

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IMPORTANT WARNING AND 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 modeling 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 organization cannot be held responsible or liable for design errors that are based on the output of Plaxis calculations.

The English version of PLAXIS products (software, documentation, DISCLAIMER, etc.) is leading. Other language versions of these products are intended solely as a convenience to the users. The most up-to-date version of the English manual is available at the PLAXIS website: http://www.plaxis.nl . A list of translated terms used in the non-English program, can be found in the manual of the non-English version. Although great care has been taken to translate these products, the PLAXIS organization cannot be held responsible or liable for translation errors. Furthermore, due to the time required for translations, translated products are generally available at a later stage than the original English version or may not be available at all. Hence, the most up-to-date version of any product is always the English version.

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 yet included in this version, but is intended to become available in future versions.

2D Demo Version: A Demo Version of PLAXIS is available for those interested in learning about the program features and capabilities before ordering the Professional Version. The Demo Version is based on the pre- and postprocessor of the Professional Version, but is limited in the number of material sets and calculation phases that can be defined. The postprocessor can be evaluated on the basis of the tutorial examples that are installed in the examples directory, or on user defined examples.

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-dependent 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 program is designed for the analysis of tunnel calculations, but it also enables the analysis of a large range of other geotechnical problems. Large 3D finite element meshes 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 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.

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

Trial Versions: 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.

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 products and users services, contact:

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SHORT REVIEW OF FEATURES

PLAXIS 3D FOUNDATION is a finite element package intended for the three-dimensional deformation analysis of foundation structures. Foundations form the interaction between an upper structure and the soil. Settlements depend on local soil conditions and on the construction method. Especially for pile-raft foundations there is an important interplay between the pile, the raft and the soil to support the forces from the upper structure. In this interplay deformations are a key factor. Such a situation can only be analysed effectively by means of three-dimensional finite element calculations in which proper models are incorporated to simulate soil behaviour and soil-structure interaction. The PLAXIS 3D FOUNDATION program offers these facilities. A brief summary of the most important features is presented below.

New features: Version 1.5 of the PLAXIS 3D FOUNDATION program offers additional functionality compared to previous releases. New features include the *K0 procedure*, consolidation analysis, the soft soil creep (SSC) model, the possibility to prescribe volumetric strains in soil clusters and improvements in the pore pressure generation procedure. Further features include the output of results in stress points and the generation of curves based on this data, as well as simplified output of the structural forces in volume piles.

Graphical input of projects: A project geometry is modelled using a top view approach. The input of soil data, 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. From this geometry a 3D finite element mesh is generated.

Boreholes: Soil layers are defined by means of boreholes. Multiple boreholes can be placed in the geometry to define a non-horizontal soil stratigraphy or inclined ground surface. PLAXIS automatically interpolates layer and ground surface positions in between the boreholes.

Work planes: Structures are defined in horizontal work planes. Multiple work planes can be defined to create complex foundations, multi-storey basements and relevant parts of the upper structure.

Automatic mesh generation: The PLAXIS 3D FOUNDATION program allows for an automatic generation of unstructured 2D finite element meshes based on the top view. The 2D mesh generator is a special version of the Triangle generator, which was developed by Sepra[1]. There are options for global and local mesh refinement. From this 2D mesh, a 3D mesh is automatically generated, taking into account the soil stratigraphy and structure levels as defined in the bore holes and work planes.

Volume elements: Quadratic 15-node wedge elements are available to model the deformations and stresses in the soil. Due to non-horizontal soil stratigraphy, these

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

elements may degenerate once to 13-node volume elements or twice to 10-node tetrahedral elements.

Beams: Foundations may involve structural objects like walls, floors and beams. A special type of beam element can be used to model slender one-dimensional objects with a significant flexural rigidity. The stiffness of these elements is defined using elastic stiffness properties or non-linear deformation curves.

Walls and floors: Special plate elements can be used to model raft foundations, basements, walls and floors of buildings, as well as other parts of structures. The behaviour of these elements is defined using elastic stiffness properties or non-linear deformation curves (M-κ and N-ε diagrams).

Interfaces: These joint elements can be added to walls to allow for a proper modelling of soil-structure interaction. Interfaces may be used to simulate, for example, the thin zone of intensely shearing material at the contact between a wall 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.

Piles: Circular and square piles can be defined using a pile designer. Massive piles are composed of volume elements whereas hollow piles are composed of wall elements. Pile-soil interaction can be modelled using interfaces around the pile.

Loads: The program allows for various types of loads (point loads, line loads, distributed loads) that could be applied in the model. Different loads and load levels can be activated independently in each construction stage.

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 bearing capacities and collapse loads of footings, as well as other applications in which the failure behaviour of the soil plays a dominant role.

Advanced soil models: As a general second-order model, an elastoplastic type of hyperbolic model is available, which is called the Hardening Soil model. This model allows for plastic compaction (cap hardening) as well as plastic shearing due to deviatoric loading (friction hardening). 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. More detailed information on these models can be found in the Material Models Manual.

Structural behaviour: Structural behaviour may be defined as linear elastic material orthotropy or as non-linear elastic force-deformation curves. This applies to beams, walls, floors and springs. Geometric orthotrophy of plates with a particular profile can also be emulated to a certain extend.

Steady-state pore pressure: Complex pore pressure distributions may be generated on the basis of the input of water levels or pore pressure distributions in the bore holes.

Excess pore pressure: PLAXIS distinguishes between drained and undrained soils to model permeable sands as well as almost impermeable clays. Excess pore pressures are computed when undrained soil layers are subjected to loading.

Automatic load stepping: The PLAXIS 3D FOUNDATION program can be run in an automatic step-size selection mode. This avoids the need for users to select suitable load increments for non-linear 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 load.

Staged construction: This PLAXIS feature enables a realistic simulation of construction and excavation processes by activating and deactivating clusters of elements, application of loads, changing of water pressure distributions, etc. This procedure allows for a realistic assessment of stresses and displacements as caused, for example, by the construction and loading of a foundation.

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.

Preview option: A convenient preview option is available to check model and calculation settings in a graphical 3D environment. Since 3D calculations can be quite time consuming, it is important to check the model carefully before starting the calculation process.

Presentation of results: The PLAXIS postprocessor has enhanced 3D 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 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 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 FOUNDATION calculation.

HARDWARE SPECIFICATIONS

System requirements: The program runs on Pentium PC's using Windows® NT4 (Service Pack 4), Windows® 2000 or Windows® XP; Windows® 2000 is the preferred operating system.

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

Processor: A 2.0 GHz processor or faster is recommended.

Hard disk: To install the 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 256 MB in Windows® NT or 2000 environments, or 512 MB in Windows® XP. The use of extra memory over the minimum requirements, up to 2 GB, can result in a faster operation of the program and/or a larger number of elements that can be used in finite element models.

Video modes: The PLAXIS 3D FOUNDATION program requires a minimum screen resolution of 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 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. A network hardlock can only be installed on a computer using a Windows operating system (either workstation or server), and requires the TCP/IP protocol.

INSTALLATION

The 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 is automatically created in the *Programs* sub-menu of the *Start* menu. The installation 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 installation CD in the CD-ROM drive. Within 10-20 seconds an introduction screen should appear. If this is not the case, then:
  - Click the Windows® *Start* button and select *Run...* from the *Start* menu.
  - In the *Open* edit field type "D:\AUTORUN\AUTORUN.EXE" (assuming that the installation is executed from CD-ROM drive "D").
  - Click the *OK* button to start the introduction screen.
- Choose the option *Install Version XX*.
- Follow the instructions on the screen.
- Before starting the 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 the program you can either use the Windows' *Add/Remove* programs utility from the *Control Panel* or re-run the installation from the 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.

TROUBLE SHOOTING INSTALLATION

In some exceptional cases the installation program fails to successfully install the PLAXIS 3D FOUNDATION 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.