

Slope stability software for soft soil engineering

D-GEO STABILITY

Deltares systems



User Manual

Deltares
Enabling Delta Life 

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1 General Information

1.1 Foreword

More than a century ago notorious slope failures have marked the start of geo-engineering. A major slope failure in Berlin in 1879, massive slope failures during construction of the Panama Canal in 1909, a quay collapse in Gothenburg Sweden in 1916, and a dramatic railway embankment collapse in The Netherlands in 1918. These events triggered authorities and engineers to better understand what really happened. In a swift response scientific committees established by the authorities stated that water pressure is likely a major culprit.

In 1925 Prof. Terzaghi astonished these committees with the first basic book on the principles of soil mechanics, and since then the profession of geo-engineering got real impetus.

Though in Sweden Fellenius designed an elegant and practical circular method to evaluate slope stability around 1916, already in 1846 Alexander Collin had shown the relation of water and strength of clay and proved that a slip surface is actually a cycloid. Collin's work was forgotten. It was rediscovered a century later and applied in Lorimer's method. Since then Taylor, Bishop, Morgenstern-Price, Janbu and Spencer have developed practical methods, and de Josselin de Jong improved the fundamentals by the double sliding mechanism. The existence of various methods reveals that there is no absolutely correct method and special care and experience are required when applying them. Recently, Teunissen showed us that induced non-uniformity, which is inherent to localization and fundamental in slip line failure modes, still represent space for further improvement. The challenge is to incorporate the proper slip mechanism and its relation to local deformations, without losing the elegance of the Fellenius' original method.

Was in earlier times the determination of slope safety a cumbersome handwork of tedious calculations, since around the 1960s numerical analysis on the first generation computers led the way to self-controlling, fast, flexible and relatively cheap computer codes, such as D-GEO STABILITY, now suited to run on modern hard- and software. An experienced supporting team takes care of catching up with relevant scientific progress and new developments such as risk engineering, geostatistics and random field approach, and the latest computer art of processing and visualization. The philosophy after D-GEO STABILITY is to keep it user-friendly and up-to-date such that a sufficiently large family of happy users will allow for continuity and further progress.

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1.2 Preface

D-GEO STABILITY is developed specifically for geotechnical engineers. It is a tool used to analyze slope stability in two-dimensional geometry. D-GEO STABILITY has proved itself a powerful tool for solving soil stability problems in everyday engineering practice. D-GEO STABILITY's graphical interface requires just a short training period, allowing users to focus their skill directly on the input of sound geotechnical data and the subsequent evaluation of the calculated stability of a slope.

D-GEO STABILITY comes as a standard module that can be extended with other modules to fit more advanced applications:

- ◇ Spencer model
- ◇ Uplift Van model



- ◇ Reliability model
- ◇ Probabilistic random field model

1.3 Features in standard module

This section contains an overview of the features in D-GEO STABILITY for the calculation of slope stability. For more information on this topic see the Reference and Background sections of this manual.

1.3.1 Soil modeling

- ◇ *Multiple layers*

The two-dimensional soil structure can be composed of several soil layers with an arbitrary shape and orientation. The deep soil layer is assumed to be infinitely thick. Each layer is connected to a certain soil type. It is possible to combine layers with different material models.
- ◇ *Geotextiles*

It is possible to model geotextiles with arbitrary inclination. The stability of a slope will increase if a slip plane intersects with a geotextile.
- ◇ *Nails*

It is possible to model nails with arbitrary inclination. The resisting moment of the soil will increase due to the nails.
- ◇ *Drained and undrained behavior*

Soil parameters are defined per soil type. Besides input of a cohesion c and internal friction angle, a direct relationship between shear stress and normal stress can be applied by entering a so-called *sigma-tau curve*. Alternatively, it is possible to use an undrained shear strength s_u , either by direct input of the measured value, or by input of the ratio with the pre-consolidation stress. It is possible to combine layer with different models.

1.3.2 Loads

D-GEO STABILITY provides the following options for defining loads:

- ◇ *Pore Fluid load*

Separate piezometric level lines can be specified to determine hydrostatic pore pressures distributions and the phreatic level in each layer. The volumetric weight of water can be adjusted. It is also possible to include the effect of suction above the phreatic line in calculations. (Excess) pore water pressures can be defined with piezometric level lines or with a degree of consolidation per soil layer. It is also possible to use an external file containing a net of nodes in which the pore pressure is known, generated with the water flow model MSeep.
- ◇ *Permanent and temporary surcharges*

Permanent point loads can be positioned anywhere in the geometry. Distributed loads can be positioned as permanent or temporary loads (very short loading time) on the surface of the soil structure. For these loads, an angle of dispersion can be defined while a degree of consolidation must be specified for the temporary loads.
- ◇ *Earthquake*

In order to simulate the effects of an earthquake, certain coefficients can be entered to introduce additional moment and excess pore pressure and to modify the free water movement.
- ◇ *Tree on Slope*

The effect of wind on trees rooted in the slope can be modeled.

1.3.3 Slip plane determination

A limit equilibrium method like Bishop, Uplift-Van or Spencer determines the safety factor along a given slip plane. In a geometry, an infinite amount of slip planes can occur. Therefore, a search algorithm needs to find which slip plane is representative.

The default search algorithm is the “grid” method. By defining a square with center points and a number of tangent lines, all combinations of possible slip planes are investigated. If the representative plane is on the edge of the grid, it is an option to move the grid in that direction to ensure a minimum.

This grid based procedure works for all implemented limit equilibrium methods. It becomes very time consuming if the search space is very large (Bishop, Van) or if an unconstrained slip plane is sought after using Spencer’s method. The Genetic Algorithm offers an alternative that is faster in case of a large search space. The precision of the result depends on the input parameters.

In short, two optimization techniques are available to find the representative slip plane:

- ◇ the *Grid* method calculates all combinations of center points and tangent lines, if applicable.
- ◇ the *Genetic algorithm* finds the representative plane through an algorithm that is more efficient in a large search space, with many degrees of freedom for the slip plane.

1.3.4 Results

After analysis, D-GEO STABILITY can present results in a tabular and graphical form. The tabular report contains an echo of the input data, concise information on all calculated slip surfaces and (if required) detailed information on the critical slip surface.

It is possible to view graphical output of the distribution of various stress components along the (critical) slip plane, as well as view graphs of the water pressure and vertical effective stress along verticals.

A probabilistic analysis will yield a graph with influence factors. Influence factors are in fact the result of an automated sensitivity analysis, and show how much uncertainties in specific parameters contribute to the overall uncertainty in the factor safety.

1.4 Features in additional modules

1.4.1 Spencer model

This model is intended for special (non-circular) stability analysis. It determines a single safety factor for a user-defined position of an arbitrary shaped slip surface.

1.4.2 Uplift Van model

This model is intended for usual uplift stability analysis. It determines automatically the lowest safety factor, assuming a horizontal plane, bounded by two circles.

1.4.3 Reliability based design methods

With D-GEO STABILITY's reliability module, it is easy to switch between the following design methods:

- ◇ **Mean value analysis**
Calculation of the safety factor, using fixed mean values of the parameters.
- ◇ **Design value analysis**
Calculation of the safety factor, using fixed design values of the parameters. D-GEO STABILITY derives these unfavorable lower or upper limits from stochastic parameter distributions and partial factors.
- ◇ **Probabilistic design**
Calculation of the safety factor (mean value), a probability of failure and influence factors. The probabilistic FORM (*First Order Reliability Method*) method uses variations of stochastic parameters for strength and pore pressure. A system of probabilistic defaults enables an approximate reliability analysis without any additional input of stochastic data. The defaults are largely based on the Dutch NEN design standard. D-GEO STABILITY uses the defaults also to calculate approximate design values from mean values or approximate mean values from design values.
- ◇ **Probabilistic random field model**
The Bishop probabilistic random field model performs a probabilistic slope stability analysis, in order to determine the probability that the safety factor is less than the required value. Furthermore, this model calculates sensitivity factors, which are used by the computer program PCRING for the analysis of dike systems. The computation model is based on Bishop's method of slices for equilibrium analysis, random field modeling of spatial variability of soil strength and pore pressures, and first order second moment probabilistic reliability analysis. The probability of the external water level can be taken into account optionally.

1.4.4 Product integration

D-GEO STABILITY is an integrated component of the Deltares Systems tools. This means that it is possible to exchange relevant data with MGeobase (central project environment), D-SETTLEMENT formerly known as MSettle (transient settlements), MSeep (seepage) and D-GEO PIPELINE formerly known as MDrill (pipeline installation). Besides the exchange of input data, D-GEO STABILITY can also import a settled geometry calculated by D-SETTLEMENT or a pore pressure load generated by MSeep. MGeobase is used to maintain a central project database with measurements, soil properties and geometry. MGeobase offers power tools to create geotechnical profiles and longitudinal cross-sections automatically from measurements. MGeobase can also use D-GEO STABILITY to perform a batch stability analysis for multiple cross-sections.

1.5 History

D-GEO STABILITY was first named MStab and developed at GeoDelft/Deltares in 1987/1988 with the support of both Oranjewoud BV and the Road and Hydraulic Engineering Division of the Ministry of Transport and Public Works.

MStab version 1.0 was first released in 1988 and has since been upgraded a number of times, each time adding new features and improving its user interface to suit the new demands of its users.

MStab version 6.0 was released in 1995. This version included a major alteration to the geometry file and a more flexible way of adding and deleting points and layer boundaries. Furthermore, each soil layer now had to be assigned a soil type, while soil properties were in turn assigned to a soil type. As a result, these properties were linked to the soil layers through the soil type. Lastly, traffic loads became temporarily distributed loads with a degree of consolidation for each layer.

MStab version 7.0 was released in 1998, the first Windows version of MStab.

MStab version 8.0 (1999) contains further improvements, including the option of non-circular slip planes.

MStab version 9.0 (2001) includes an enhanced module for geometrical modeling, and improved versions of the user manual and on-line Help have been released.

MStab version 9.7 (2002) includes separately licensed modules for the general Spencer method, and for the new “Uplift Van” and “Uplift Spencer” methods. The new methods determine automatically a slip plane in cases with excessive interface water pressures.

MStab version 9.8 (2004) contains the following new features: *Reliability Analysis* module, *Bishop Probabilistic Random Field* module, calculated undrained shear strength, combination of material models.

MStab version 9.10 (August 2007) contains the following new features: Tree on slope, Zone plot, Pseudo values shear strength model and Horizontal balance check.

D-GEO STABILITY version 10.1 was released in 2011. The name of the program has changed: D-GEO STABILITY replaces MStab. A genetic algorithm might be used to find the minimum center point in a calculation. It is possible to find a Spencer slip plane with a genetic algorithm. The correlation coefficients of soil groups (probabilistic calculation) is adjusted. The error in *Horizontal Balance* calculation above phreatic line is solved. It is possible to calculate with soil nails.

D-GEO STABILITY version 14.1 (2014). A Spencer plane has a zone number as well (*Zone Plot* option). The shear stresses per slice for Fellenius model are now correct. The use of nails with the Uplift-Van method is now possible.

D-GEO STABILITY version 15.1 (April 2015). This version implements some improvements:

- ◇ For *Horizontal Balance* model, a negative safety factor could be found. This is now fixed.
- ◇ A toggle button is implemented in the *View Input* (Figure 2.5), to switch between same scale for X and Y-axis and not same scale for X and Y-axis.
- ◇ In the *Calculation Options* window (Figure 5.1), a range for the horizontal position of the

entry point of the critical slip plane can be specified.

- ◇ The *Help* file is no more available; clicking on the *Help* button will open the *User Manual* in which a search by specific word can be performed.
- ◇ The background section of the manual is improved for circular slip plane ([section 16.2](#)).

D-GEO STABILITY version 16.1 (January 2016). With this version, license(s) can be borrowed for a certain period allowing working without connection to the licence server (see [Figure 3.6](#) for more information). In this version, the critical angle for nails works properly ([section 4.5.3](#)).

D-GEO STABILITY version 16.2 (December 2016). This release contains several changes with regard to previous versions that can cause different calculation results. Most relevant changes are:

- ◇ Method Uplift-Van incorporates the change of water pressures along the horizontal part of the slip plane ([section 16.3.4](#)). The resulting force is added to the horizontal equilibrium. The effect of the driving moment of this horizontal part is also added to the equilibrium.
- ◇ The Su-calculated model is also implemented conform the SHANSEP method. Over-consolidation is represented through a “yield stress field” ([section 4.2.3](#)). Using a reference line ([section 4.4.5](#)), one can model the effect of an elevation as well as an excavation. If no reference line is given, the current effective stress is used as the pre-load stress.
- ◇ The dilatancy angle (ψ) is added to the material properties ([Figure 4.22](#)). If $\varphi = \psi$, the earlier implemented associative material behavior is represented. By entering a different value for psi, one can perform a non-associative analysis (see also [section 19.1](#)).

1.6 Limitations

When working with D-GEO STABILITY, the following limitations apply:

- ◇ D-GEO STABILITY can automatically determine the position of a critical slip circle. This search algorithm is accurate as long as:
 - the distribution of center points and tangent lines is reasonably fine;
 - the location of the initial trial grid will yield a slip circle at the right slope;
 - the shape of the true slip surface does not deviate significantly from the assumed shape.
- ◇ D-GEO STABILITY discards the friction following from the horizontal stress component at the vertical slice interfaces. D-GEO STABILITY therefore assumes that the orientation of a slip surface is predominantly horizontally.
- ◇ D-GEO STABILITY assumes values for the total vertical stress that are estimated from the composed weight of a vertical column of soil and from the additional load spread. The influence of load spread by a non-horizontal soil surface is therefore not taken into account.
- ◇ Application of D-GEO STABILITY is allowed as long as the two-dimensional plane-strain assumption applies.

See also [section 20.4.2 “Assumptions and limitations of the Reliability module”](#).

1.7 Minimum System Requirements

The following minimum system requirements are needed in order to run and install the D-GEO STABILITY software, either from CD or by downloading from the Deltares Systems website via MS Internet Explorer:

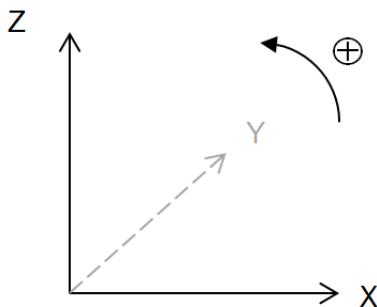
- ◇ Operating systems:
 - Windows 2003,
 - Windows Vista,
 - Windows 7 – 32 bits
 - Windows 7 – 64 bits
 - Windows 8
- ◇ Hardware specifications:
 - 1 GHz Intel Pentium processor or equivalent
 - 512 MB of RAM
 - 400 MB free hard disk space
 - SVGA video card, 1024 × 768 pixels, High colors (16 bits)
 - CD-ROM drive
 - Microsoft Internet Explorer version 6.0 or newer (download from www.microsoft.com)

To display the D-GEO STABILITY Help texts properly, the Symbol TrueType font must be installed on the system.

1.8 Definitions and Symbols

coordinate system

The horizontal axis is defined as the X -axis. The vertical axis is defined to be the Z -direction. Upward is positive and downward negative. Perpendicular to the cross section is the Y -direction.



Geometry

Z_{surface}	Surface level
Z_{water}	Phreatic level
Z_{piezo}	Piezometric level (also called hydraulic head)

Soil material

c	Cohesion
s_u	Undrained shear strength
$s_{u;\text{bottom}}$	Undrained shear strength at the bottom of the layer
$s_{u;\text{gradient}}$	Gradient in shear strength over the depth of the layer
$s_{u;\text{top}}$	Undrained shear strength at the top of the layer
POP	Pre-overburden pressure

U_{ij}	Degree of consolidation: ratio (in percent) between the excess pore pressure and the vertical total stress increment, both in layer i , by addition of layer j
φ	Friction angle of shearing resistance
γ_{sat}	Unit weight of saturated soil (below the phreatic line)
γ_{unsat}	Unit weight of unsaturated soil (above the phreatic line)
σ_p	Pre-consolidation stress (also written P_c)

Slices

b_i	Width of slice i
h_i	Height of slice i
k	Number of layers along slice i
l_i	Length of the arc at bottom of slice i : $l_i = b_i / \cos \alpha_i$
n	Total number of slices in which the sliding part of the ground mass is divided
n_{left}	Number of slices in which the left sliding part of the ground mass is divided (Uplift Van)
n_{right}	Number of slices in which the right sliding part of the ground mass is divided (Uplift Van)
X_i	Horizontal coordinate of the middle of slice i
$Z_{i;\text{top}}$	Vertical coordinate of the middle top of slice i
$Z_{i;\text{bottom}}$	Vertical coordinate of the middle bottom of slice i
α_i	Slide plane angle (at the bottom) of slice i
β_i	Slope angle (at the top) of slice i

Stresses acting on a slice

u	Hydraulic (piezometric) pore pressure
u_h	Hydrostatic pore pressure (from the position of the phreatic line)
σ	Total vertical soil stress (positive in compression)
σ'	Effective vertical soil stress (positive in compression)
τ	Shear stress

Slip plane / Slip circle(s)

F_s	The factor of safety
R	The radius of the slip circle (Bishop, Fellenius)
R_{left}	The radius of the left slip circle (Uplift Van)
R_{right}	The radius of the right slip circle (Uplift Van)
X_c	The X-coordinate of the slip circle (Bishop, Fellenius)
$X_{c;\text{left}}$	The X-coordinate of the left slip circle (Uplift Van)
$X_{c;\text{right}}$	The X-coordinate of the right slip circle (Uplift Van)
Z_c	The Z-coordinate of the slip circle (Bishop, Fellenius)
$Z_{c;\text{left}}$	The Z-coordinate of the left slip circle (Uplift Van)
$Z_{c;\text{right}}$	The Z-coordinate of the right slip circle (Uplift Van)

Probabilistic

F_{required}	The required value for the safety factor
Z	The limit state function: $Z = F_s - F_{\text{required}}$
$\mu[x]$	The mean value of parameter x
$\sigma[x]$	The standard deviation of parameter x , quantifying the uncertainty
V	The coefficient of variation: $V = \sigma[x] / \mu[x]$
$P(x > x_{\text{charac}})$	The probability of exceeding a characteristic value: $P(x > x_{\text{charac}}) = 1 - P(x < x_{\text{charac}})$

$\Phi_N(u_{\text{charac}})$	<p>The probability that parameter x does not exceed a characteristic value:</p> $\Phi_N(u_{\text{charac}}) = P(x < x_{\text{charac}}) = \int_{-\infty}^{u_{\text{charac}}} \varphi_N(u) \times du$
$\varphi_N(u)$	<p>Standard normal probability density:</p> $\varphi_N(u) = \frac{\exp(-u^2/2)}{\sqrt{2\pi}\sigma[x]}$
f_{partial}	<p>The partial factor, used to reduce characteristic strength values to safe low values</p>
β	<p>The reliability index:</p> $\beta = \frac{\mu[F_s] - F_{\text{required}}}{\sigma[F_s]}$ <p>connected to the probability of failure: $\Phi_N(-\beta) = P(F_s < F_{\text{required}})$</p>
Design point α_i	<p>The most likely set of parameter values with $F_s = F_{\text{required}}$</p> <p>The influence factor for parameter x_i, describing the sensitivity of the limit state function for parameter variation, weighted by the standard deviation:</p> $\alpha_i = \frac{\sigma[x_i] \frac{\partial Z}{\partial x_i}}{\sqrt{\sum_{i=1}^n \sigma^2[x_i] \left(\frac{\partial Z}{\partial x_i}\right)^2}}$

1.9 Getting Help

From the *Help* menu, choose the *Manual* option to open the User Manual of D-GEO STABILITY in PDF format. Here help on a specific topic can be found by entering a specific word in the *Find* field of the PDF reader.

1.10 Getting Support

Deltares Systems tools are supported by Deltares. A group of 70 people in software development ensures continuous research and development. Support is provided by the developers and if necessary by the appropriate Deltares experts. These experts can provide consultancy backup as well.

If problems are encountered, the first step should be to consult the online Help at www.deltaressystems.com menu 'Software'. Different information about the program can be found on the left-hand side of the window (Figure 1.1):

- ◇ In 'Support - Frequently asked questions' are listed the most frequently asked technical questions and their answers.
- ◇ In 'Support - Known issues' are listed the bugs of the program.
- ◇ In 'Release notes' are listed the differences between an old and a new version.

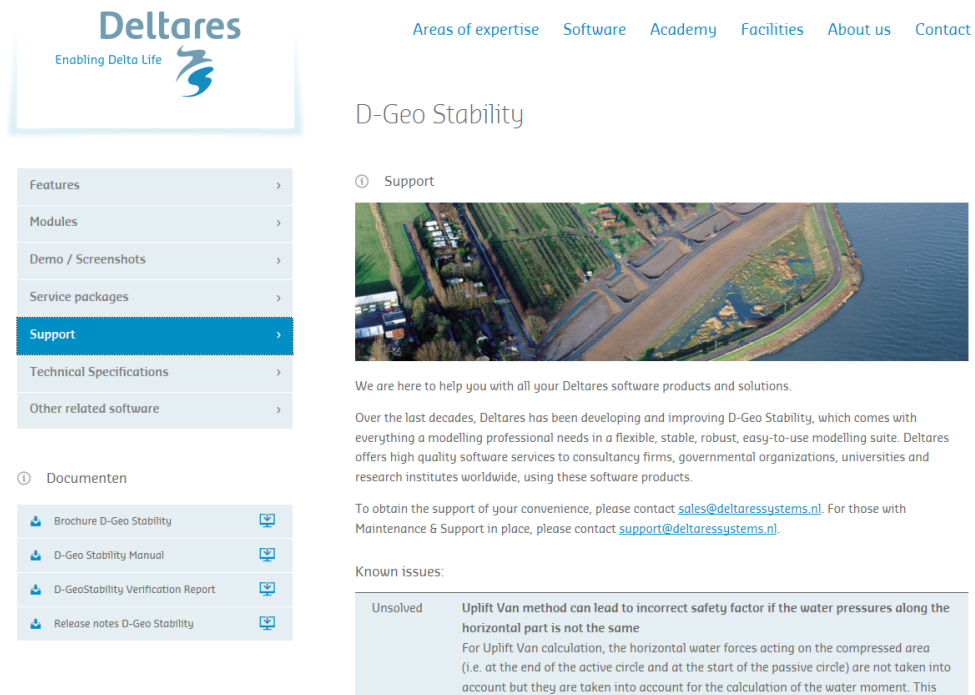


Figure 1.1: Deltares Systems website (www.deltaessystems.com)

If the solution cannot be found there, then the problem description can be e-mailed (preferred) or faxed to the Deltares Systems Support team. When sending a problem description, please add a full description of the working environment. To do this conveniently:

- ◇ Open the program.
- ◇ If possible, open a project that can illustrate the question.
- ◇ Choose the *Support* option in the *Help* menu. The *System Info* tab contains all relevant information about the system and the software. The *Problem Description* tab enables a description of the problem encountered to be added.

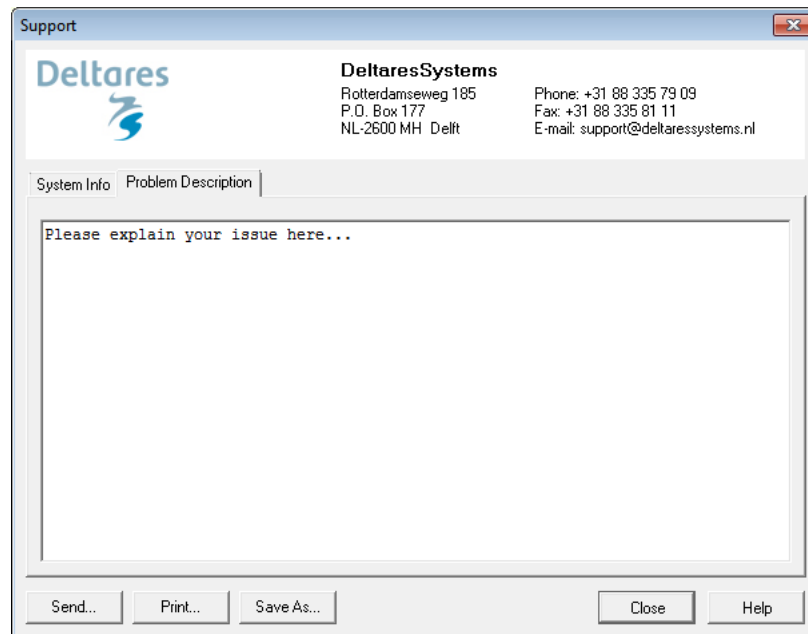


Figure 1.2: Support window, Problem Description tab

- ◇ After clicking on the *Send* button, the *Send Support E-Mail* window opens, allowing sending current file as an attachment. Marked or not the *Attach current file to mail* check-box and click *OK* to send it.

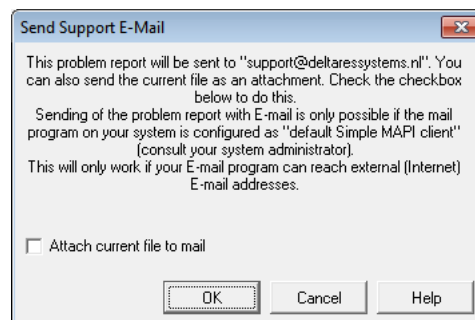


Figure 1.3: Send Support E-Mail window

The problem report can either be saved to a file or sent to a printer or PC fax. The document can be emailed to geo.support@deltares.nl or alternatively faxed to +31(0)88 335 8111.

1.11 Deltares

Since January 1st 2008, GeoDelft together with parts of Rijkswaterstaat /DWW, RIKZ and RIZA, WL |Delft Hydraulics and a part of TNO Built Environment and Geosciences are forming the Deltares Institute, a new and independent institute for applied research and specialist advice. Founded in 1934, GeoDelft was one of the world's most renowned institutes for geotechnical and environmental research. As a Dutch national Grand Technological Institute (GTI), Deltares role is to obtain, generate and disseminate geotechnical know-how. The institute is an international leader in research and consultancy into the behavior of soft soils (sand clay and peat) and management of the geo-ecological consequences which arise from these activities. Again and again subsoil related uncertainties and risks appear to be the key factors in civil engineering risk management. Having the processes to manage these uncertainties makes Deltares the obvious Partner in risk management for all parties involved in the

civil and environmental construction sector. Deltares teams are continually working on new mechanisms, applications and concepts to facilitate the risk management process, the most recent of which is the launch of the concept "GeoQ" into the geotechnical sector.

For more information on Deltares, visit the Deltares website: www.deltares.nl.

1.12 Deltares Systems

Deltares objective is to convert Deltares knowledge into practical geo-engineering services and software. Deltares Systems has developed a suite of software for geotechnical engineering. Besides software, Deltares Systems is involved in providing services such as hosting on-line monitoring platforms, hosting on-line delivery of site investigation, laboratory test results, etc. As part of this process Deltares Systems is progressively connecting these services to their software. This allows for more standardized use of information, and the interpretation and comparison of results. Most software is used as design software, following design standards. This however, does not guarantee a design that can be executed successfully in practice, so automated back-analysis using monitoring information are an important aspect in improving geotechnical engineering results.

Deltares Systems makes use of Deltares's intensive engagement in R&D for GeoBrain. GeoBrain's objective is to combine experience, expertise and numerical results into one forecast, using Artificial Intelligence, Neural Networks and Bayesian Belief Networks. For more information about Deltares Systems' geotechnical software, including download options, visit www.deltaessystems.com.

1.13 Rijkswaterstaat/DWW

The Road and Hydraulic Engineering Division (Rijkswaterstaat/DWW) of the Dutch Ministry of Transport, Public Works and Water Management is the advisory division for road and hydraulic engineering related to technology and the environment. It researches, advises and transfers knowledge on nature and on the environmental engineering of the physical infrastructure, water and water defense systems and the supply of construction raw materials, including the environmental aspects. DWW has sponsored the development of D-GEO STABILITY in order to support a uniform and reliable design of embankments, dikes and other geotechnical structures.

For more information on DWW, visit www.minvenw.nl/rws/dww/home.

1.14 On-line software (Citrix)

Besides purchased software, Deltares Systems tools are available as an on-line service. The input can be created over the internet. Heavy duty calculation servers at Deltares guarantee quick analysis, while results are presented on-line. Users can view and print results as well as locally store project files. Once connected, clients are charged by the hour. For more information, please contact the Deltares Systems sales team: sales@deltaessystems.nl.

2 Getting Started

This [Getting Started](#) chapter aims to familiarize the user with the structure and user interface of D-GEO STABILITY. The *Tutorial* section which follows uses a selection of case studies to introduce the program's functions. Getting Started

2.1 Starting D-Geo Stability

To start D-GEO STABILITY, click *Start* on the Windows menu bar and then find it under *Programs*, or double-click an D-GEO STABILITY input file that was generated during a previous session.

For an D-GEO STABILITY installation based on floating licenses, the *Modules* window may appear at start up ([Figure 2.1](#)). Check that the correct modules are selected and click *OK*.

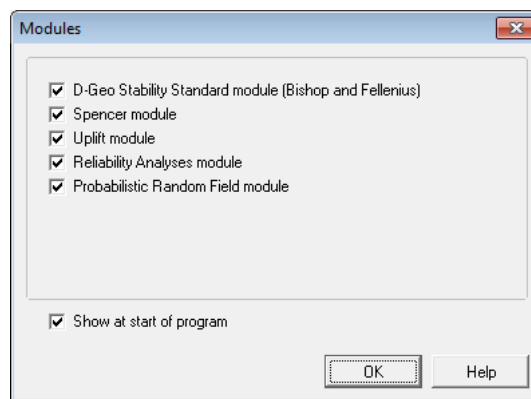


Figure 2.1: Modules window

When D-GEO STABILITY is started from the Windows menu bar, the last project that was worked on will open automatically, unless the program has been configured otherwise under *Tools: Program Options*.

2.2 Main Window

When D-GEO STABILITY is started, the main window is displayed ([Figure 2.2](#)). This window contains a menu bar ([section 2.2.1](#)), an icon bar ([section 2.2.2](#)), a *View Input* window ([section 2.2.3](#)) that displays the pre-selected or most recently accessed project, an info bar ([section 2.2.4](#)), a title panel ([section 2.2.5](#)) and a status bar ([section 2.2.6](#)).

The caption of the main window of D-GEO STABILITY displays the program name, followed by the model and the default shear strength names and the project name. When a new file is created, the default model is *Bishop*, the default shear strength is *C – Phi* and the project name is *Project1*.

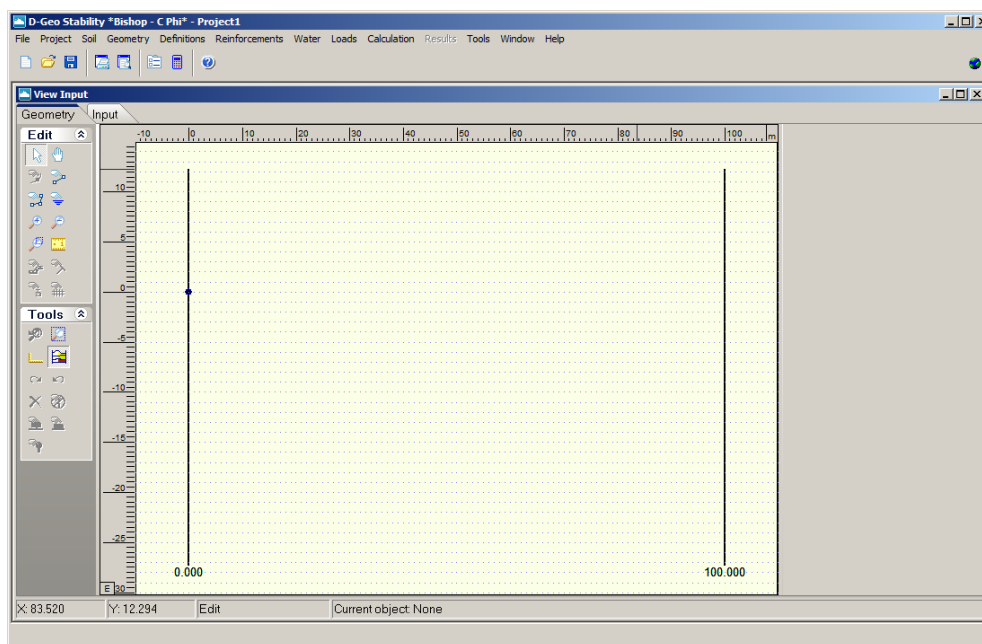


Figure 2.2: D-Geo Stability main window

2.2.1 The menu bar

To access the D-GEO STABILITY menus, click the menu names on the menu bar.

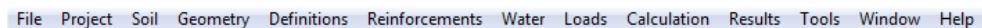


Figure 2.3: D-Geo Stability menu bar

The menu contains the following functions:

<i>File</i>	Standard Windows options for opening and saving as well as several D-GEO STABILITY options for exporting and printing the active window (section 3.1).
<i>Project</i>	Global model selection. Input of project identification and layout options for specific windows. Modification of probabilistic defaults (section 4.1).
<i>Soil</i>	Definition of soil type properties (section 4.2).
<i>Geometry</i>	Definition of general geometrical data like layers, soil types and piezometric lines (section 4.3).
<i>Definitions</i>	Definition of specific geometrical data for D-GEO STABILITY models, like the initial/possible slip plane position, geotextiles, “forbidden lines”, reference level et cetera (section 4.4).
<i>Reinforcements</i>	Input of the geotextiles and nails (section 4.5).
<i>Water</i>	Input of water weight, degree of consolidation or import of pore pressures from MSeep. Input of external water levels for probabilistic design (section 4.6).
<i>Loads</i>	Options for input of distributed surcharge and earth quake coefficients (section 4.7).
<i>Calculation</i>	Determine the stresses along the critical slip circle or a user-defined slip plane, for a selected design analysis type (chapter 5).
<i>Results</i>	Graphical or tabular output of the safety level and stress components along the slip plane. Graphical output of the influence factors (chapter 6).

<i>Tools</i>	Options for editing D-GEO STABILITY program defaults (section 3.2).
<i>Window</i>	Default Windows options for arranging the D-GEO STABILITY windows and choosing the active window.
<i>Help</i>	Online Help options (section 1.9).

Detailed descriptions of these menu options can be found in the Reference section.









2.2.2 The icon bar

Use the buttons on the icon bar to quickly access frequently used functions (see below).



Figure 2.4: D-Geo Stability icon bar

Click on the following buttons to activate the corresponding functions:

	Start a new D-GEO STABILITY project.
	Open the input file of an existing project.
	Save the input file of the current project.
	Print the contents of the active window.
	Display a print preview of the active window.
	Open the <i>Project Properties</i> window. Here the project title and other identification data can be entered, and the View Layout and Graph Settings for the project can be determined.
	Start the calculation.
	Display the contents of online Help.
	Display the Dutch website of the Deltares Software Simulation Products and Solutions .

2.2.3 View Input

The *View Input* window displays the geometry and additional D-GEO STABILITY input of the current project. The window has the following two tabs:

- ◇ *Geometry*

In this view it is possible to define, inspect and modify the positions and soil types of different layers. For more information on these general D-GEO STABILITY options for geometrical modeling, see the description of the *Geometry* menu (section 4.3).

- ◇ *Input*

In this view it is possible to define, inspect and modify the additional, D-GEO STABILITY specific input. For more information on the available options, see below in this section. See also the description of the *Definitions* menu (section 4.4).

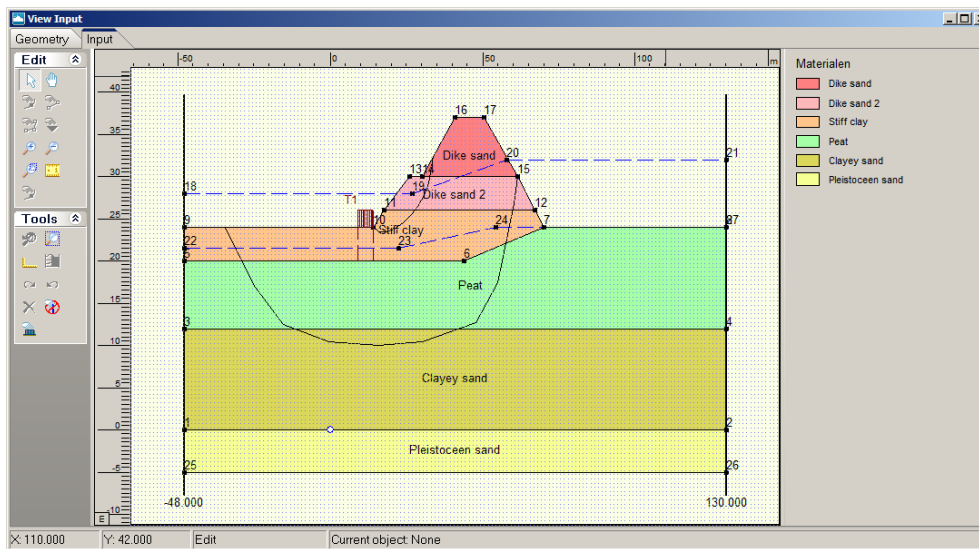


Figure 2.5: View Input window

It is possible to use the buttons on the panels at the left to control the graphical view and to add input data. Click on the following buttons in the *Edit* and *Tools* panel to activate the corresponding functions:



Select and Edit mode

In this mode, the left-hand mouse button can be used to graphically select a previously defined grid, load, geotextile or forbidden line. Items can then be deleted or modified by dragging or resizing, or by clicking the right-hand mouse button and choosing an option from the menu displayed. Pressing the *Escape* key will return the user to this *Select and Edit* mode.



Pan

Click this button to change the visible part of the drawing by clicking and dragging the mouse.



Add point(s) to boundary / PL-line

Click this button to add points to all types of lines (lines, polylines, boundary lines, PL-lines). By adding a point to a line, the existing line is split into two new lines. This provides more freedom when modifying the geometry.

*Add single lines(s)*

Click this button to add single lines. When this button is selected, the first left-hand mouse click will add the info bar of the new line and a “rubber band” is displayed when the mouse is moved. The second left-hand mouse click defines the end point (and thus the final position) of the line. It is now possible to either go on clicking start and end points to define lines, or stop adding lines by selecting one of the other tool buttons, or by clicking the right-hand mouse button, or by pressing the *Escape* key.

*Add polyline(s)*

Click this button to add poly-lines. When this button is selected, the first left-hand mouse click adds the starting point of the new line and a “rubber band” is displayed when the mouse is moved. A second left-hand mouse click defines the end point (and thus the final position) of the first line in the poly-line and activates the “rubber band” for the second line in the poly-line. Every subsequent left-hand mouse click again defines a new end point of the next line in the poly-line. It is possible to end a poly-line by selecting one of the other tool buttons, or by clicking the right-hand mouse button, or by pressing the *Escape* key.

*Add PL-line(s)*

Click this button to add a piezometric level line (PL-line). Each PL-line must start at the left limit and end at the right limit. Furthermore, each consecutive point must have a strictly increasing X coordinate. Therefore, a PL-line must be defined from left to right, starting at the left limit and ending at the right limit. To enforce this, the program will always relocate the first point clicked (left-hand mouse button) to the left limit by moving it horizontally to this limit. If trying to define a point to the left of the previous point, the rubber band icon indicates that this is not possible. Subsequently clicking on the left side of the previous point, the new point will be added at the end of the rubber band icon instead of the position clicked.

*Zoom in*

Click this button to enlarge the drawing, then click the part of the drawing which is to be at the center of the new image. Repeat if necessary.

*Zoom out*

Click this button, then click on the drawing to reduce the drawing size. Repeat if necessary.

*Zoom rectangle*

Click this button then click and drag a rectangle over the area to be enlarged. The selected area will be enlarged to fit the window. Repeat if necessary.

*Measure the distance between two points*

Click this button, then click the first point on the View Input window and place the cross on the second point. The distance between the two points can be read at the bottom of the View Input window. To turn this option off, click the escape key.

*Add geotextile*













In this mode, it is possible to use the left mouse button to graphically define the starting and end point of a geotextile section. The stability of a slope will increase if a slip plane crosses a geotextile.

*Add nail*

In this mode, it is possible to use the left mouse button to graphically define the starting and end point of a nail. The resistance of the soil will increase.

*Add fixed point*

Click this button to graphically define the position of a point that will be part of the critical slip circle.

	Add calculation grid Click this button to graphically define the initial position of the trial grid with slip-circle center points and the corresponding positions of the trial horizontal tangent lines of the slip circle.
	Undo zoom Click this button to undo the zoom. If necessary, click several times to retrace each consecutive zoom-in step that was made.
	Zoom limits Click this button to display the complete drawing.
	Same scale for X and Y axis Click this button to use the same scale for the horizontal and vertical directions.
	Undo Click this button to undo the last change(s) made to the geometry
	Redo Click this button to redo the previous Undo action.
	Automatic regeneration of geometry on/off When selected, the program will automatically try to generate a new valid geometry whenever geometry modifications require this. During generation, (poly)lines (solid blue) are converted to boundaries (solid black), with interjacent layers. New layers receive a default material type. Existing layers keep the materials that were assigned to them. Invalid geometry parts are converted to construction elements. Automatic regeneration may slow down progress during input of complex geometry, because validity will be checked continuously.
	Delete Click this button to delete a selected element. Note that this button is only available when an element is selected.
	Add forbidden lines Click this button to display a window in which it is possible to add, modify or delete lines. Slip circles are not allowed to cross forbidden lines.
	Add line loads Click this button to display a window in which it is possible to add, modify or delete point loads per unit of length.
	Add uniform loads Click this button to display a window in which it is possible to add, modify or delete uniform loads per unit of area.
	Edit tree on slope Click this button to display a window in which it is possible to input an area on the slope where trees are present.

See [section 7.3.2](#) for more information on how using those buttons.

2.2.4 Info bar


This bar situated at the bottom of the *View Input* window displays the coordinates of the current position of the cursor and the distance between two points when the icon *Measure the distance between two points*  is selected from the *Edit* panel.

Table 2.1: Keyboard shortcuts for D-Geo Stability

Keyboard shortcut	Opened window
Ctrl + N	New
Ctrl + O	Open
Ctrl + S	Save
F12	Save As
Shift + Ctrl + C	Copy Active Window to Clipboard
Ctrl + M	Model
Ctrl + T	Materials
Ctrl + L	Slip Circle Definition
F9	Start Calculation
Ctrl + R	Report

2.2.5 Title panel

This panel situated at the bottom of the main window displays the project titles, as entered on the *Identification* tab in the *Project Properties* window ([section 4.1.3](#)).

2.2.6 Status bar

This bar situated at the bottom of the main window displays a description of the selected icon of the icon bar ([section 2.2.2](#)) or of the *View Input* window ([section 2.2.3](#)).

2.3 Files

<i>*.sti</i>	<i>Input file (ASCII):</i> Contains the D-GEO STABILITY specific input with the problem description. After interactive generation, this file can be reused in subsequent D-GEO STABILITY analysis.
<i>*.geo</i>	<i>Input file (ASCII):</i> Contains geometry data, resulting for example for a settlement analysis with D-SETTLEMENT (formerly known as MSettle).
<i>*.sto</i>	<i>Output file (ASCII):</i> After a calculation has been performed, all output is written to this file. If there are any errors in the input, they are described in this file.
<i>*.sed</i>	<i>Optional Input file (ASCII):</i> Contains pore pressures from MSeep.
<i>*.set</i>	<i>Working file (ASCII):</i> Contains settings data.

2.4 Tips and Tricks


2.4.1 Keyboard shortcuts

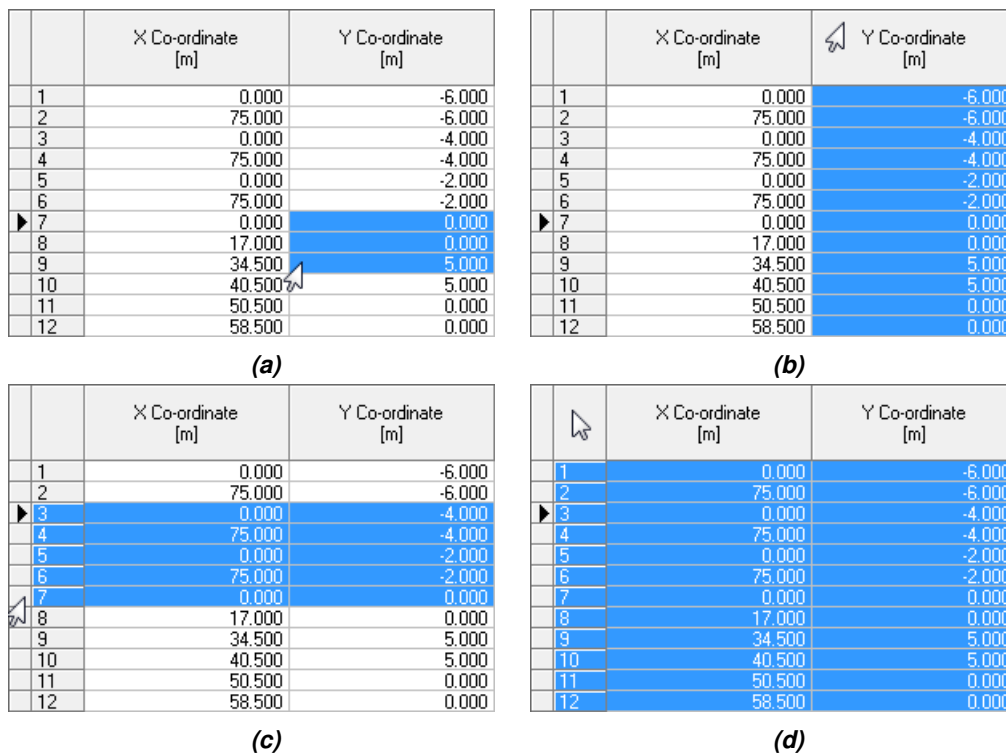
Use the keyboard shortcuts given in [Table 2.1](#) to directly open a window without selecting the option from the menu bar.

2.4.2 Exporting figures and reports

All figures in D-GEO STABILITY such as geometry and graphical output can be exported in WMF (Windows Meta Files) format. In the *File* menu, select the option *Export Active Window* to save the figures in a file. This file can be later imported in a Word document for example or added as annex in a report. The option *Copy Active Window to Clipboard* from the *File* menu can also be used to copy directly the figure in a Word document. The report can be entirely exported as PDF (Portable Document Format) or RTF (Rich Text Format) file. To look at a PDF file Adobe Reader can be used. A RTF file can be opened and edited with word processors like MS Word.

2.4.3 Copying part of a table

It is possible to copy part of a table into another document, an Excel sheet for example, or use it within D-GEO STABILITY. If the cursor is placed on the left-hand side of a cell of the table, the cursor changes in an arrow which points from bottom left to top right. Select a specific area by using the mouse (see Figure 2.6a). Then, using the copy button  (or ctrl+C) this area can be copied.



(a)

	X Co-ordinate [m]	Y Co-ordinate [m]
1	0.000	-6.000
2	75.000	-6.000
3	0.000	-4.000
4	75.000	-4.000
5	0.000	-2.000
6	75.000	-2.000
7	0.000	0.000
8	17.000	0.000
9	34.500	5.000
10	40.500	5.000
11	50.500	0.000
12	58.500	0.000

(b)

	X Co-ordinate [m]	Y Co-ordinate [m]
1	0.000	-6.000
2	75.000	-6.000
3	0.000	-4.000
4	75.000	-4.000
5	0.000	-2.000
6	75.000	-2.000
7	0.000	0.000
8	17.000	0.000
9	34.500	5.000
10	40.500	5.000
11	50.500	0.000
12	58.500	0.000

(c)

	X Co-ordinate [m]	Y Co-ordinate [m]
1	0.000	-6.000
2	75.000	-6.000
3	0.000	-4.000
4	75.000	-4.000
5	0.000	-2.000
6	75.000	-2.000
7	0.000	0.000
8	17.000	0.000
9	34.500	5.000
10	40.500	5.000
11	50.500	0.000
12	58.500	0.000

(d)

	X Co-ordinate [m]	Y Co-ordinate [m]
1	0.000	-6.000
2	75.000	-6.000
3	0.000	-4.000
4	75.000	-4.000
5	0.000	-2.000
6	75.000	-2.000
7	0.000	0.000
8	17.000	0.000
9	34.500	5.000
10	40.500	5.000
11	50.500	0.000
12	58.500	0.000

Figure 2.6: Selection of different parts of a table using the arrow cursor

To select a row, click on the cell before the row number (see Figure 2.6b). To select a column, click on the top cell of the column (see Figure 2.6c). To select the complete table, click on the top left cell (see Figure 2.6d). In some tables the button *Copy* is also present at the left hand pane.

2.4.4 Command line

There are two tools available for processing large amounts of D-GEO STABILITY calculations and producing graphical output: Batch processing and Plot.

Batch Processing

Batch Processing of D-GEO STABILITY is possible by using `/b` as a command line parameter, whether or not followed by a second parameter. The second parameter has multiple options:

- ◇ the name of an inputfile
- ◇ the name of a folder

In each of the accounts, the program is closed after the last calculation has been made. When the second parameter is left out, e.g. `C:\Program Files\Deltares\DGeoStability\DGeoStability.exe /b`, a dialog box is shown (see [Figure 2.7](#)) enabling the user to choose which folder has to be used for processing. This folder can be typed in the *Combobox*, selected from the list of the last nine folders used for processing or looked up using the *Browse* button. If the option *Include subfolders* is on, all subfolders will be processed (recursive).

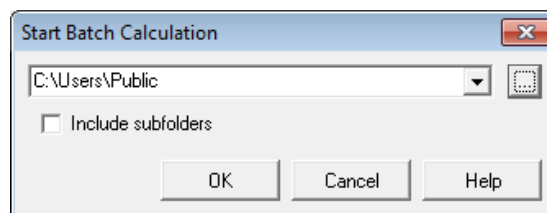


Figure 2.7: D-Geo Stability batch processing window

When the second parameter is given, e.g. `C:\Program Files\Deltares\DGeoStability\DGeoStability.exe /b D:\tmp\DGeoStabilityBatch\<Filename>`, only this file will be processed. When the second parameter is a folder, this folder will be processed, including all (recursive) subfolders.

Plot

The command line parameter `/plot` is available in D-GEO STABILITY. When processing large amounts of calculations, using this parameter enables you to create plots of every calculation during processing. A wmf picture is exported of the critical circle, or the 2 zone circles in case of zoneplot of every calculation. E.g.: `C:\Program Files\Deltares\DGeoStability\DGeoStability.exe /b /Plot <Filename>` gives the critical circle of the chosen file. For this parameter the same second parameter rules apply, as described in the previous paragraph.

3 General

This part of the manual contains a detailed description of the available menu options for inputting data for a soil structure, calculating slope stability and viewing results.

The examples in the tutorial section provide a convenient starting point for familiarization with the program.

3.1 File menu

Besides the familiar Windows options for opening and saving files, the File menu contains a number of options specific to D-GEO STABILITY.

◇ *New*

Select this option to display the *New File* window (Figure 3.1). Three choices are available to create a new geometry:

- *Select New geometry*
to display the *View Input* window, showing only the geometry limits (with their defaults values) of the geometry;
- *Select New geometry wizard*
to create a new geometry faster and easier using the wizard option (involving a step-by-step process for creating a geometry, see section 4.3.2);
- *Select Import geometry*
to use an existing geometry.

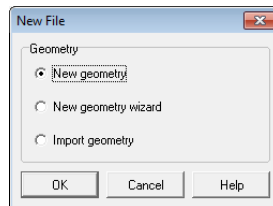


Figure 3.1: *New File* window

◇ *Copy Active Window to Clipboard*

Use this option to copy the contents of the active window to the Windows clipboard so that they can be pasted into another application. The contents will be pasted in either text format or Windows Meta File format.

◇ *Export Active Window*

Use this option to export the contents of the active window as a Windows Meta File (*.wmf), a Drawing Exchange File (*.dxf) or a text file (*.txt).

◇ *Page Setup*

This option allows definition of the way D-GEO STABILITY plots and reports are to be printed. The printer, paper size, orientation and margins can be defined as well as whether and where axes are required for plots. Click *Autofit* to get D-GEO STABILITY to choose the best fit for the page.

◇ *Print Preview Active Window*

This option will display a print preview of the current contents of the *View Input* or *Results* window.

◇ *Print Active Window*

This option prints the current contents of the *View Input* or *Results* window.



3.2 Tools menu

On the menu bar, click *Tools* and then choose *Program Options* to open the corresponding input window. In this window, the user can optionally define their own preferences for some of the program's default values.

3.2.1 Program Options

Program options – View

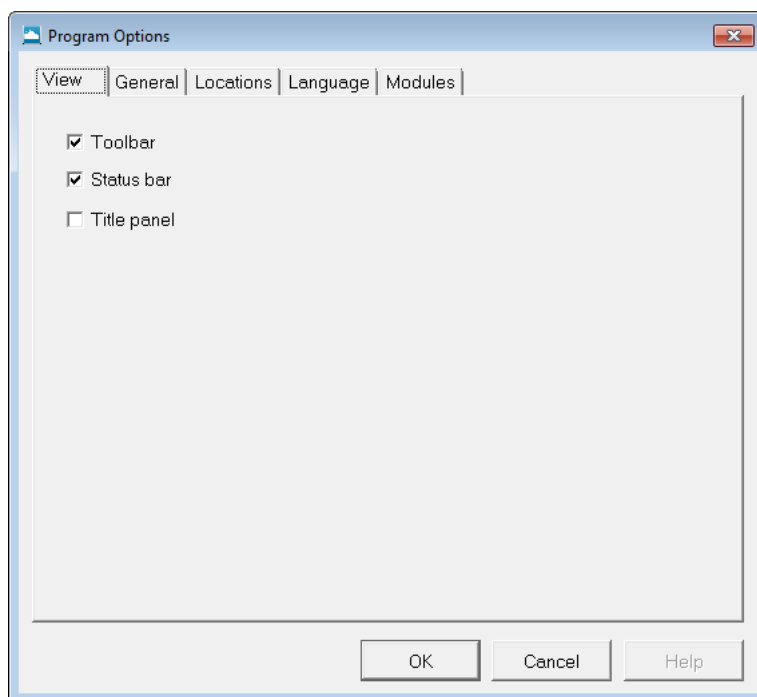


Figure 3.2: Program Options window, View tab

<i>Toolbar or Status bar</i>	Mark the relevant check-box to display the toolbar and/or status bar each time D-GEO STABILITY is started.
<i>Title panel</i>	Mark the check-box to display the project titles, as entered on the <i>Identification</i> tab in the <i>Project Properties</i> window, in a panel at the bottom of the <i>View Input</i> window.

Program options – General

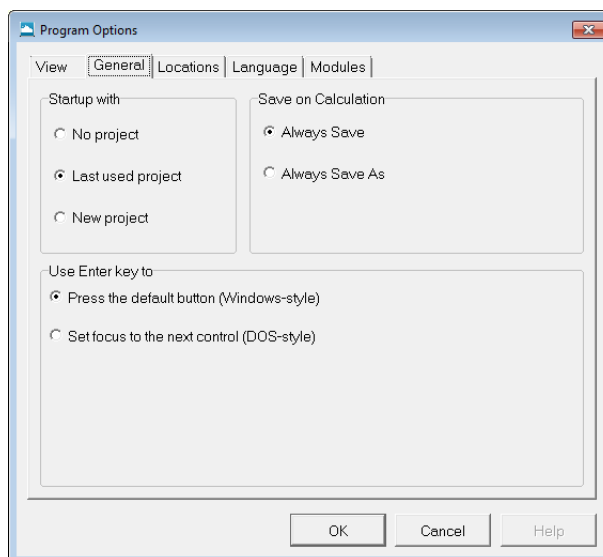


Figure 3.3: Program Options window, General tab

<i>Start-up with</i>	<p>Click one of these toggle buttons to determine whether a project should be opened or initiated when the program is started.</p> <p><i>No project:</i> Each time D-GEO STABILITY is started, the buttons in the toolbar or the options in the File menu must be used to open an existing project or to start a new one.</p> <p><i>Last used project:</i> Each time D-GEO STABILITY is started, the last project that has been worked on is opened automatically.</p> <p><i>New project:</i> A new project is created. The user is offered three options at the start up of D-GEO STABILITY: New Geometry, new Geometry wizard and Import geometry.</p> <p>Note that this option is ignored when the program is started by double-clicking an input file.</p>
<i>Save on Calculation</i>	<p>The toggle buttons determine how input data is saved prior to calculation. The input data can either be saved automatically, using the same file name each time, or a file name can be specified each time the data is saved.</p>
<i>Use Enter key to</i>	<p>The toggle buttons allow the way the Enter key is used in the program: either as an equivalent of pressing the default button (Windows-style) or to shift the focus to the next item in a window (for users accustomed to the DOS version(s) of the program).</p>

Program options – Locations

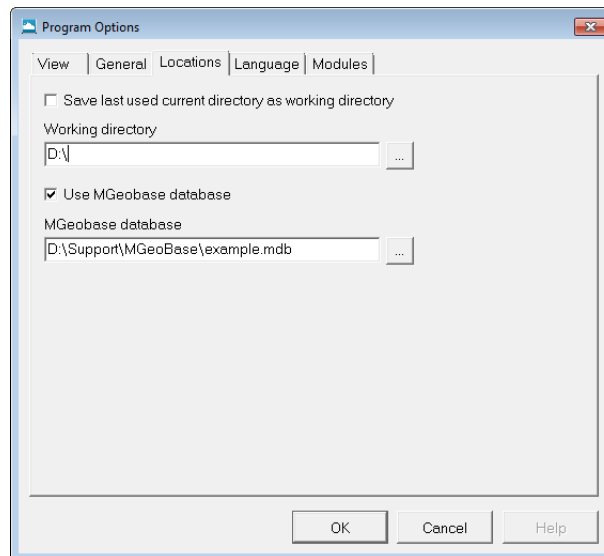


Figure 3.4: Program Options window, Locations tab

<i>Working directory</i>	D-GEO STABILITY will start up with a working directory for selection and saving of files. Either choose to use the last used directory, or specify a fixed path.
<i>MGeobase database</i>	Here it is possible to assign a database location. This database (*.gdb or *.mdb) can be accessed with several options in D-GEO STABILITY to retrieve D-GEO STABILITY specific data from this file location.

Program options – Language

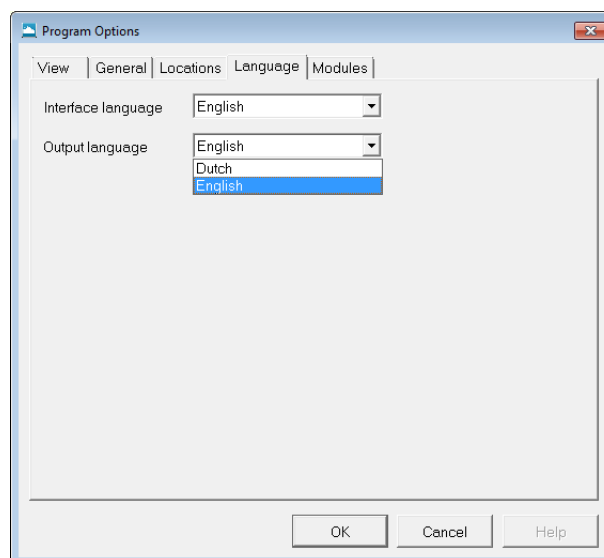


Figure 3.5: Program Options window, Language tab

Select the language to be used in the D-GEO STABILITY windows and on printouts.

<i>Interface language</i>	Currently, the only available interface language is English.
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<i>Output language</i>	Two output languages are supported, English and Dutch. The selected output language will be used in all exported reports and graphs.
------------------------	--

Program options – Modules

For a D-GEO STABILITY installation based on floating licenses, the *Modules* tab can be used to claim a license for the particular modules that are to be used. If the Show at start of program check-box is marked then this window will always be shown at start-up. For a D-GEO STABILITY installation based on a license dongle, the *Modules* tab will just show the modules that may be used.

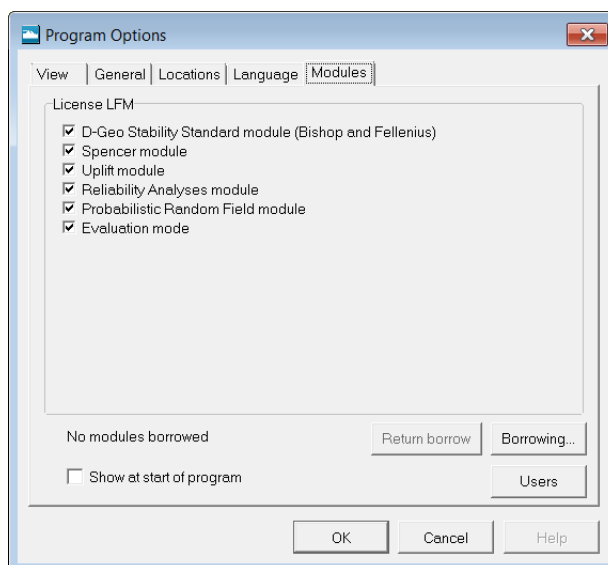


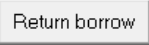


Figure 3.6: Program Options window, Modules tab

	Click this button to see which modules are (at this moment) in used and who (within the company) is using them.
	Click this button to borrow the selected modules for a certain period. The modules will be taken from the server pool and will be available on this computer even if no connection to the license server is available. Set the date and time for the expiration of the borrowing and press <i>OK</i> .
	Click this button to end the borrow immediately.

3.3 Help menu

The *Help* menu allows access to different options.

3.3.1 Error Messages

If errors are found in the input, no calculation can be performed and D-GEO STABILITY opens the *Error Messages* window displaying more details about the error(s). Those errors must be corrected before performing a new calculation. To view those error messages, select the *Error Messages* option from the *Help* menu. They are also written in the *.err file. They will be overwritten the next time a calculation is started.

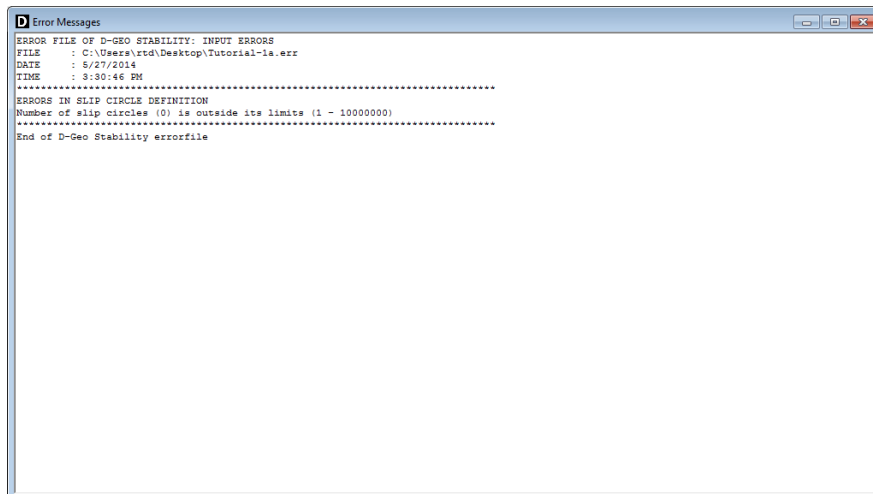


Figure 3.7: Error Messages window

3.3.2 Manual

Select the *Manual* option from the *Help* menu to open the User Manual of D-GEO STABILITY in PDF format. Here help on a specific topic can be found by entering a specific word in the *Find* field of the PDF reader.

3.3.3 Deltares Systems Website

Select *Deltares Systems Website* option from the *Help* menu to visit the Deltares Systems website (www.deltaresystems.com) for the latest news.

3.3.4 Support

Use the *Support* option from the *Help* menu to open the *Support* window in which program errors can be registered. Refer to [section 1.9](#) for a detailed description of this window.

3.3.5 About D-GEO STABILITY

Use the *About* option from the *Help* menu to display the *About D-GEO STABILITY* window which provides software information (for example the version of the software).



Figure 3.8: About D-GEO STABILITY window

4 Input

Before the analysis can be started, data for the soil structure, soil types and loads need to be input.

4.1 Project menu

The *Project* menu can be used to set the model settings. The project preferences can be set and it is possible to view the input file.

4.1.1 Model

On the menu bar, click *Project* and then choose *Model* to display an input window with the following data. Calculation methods

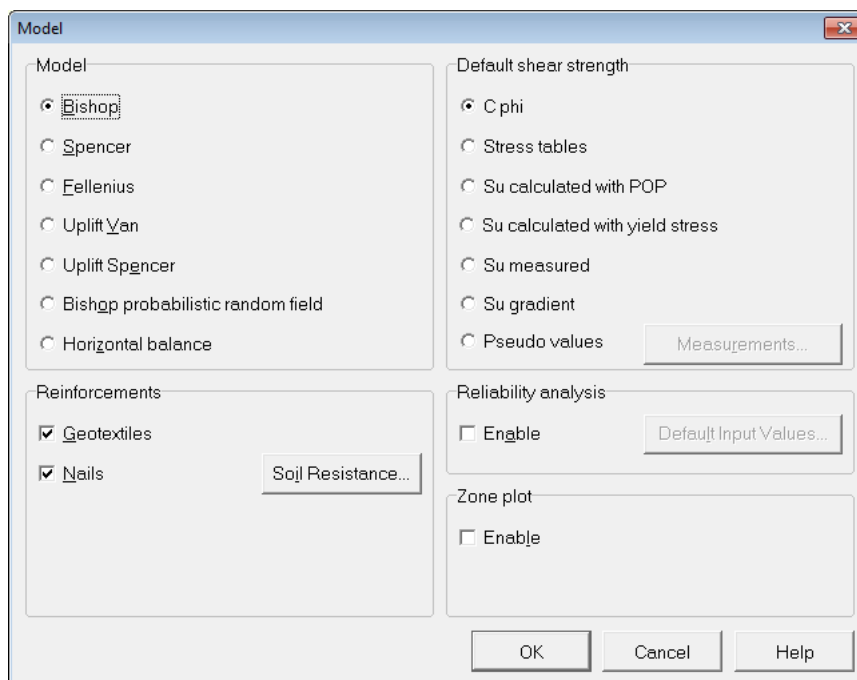


Figure 4.1: Model window

Model


Choose one of the following methods:

<i>Bishop</i>	Usual choice for slope stability analysis. Automatically finds a circular slip plane with minimum safety. Equilibrium of moments and vertical forces is ensured. For background information, see section 16.2 .
<i>Spencer</i>	For special slip plane analysis. User-defined coordinates now fix the slip plane. Equilibrium is ensured for moments, vertical forces and horizontal forces. For background information, see section 16.4 .
<i>Fellenius</i>	Obsolete. Automatically finds a circular slip plane with minimum safety. Only equilibrium of moments is ensured. For background information, see section 16.2 .
<i>Uplift Van</i>	Usual choice for uplift stability analysis. Finds automatically a slip plane with minimum safety. The plane consists of a horizontal part bounded by two circles. Equilibrium is ensured for moments and vertical forces. For background information, see section 16.3 .

<i>Uplift Spencer</i>	An alternative choice for uplift stability analysis. Automatically finds a slip plane with minimum safety. The plane consists of a horizontal part bounded by a circle (active side) and a straight plane (passive side). Compared to Van's method, equilibrium is now also ensured for horizontal forces.
<i>Bishop prob. random field</i>	A special module for advanced probabilistic design, incorporating spatial variability. This module, formerly known as MProStab, is described in chapter 21 .
<i>Horizontal Balance</i>	To check the horizontal balance especially in case of seepage forces due to different water levels at the left and the right of a dike retaining water.

Reinforcements

Mark the reinforcements used in the project:

<i>Geotextiles</i>	Mark this check-box to enable the usage of geotextiles in the project.
<i>Nails</i>	Mark this check-box to enable the usage of nails in the project.
	This button is available only if <i>Nails</i> is marked. When clicking this button, the <i>Soil Resistance</i> window appears (Figure 4.2) in which the lateral and shear stresses criterion at the interface soil/nails can be defined.

- ◇ In *Dowel action* sub-window, the lateral stress along the nail can be defined in two ways:
 - the lateral stress is defined as a stress curve (distance from nail head vs. ultimate stress) for each nail if option *Input of ultimate lateral stress along nail* is selected. Refer to [section 4.5.3.3](#) for the input of this curve.
 - the lateral stress is automatically determined by the program using the soil parameters if option *Use soil parameters c, phi / Su* is selected. Refer to [section 4.2.4.6](#) for the input of the extra soil parameters needed.
- ◇ In *Pull-out* sub-window, the shear stress along the nail can either:
 - be defined as a stress curve (distance from nail head vs. ultimate stress) for each nail if option *Input of ultimate lateral stress along nail* is selected;
 - be defined as a bond stress diagram (normal ultimate stress σ'_n vs. shear ultimate stress τ) for each soil type if option *Input of bond stress diagram (sigma, tau)* is selected.

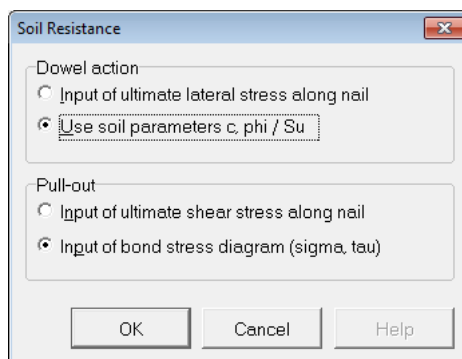


Figure 4.2: Soil Resistance window

Default Shear Strength

Choose one of the following methods for entering the default shear strength model:

<i>C phi</i>	Use by default the input of cohesion and internal friction angle.
<i>Stress tables</i>	Use by default the input of user-defined Sigma-Tau curves. These curves relate the effective normal stress along a slip plane directly to the shear strength.
<i>Su calculated with POP</i>	Use by default the input of the ratio S between undrained shear strength and yield stress, where the yield stress is calculated from the POP value of the material.
<i>Su calculated with yield stress</i>	Use by default the input of the ratio S between undrained shear strength and yield stress, where the yield stress is calculated from the user-defined yield stress measurements.
<i>Su measured</i>	Use by default the direct input of undrained shear strength at the top and the bottom of a layer.
<i>Su gradient</i>	Use by default the input of the undrained shear strength at the top of the layer and the gradient over the depth of the layer.
<i>Pseudo values</i>	Use by default the input of Sigma-Tau curves based on <i>in situ</i> measurements.
Measurements...	This button is available only with the <i>Pseudo values</i> shear strength model. When clicking this button, the <i>Measurements</i> window appears (Figure 4.3) in which the type of inputted measurements used with the <i>Pseudo values</i> model can be defined: <ul style="list-style-type: none"> - <i>Local</i> for measurements resulting of laboratory tests performed on soil samples from the surrounding area where the stability analysis is performed, - <i>Global</i> for measurements from a set of tests.

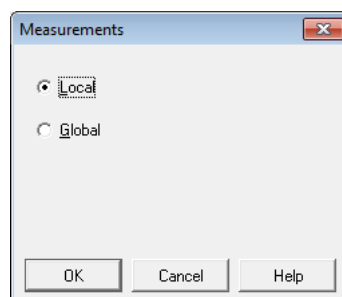


Figure 4.3: Measurements window

It is possible to change the choice of shear strength description per soil type via the *Soil* menu (section 4.2).

Reliability Analysis

Enable Mark this check-box to enable the usage of reliability based design (chapter 20). This option can be used only in combination with Bishop and Uplift Van models.

Default Input Values...

When clicking this button the *Default Input Values* window appears (Figure 4.4) in which the type of input parameters, either *mean* values or *design* values can be chosen.

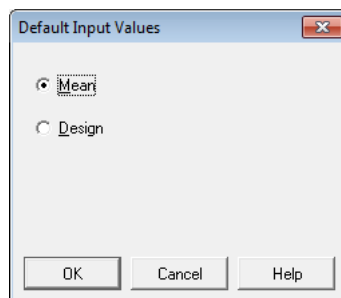


Figure 4.4: Default Input Values window

Zone plot

Enable Mark this check-box to enable the usage of zone plot which allows defining different safety factors in the dike body.

4.1.2 Probabilistic Defaults

On the menu bar, click *Project* and then choose *Probabilistic Defaults* to open the input window. This option is only available if *Reliability Analysis* has been selected in the *Model* window (section 4.1.1). In this window the default settings for the uncertainty in soil parameters, pore pressure parameters and in model factor.

Probabilistic Defaults				
Strength				
	Coef. of var. (Std. dev./mean) [-]	Design value factors Partial Std. dev. [-] [-]		Distribution
Drained cohesion (c)	0.25	1.25	-1.65	Log normal
Friction angle (phi)	0.15	1.10	-1.65	Log normal
Strength from stress table	0.20	1.15	-1.65	Log normal
Ratio S	0.25	1.15	-1.65	Log normal
Undrained shear strength (Su)	0.25	1.15	-1.65	Log normal
State				
	Coef. of var. (Std. dev./mean) [-]	Design value factors Partial Std. dev. [-] [-]		Distribution
EOP	0.10	1.10	-1.65	Log normal
Nails				
	Coef. of var. (Std. dev./mean) [-]	Design value factors Partial Std. dev. [-] [-]		Distribution
Compression ratio (Cc/1+eo)	0.25	1.00	0.00	Log normal
Pore pressure				
	Std. dev.	Design value factors Partial Std. dev. [-] [-]		Distribution
Consolidation coefficient 50% [%]	20.00	1.00	1.65	Normal
Hydraulic pressure [kN/m ²]	0.50	1.00	1.65	Log normal
Model factor				
	Mean	Std. dev.	Distribution	
Limit value stability factor β_{Bishop} [-]	1.00	0.08	Log normal	
Limit value stability factor β_{van} [-]	0.95	0.08	Log normal	
<input type="button" value="Reset"/> <input type="button" value="OK"/> <input type="button" value="Cancel"/> <input type="button" value="Help"/>				

Figure 4.5: Probabilistic Defaults window

Coef. of var. (Std. dev./mean)	The coefficient of variation (equals to the standard deviation divided by the mean value).
Partial	The partial factor, used to reduce characteristic values to safe low values.
Std. dev.	The standard deviation of a parameter, quantifying the uncertainty.
Distribution	The distribution type of a parameter: Log normal = lognormal probability distribution, Normal = standard normal probability distribution, None = zero standard deviation.
Mean	The mean value of a parameter.

4.1.3 Project Properties

On the menu bar, click *Project* and then choose *Properties* to open the input window. The *Project Properties* window contains six tabs, on which allow then settings for the current project to be changed.



Note: It is recommended to specify the settings in the *Project Properties* before inputting the data into the file. The settings can be changed at any time. It is also possible to save the setting as default, defining the settings the same each time D-GEO STABILITY is run.

Project Properties – Identification

Use the *Identification* tab to specify the project identification data.

Figure 4.6: *Project Properties window, Identification tab*

<i>Titles</i>	Use <i>Title 1</i> to give the project a unique, easily recognizable name. <i>Title 2</i> and <i>Title 3</i> can be added to indicate specific characteristics of the calculation. The three titles will be included on printed output.
<i>Date</i>	The date entered here will be used on printouts and graphic plots for this project. Either mark the <i>Use current date</i> check-box on each printout, or enter a specific date.
<i>Drawn by</i>	Enter the name of the user performing the calculation or generating the printout.
<i>Project ID</i>	Enter a project identification number.
<i>Annex ID</i>	Specify the annex number of the printout.

Enable the check-box *Save as default* to use these settings every time D-GEO STABILITY is started or a new project is created.

Project Properties – View Input

Use the *View Input* tab to specify the availability of components in two tabs of the *View Input* window ([section 2.2.3](#)).

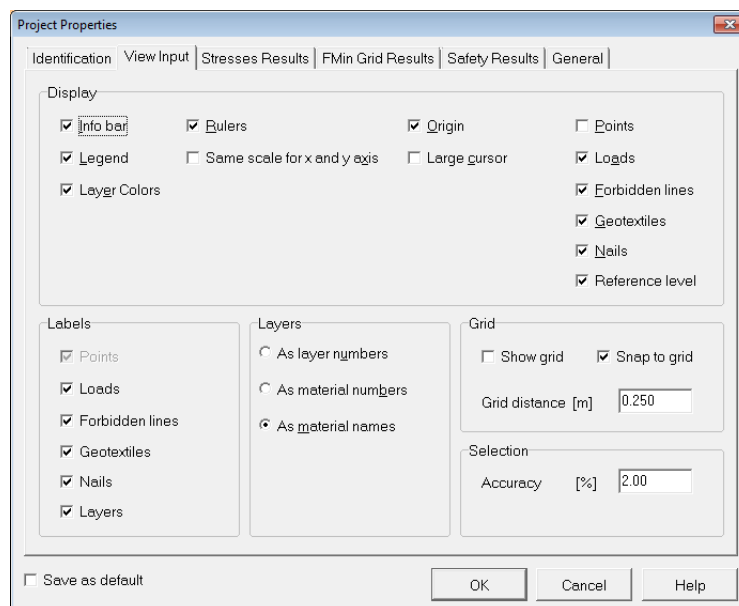


Figure 4.7: Project Properties window, View Input tab

<i>Info bar</i>	Mark this check-box to display the information bar at the bottom of the <i>View Input</i> window.
<i>Legend</i>	Mark this check-box to display the legend with soil types.
<i>Layer Colors</i>	Mark this check-box to display each soil layer using a different color. It is recommended that this option is deselected if printouts are to be photo-copied or faxed.
<i>Rulers</i>	Mark this check-box to display the horizontal and vertical rulers.
<i>Same scale for x and y axis</i>	Mark this check-box to use the same scale for the horizontal and vertical directions.
<i>Origin</i>	Mark this check-box to display the origin.
<i>Large cursor</i>	Mark this check-box to use the large cross-hair cursor instead of the small one.
<i>Points</i>	Mark this check-box to display geometry points in the <i>View Input</i> window, defined in section 4.3.8 .
<i>Loads</i>	Mark this check-box to display loads in the <i>View Input</i> window, defined in section 4.7.1 and section 4.7.2 .
<i>Forbidden lines</i>	Mark this check-box to display forbidden lines in the <i>View Input</i> window, defined in section 4.4.3 .
<i>Geotextiles</i>	Mark this check-box to display geotextiles in the <i>View Input</i> window, defined in section 4.5.1 .
<i>Nails</i>	Mark this check-box to display nails in the <i>View Input</i> window, defined in section 4.5.3 .
<i>Reference level</i>	Mark this check-box to display the reference line in the <i>View Input</i> window, defined in section 4.4.5 .
<i>Labels</i>	Mark the check-box of the elements (<i>Points</i> , <i>Loads</i> , <i>Forbidden lines</i> , <i>Geotextiles</i> , <i>Nails</i> and <i>Layers</i>) to display the labels of this element.
<i>Layers</i>	Soil layers may be identified by their material name, their index in the list of materials, or their index in the list of layers in the soil profile.
<i>Show Grid</i>	Mark this check-box to display and use a grid.
<i>Snap to Grid</i>	Mark this check-box to ensure that objects align to the grid automatically when they are moved or positioned.
<i>Grid Distance</i>	Alter this value to modify the default grid distance.

Accuracy Mouse selection accuracy, define a large value for a large selection area.

Project Properties – Stresses Results

The *Stresses Results* tab allows selecting the way the *Stresses* and *Stresses in Geometry* results are presented in the *Results* windows (see [section 6.2](#) and [section 6.3](#)).

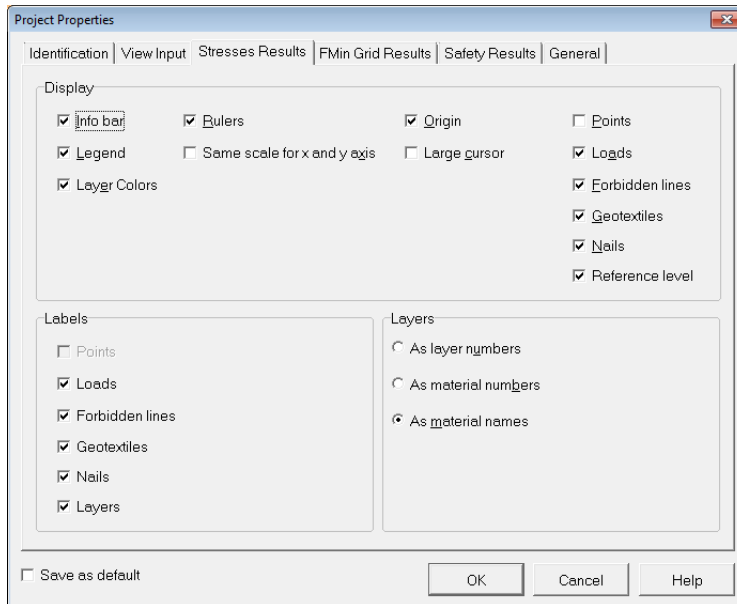


Figure 4.8: Project Properties window, Stresses Results tab

<i>Info bar</i>	Mark this check-box to display the title panel with the information bar at the bottom of the <i>Stresses Result</i> window
<i>Legend</i>	Mark this check-box to display the legend with soil types.
<i>Layer Colors</i>	Mark this check-box to display each soil layer using a different color. It is recommended that this option is deselected if printouts are to be photo-copied or faxed.
<i>Rulers</i>	Mark this check-box to display the rulers.
<i>Same scale for x and y axis</i>	Mark this check-box to enforce the same length scale for horizontal and vertical axis.
<i>Origin</i>	Mark this check-box to display the origin.
<i>Large cursor</i>	Mark this check-box to use the large cursor instead of the small one.
<i>Points</i>	Mark this check-box to display geometry points in the <i>Stresses Results</i> window, defined in section 4.3.8 .
<i>Loads</i>	Mark this check-box to display loads in the <i>Stresses Results</i> window, defined in section 4.7.1 and section 4.7.2 .
<i>Forbidden lines</i>	Mark this check-box to display forbidden lines in the <i>Stresses Results</i> window, defined in section 4.4.3 .
<i>Geotextiles</i>	Mark this check-box to display geotextiles in the <i>Stresses Results</i> window, defined in section 4.5.1 .
<i>Nails</i>	Mark this check-box to display nails in the <i>Stresses Results</i> window, defined in section 4.5.3 .
<i>Reference level</i>	Mark this check-box to display the reference line in the <i>Stresses Results</i> window, defined in section 4.4.5 .
<i>Labels</i>	Mark the check-box of the elements (<i>Points</i> , <i>Loads</i> , <i>Forbidden lines</i> , <i>Geotextiles</i> , <i>Nails</i> and <i>Layers</i>) to display the labels of this element.

<i>Layers</i>	Soil layers may be identified by their material name, their index in the list of materials, or their index in the list of layers in the soil profile.
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Project Properties – FMin Grid Results

The *FMin Grid Results* tab allows selecting the way the minimum factors of safety are represented in the *FMin Grid* results window (section 6.4).

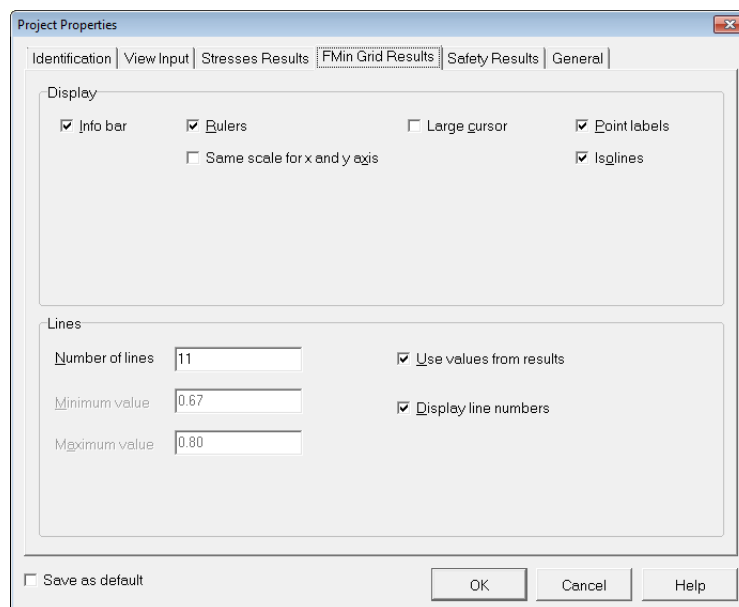


Figure 4.9: Project Properties window, FMin Grid Results tab

<i>Info bar</i>	Mark this check-box to display the information bar at the bottom of the <i>FMin Grid</i> results window.
<i>Rulers</i>	Mark this check-box to display the rulers.
<i>Same scale for x and y axis</i>	Mark this check-box to enforce the same length scale for horizontal and vertical axis.
<i>Large cursor</i>	Mark this check-box to use the large cursor instead of the small one.
<i>Points</i>	Mark this check-box to display geometry points.
<i>Iso-lines</i>	Mark this check-box to display iso-lines of the safety factor on the grid of center points.
<i>Number of lines</i>	Define the number of iso-lines between the lower and upper limits.
<i>Minimum value</i>	Define the lower limit of the iso-lines to be displayed.
<i>Maximum value</i>	Define the upper limit of the iso-lines to be displayed.
<i>Use values from results</i>	Mark this check-box if iso-lines should be displayed with the specified range and number.
<i>Display line numbers</i>	Mark this check-box to display the line numbers.

Project Properties – Safety Results

The *Safety Results* tab allows selecting the way the data in the *Safety Overview* results window is presented. In this window the safety factor distribution is drawn in the geometry.

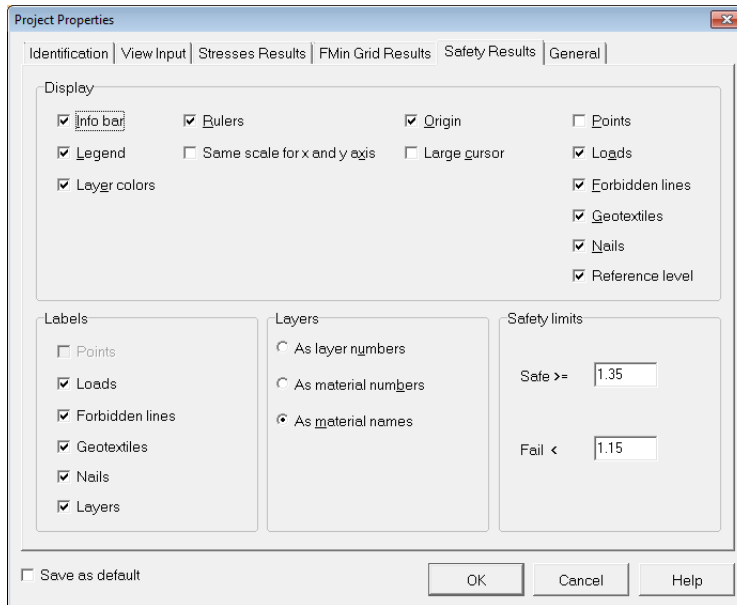


Figure 4.10: Project Properties window, Safety Results tab

<i>Info bar</i>	Mark this check-box to display the information bar at the bottom of the <i>Safety Results</i> window.
<i>Legend</i>	Mark this check-box to display the legend with soil types.
<i>Layer Colors</i>	Mark this check-box to alter the default legend colors.
<i>Rulers</i>	Mark this check-box to display the rulers.
<i>Same scale for x and y axis</i>	Mark this check-box to enforce the same length scale for horizontal and vertical axis.
<i>Origin</i>	Mark this check-box to display the origin.
<i>Large cursor</i>	Mark this check-box to use the large cursor instead of the small one.
<i>Points</i>	Mark this check-box to display geometry points in the <i>Safety Results</i> window, defined in section 4.3.8 .
<i>Loads</i>	Mark this check-box to display loads in the <i>Safety Results</i> window, defined in section 4.7.1 and section 4.7.2 .
<i>Forbidden lines</i>	Mark this check-box to display forbidden lines in the <i>Safety Results</i> window, defined in section 4.4.3 .
<i>Geotextiles</i>	Mark this check-box to display geotextiles in the <i>Safety Results</i> window, defined in section 4.5.1 .
<i>Nails</i>	Mark this check-box to display nails in the <i>Safety Results</i> window, defined in section 4.5.3 .
<i>Reference level</i>	Mark this check-box to display the reference line in the <i>Safety Results</i> window, defined in section 4.4.5 .
<i>Labels</i>	Mark the check-box of the elements (<i>Points</i> , <i>Loads</i> , <i>Forbidden lines</i> , <i>Geotextiles</i> , <i>Nails</i> and <i>Layers</i>) to display the labels of this element.
<i>Layers</i>	Soil layers may be identified by their material name, their index in the list of materials, or their index in the list of layers in the soil profile.
<i>Safe >=</i>	Enter the values that define the safe area in the <i>Safety Overview</i> plot.
<i>Fail <</i>	Enter the values that define the failure area in the <i>Safety Overview</i> plot.

Project Properties – General

The *General* tab allows defining general output preferences:

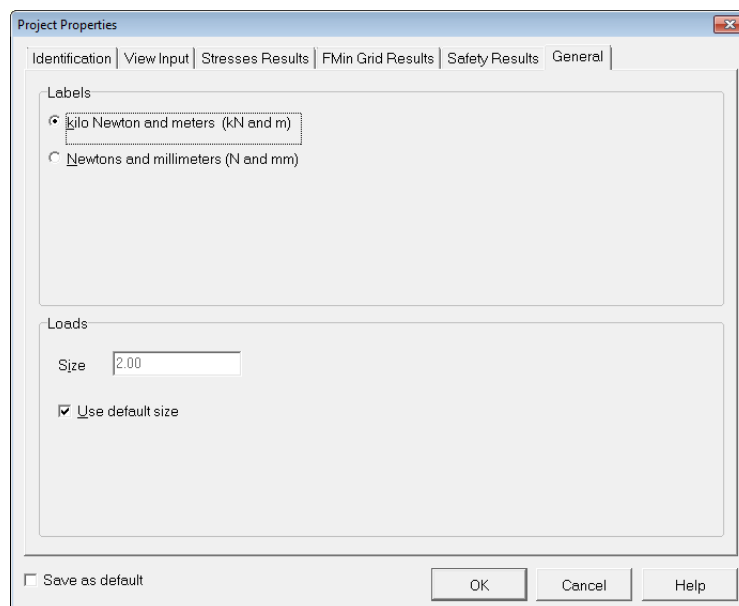



Figure 4.11: Project Properties window, General tab

<i>Labels</i>	Select the units for output of results.
<i>Size</i>	Define the load size in the geometry plot.

4.1.4 View Input File

On the menu bar, click *Project* and then choose *View Input File* to display an overview of the input data.

The data will be displayed in the D-GEO STABILITY main window. Click on the *Print Active Window* icon  to print this file.

4.2 Soil menu

The *Soil* menu can be used to enter the soil properties for the analysis. On the menu bar, click *Soil* to display a menu with the following options for definition of soil type parameters:

- ◇ [section 4.2.1](#) – *Sigma-Tau Curves* to import or enter stress tables:
 - [section 4.2.1.1](#) for traditional deterministic design.
 - [section 4.2.1.2](#) for reliability based design and pseudo values.
 - [section 4.2.1.3](#) for reliability based design and pseudo values.
- ◇ [section 4.2.2](#) – *Bond Stress Diagrams* to define friction curve at the interface between the soil and the nail.
- ◇ [section 4.2.4](#) – *Materials* to define soil type properties by one of the following options:
 - [section 4.2.4.1](#) Input of fixed parameters for traditional deterministic design.
 - [section 4.2.4.2](#) Import from a material library.
 - [section 4.2.4.3](#) Input of parameter distributions for reliability based design.
 - [section 4.2.4.4](#) Input of parameters for pseudo values shear strength model.
 - [section 4.2.4.5](#) Input of parameter for Bishop probabilistic random field method
 - [section 4.2.4.6](#) Input of parameters for the soil/nails interface
- ◇ [section 4.2.5](#) – *Model factor* to define the parameters for Bishop probabilistic random field method.

4.2.1 Sigma-Tau Curves

On the menu bar, click *Soil* and then select *Sigma-Tau Curves* in order to open the *Sigma-Tau Curves* window in which stress tables can be imported or entered. The content of this window depends on the selected model:

- ◇ Refer to [section 4.2.1.1](#) for traditional deterministic design;
- ◇ Refer to [section 4.2.1.2](#) for reliability based design;
- ◇ Refer to [section 4.2.1.3](#) for reliability based pseudo values.

4.2.1.1 Sigma-Tau Curves for deterministic design

The curves relate the normal effective stress σ'_n (sigma) to the shear strength τ (tau). Each curve is defined by entering successive coordinates. A deterministic analysis requires two coordinate pairs (σ'_n and τ -design). Furthermore the input values of both σ'_n and τ must be monotonically increasing. D-GEO STABILITY always extends the curve with a last horizontal branch.

In the *Sigma-Tau Curves* window (see [Figure 4.12](#)) it is possible to specify different sigma-tau curves. [Figure 4.12](#) gives an example a user defined sigma-tau curve.

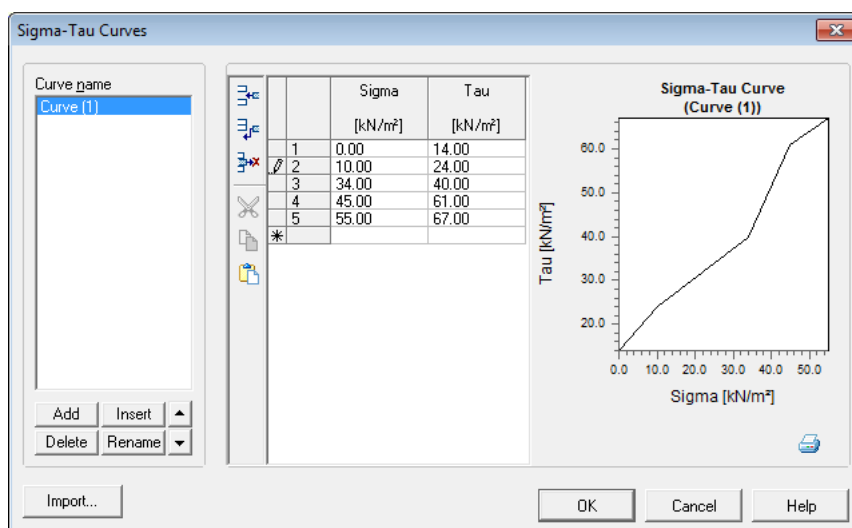


Figure 4.12: Sigma-Tau Curves window for deterministic design

Import predefined Curves

Alternatively, it is possible to use predefined Sigma-Tau curves. To do so, place a file with Sigma-Tau data, called *Tausigma.dat*, in the D-GEO STABILITY Install directory.

When clicking the button, the *Import Stress Table* window appears ([Figure 4.13](#)). This window contains predefined Sigma-Tau curves for different kind of soil.

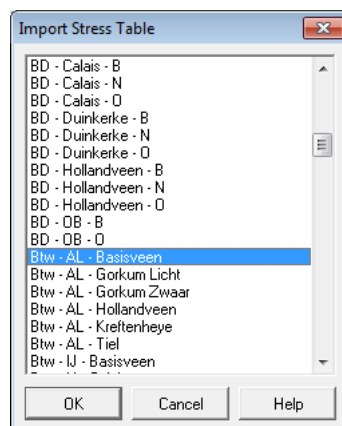


Figure 4.13: Import Stress Table window

After selecting the desired curve and clicking *OK*, this curve is added to the others manually inputted curves in the *Sigma-Tau Curves* window (Figure 4.14).

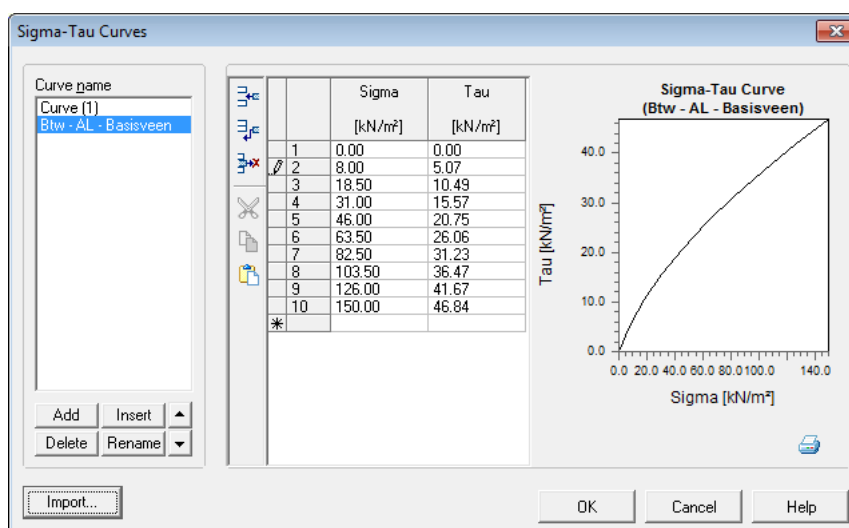


Figure 4.14: Sigma-Tau Curves window with imported data

4.2.1.2 Sigma-Tau Curves for Reliability analysis

If the *Reliability analysis* in the *Model* window is enabled (section 4.1.1), D-GEO STABILITY uses stochastic values for its calculations. The values in the sigma-tau relation are user defined. It is possible that the user provides basic values or data that includes stochastic values. If only deterministic values are provided (while the *Reliability analysis* is enabled) D-GEO STABILITY automatically determines the stochastic values of the Sigma-Tau curves. It does so using standard stochastic assumptions given in the *Probabilistic Defaults* window (section 4.1.2). In this case the stress table will consist of two additional columns. Column 3 contains the characteristic value. Column 4 contains the mean value. See Figure 4.15 for an example.

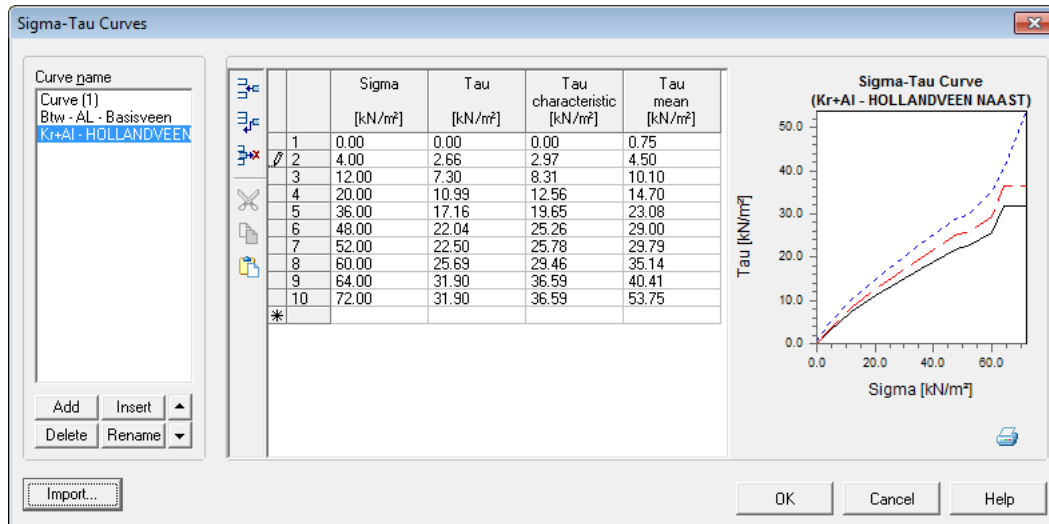


Figure 4.15: Sigma-Tau Curves window for Reliability Analysis

4.2.1.3 Sigma-Tau Curves for Pseudo values Shear strength model

If the *Pseudo values* shear strength model in the *Model* window is enabled (section 4.1.1), D-GEO STABILITY uses stochastic values for its calculations.

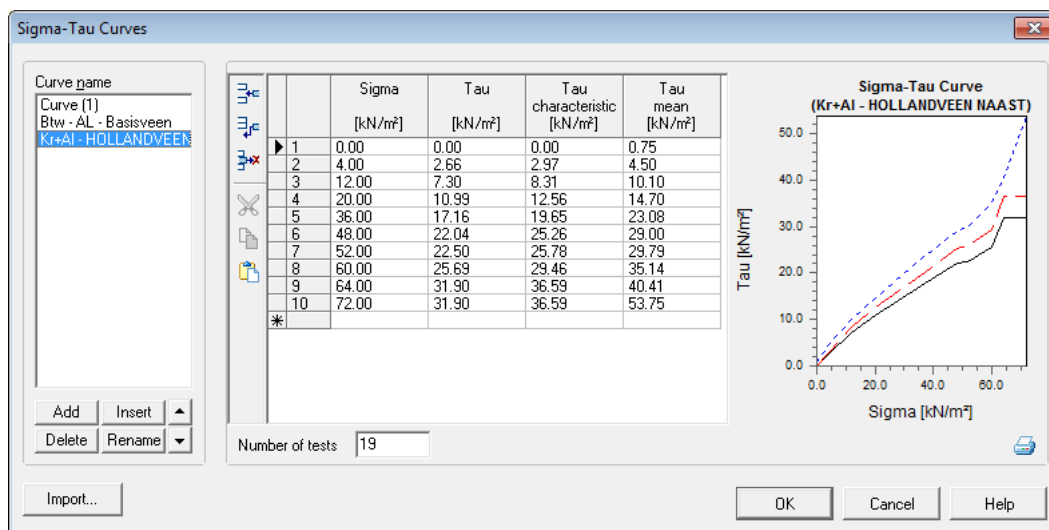


Figure 4.16: Sigma-Tau Curves window for Pseudo values shear strength model

<i>Sigma</i>	The normal stress values of the σ - τ curves.
<i>Tau</i>	The measured shear stress values (drawn in black in the chart at the right of the window).
<i>Tau characteristic</i>	The characteristic shear stress values (drawn in red).
<i>Tau mean</i>	The mean shear stress values (drawn in blue).
<i>Number of tests</i>	Only available for <i>Global</i> measurements (section 4.1.1). The number of tests performed to get the three inputted σ - τ curves (measured, characteristic and mean).

4.2.2 Bond Stress Diagrams

This option is available only if the option *Input of bond stress diagram (sigma, tau)* has been selected in the *Soil Resistance* window (section 4.1.1).

On the menu bar, click *Soil* and then select *Bond Stress Diagrams* in order to open the *Bond Stress Diagrams* window. The curves relate the normal ultimate stress σ'_n (sigma) to the shear ultimate stress τ (tau). Each curve is defined by entering successive coordinates. Two coordinate pairs (σ'_n and τ) are required. Furthermore the input values of both σ'_n and τ must be monotonically increasing. D-GEO STABILITY always extends the curve with a last horizontal branch.

In the *Bond Stress Diagrams* window it is possible to specify different bond stress diagrams. Figure 4.17 gives an example of a user defined bond stress diagram.

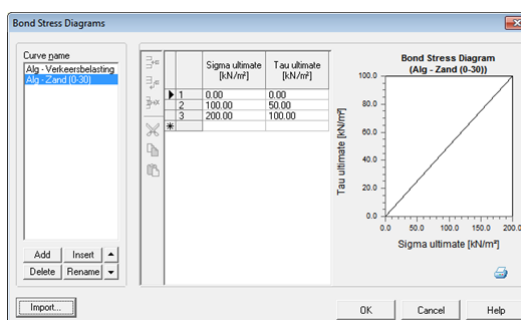


Figure 4.17: Bond Stress Diagrams window

Import predefined Diagrams

Alternatively, it is possible to use predefined bond stress diagrams. To do so, place a DAT file with bond stress data, called *BondStressDiagrams*, in the D-GEO STABILITY Install directory.

When clicking the *Import* button, the *Import Stress Table* window appears (Figure 4.18). This window contains predefined Sigma-Tau curves for different kind of soil.

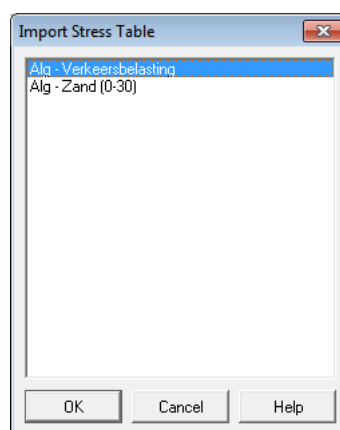


Figure 4.18: Import Stress Table window

After selecting the desired curve and clicking *OK*, this curve is added to the others manually inputted curves in the *Bond Stress Diagrams* window (Figure 4.19).

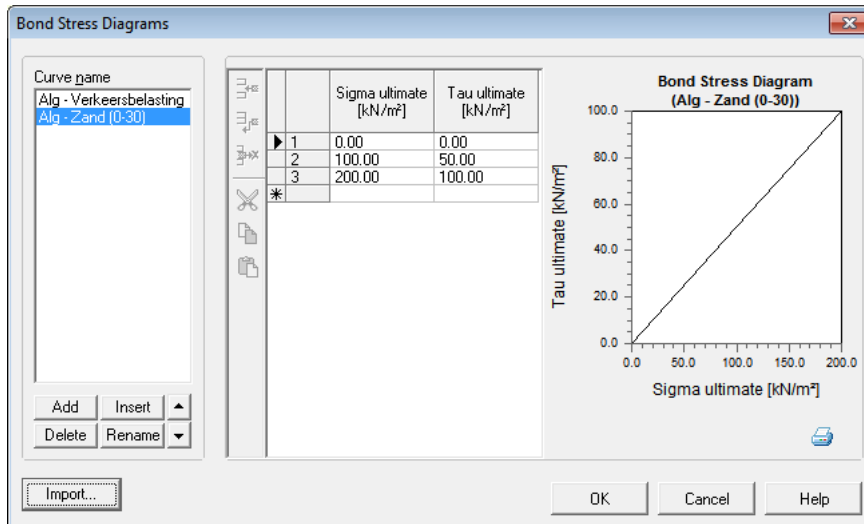


Figure 4.19: Bond Stress Diagrams window with imported data

4.2.3 Measured Yield Stresses

The list of yield stress points with X- and Z-coordinates needed with the Su-calculated with yield stress model, can be entered by selecting *Measured Yield Stresses* under the *Soil* menu.

Note that the copy and paste buttons are available to fill the list (copy and paste from an Excel sheet or Matlab or Python output).

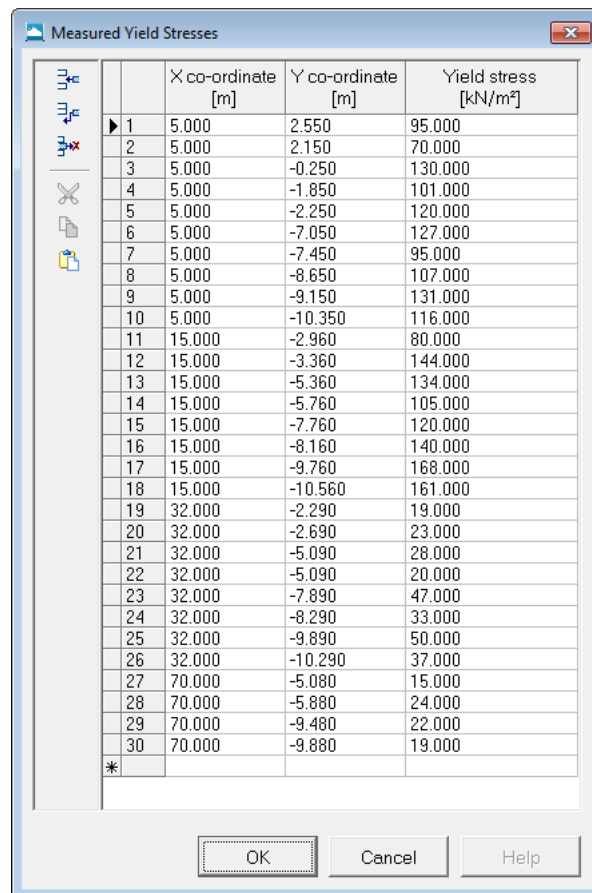


Figure 4.20: Measured Yield Stresses window

4.2.4 Materials

On the menu bar, click *Soil* and then select *Materials*, in order to open the *Materials* window in which material parameters can be imported or entered. The content of this window depends on the selected model:

- ◇ [section 4.2.4.1](#) Input of fixed parameters for traditional deterministic design;
- ◇ [section 4.2.4.2](#) Import from a material library;
- ◇ [section 4.2.4.3](#) Input of parameter distributions for reliability based design;
- ◇ [section 4.2.4.4](#) Input of parameters for pseudo values shear strength model;
- ◇ [section 4.2.4.5](#) Input of parameters for Bishop probabilistic random field method;
- ◇ [section 4.2.4.6](#) Input of parameters for the soil/nails interface;

4.2.4.1 Materials – Input of fixed parameters

The input of fixed parameters for traditional deterministic design is described in this section.

Figure 4.21: Materials window for fixed value input

<i>Total unit weight</i>	The unit weight of the soil: <ul style="list-style-type: none"> – <i>Above phreatic level</i> is the unsaturated unit weight of the soil above the phreatic line (γ_{unsat}) – <i>Below phreatic level</i> is the saturated unit weight of the soil below the phreatic line (γ_{sat}).
<i>Shear strength model</i>	Use one of the following shear strength models, either by default (as defined in section 4.1.1), or by specific selection (see below): <i>C phi</i> , <i>Stress tables</i> , <i>Su calculated with POP</i> , <i>Su calculated with yield stress</i> , <i>Su measured</i> or <i>Su gradient</i> .
	Click this button to add a new material at the end of the existing list.
	Click this button to insert a new material after the selected material.
	Click this button to delete the selected material.
	Click this button to rename the material.

Fixed – Cohesion and friction (C-phi)

Refer to [section 19.2](#) and [section 16.2.2.1.1](#) for background information.

Figure 4.22: Materials window, C-phi shear strength model

<i>Cohesion</i>	The cohesion c , in kN/m^2 .
<i>Friction angle</i>	The internal friction angle φ , in degrees.
<i>Dilatancy</i>	The dilatancy angle ψ , in degrees.

Fixed – Stress table (Sigma-Tau)

Refer to [section 19.2](#) “Stress tables” for background information.

Figure 4.23: Materials window, Stress Tables shear strength model

<i>Stress table</i>	Select a previously defined Sigma-Tau curve (section 4.2.1) from the list.
---------------------	--

Fixed – Calculated undrained shear strength (Su)

Two S_u -calculated models are available:

- ◇ S_u calculated with POP
- ◇ S_u calculated with yield stress ([section 4.2.3](#))

Refer to [section 19.4](#) “Calculated undrained shear strength” for background information.

Figure 4.24: Materials window, S_u -calculated shear strength models

<i>Undrained shear strength ratio S</i>	The uniform ratio between the undrained strength s_u and the vertical yield stress σ'_y . Values range typically between 0.18 and 0.40.
---	--

<i>POP</i>	(Only for <i>Su</i> calculated with POP model) The pre-overburden pressure. D-GEO STABILITY uses this value to calculate the vertical yield stress σ'_y from the effective vertical stress: $\sigma'_y = \max(\sigma'_{v.ref} + POP, \sigma'_v)$ The reference value of the vertical stress $\sigma'_{v.ref}$ is determined from a reference level of the historic ground surface, see section 4.4.5 "Reference Level for Ratio S" .
<i>Strength increase exponent m</i>	(Only for <i>Su</i> calculated with yield stress model) The strength increase exponent m . D-GEO STABILITY uses this parameter to calculate the undrained shear strength as follows: $s_u = \sigma'_v \times S \times OCR^m.$

Fixed – Measured undrained shear strength (*Su*)

Refer to [section 19.3 "Measured undrained strength"](#) for background information.

Figure 4.25: Materials window, *Su*-measured shear strength model

<i>Su top</i>	The apparent undrained strength s_u at the top of the layer.
<i>Su bottom</i>	The apparent undrained strength s_u at the bottom of the layer.

Fixed – Gradient undrained shear strength (*Su*)


Refer to [section 19.4 "Calculated undrained shear strength"](#) for background information.

Figure 4.26: Materials window, *Su*-gradient shear strength model

<i>Su top</i>	The apparent undrained strength s_u at the top of the layer.
<i>Su gradient</i>	The apparent gradient in undrained strength s_u over the depth of the layer (per meter).

4.2.4.2 Materials – Import from Database

It is possible to access the MGeobase material database for predefined material properties. It is necessary that the database option for D-GEO STABILITY is available. To be able to access the database, its directory first has to be indicated in the *Program Options* window from the *Tools* menu:

- ◇ Click on the *Locations* tab.
- ◇ Make sure that the *Use MGeobase database* check-box is marked.
- ◇ The *Browse* button  allows the user to determine the database file to be used.
- ◇ Select the relevant database. An example is given in [Figure 4.27](#).

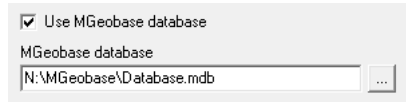



Figure 4.27: Program Options window, Locations tab, Database selection

To use the MGeobase database in the *Materials* option in the *Soil* menu, do the following:

- ◇ On the menu bar, click *Soil* and then select *Materials* in order to open the *Materials* window, see [section 4.2.4.1](#).
- ◇ Select the *Database* tab.
- ◇ Select the material of which the properties are to be imported.
- ◇ Click the arrow  button to import.

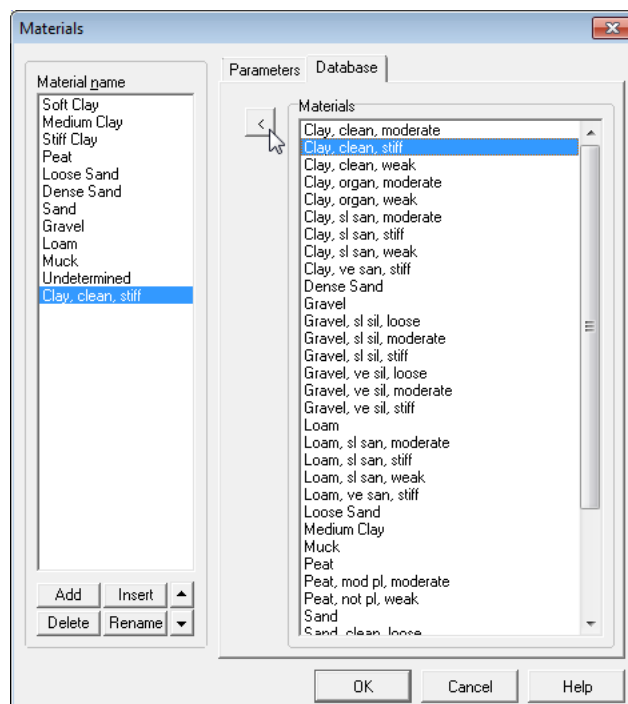


Figure 4.28: Materials window, Database tab, Import predefined soil types



Note: If the soil type has already been defined locally, then D-GEO STABILITY will ask if the existing local properties should be overwritten

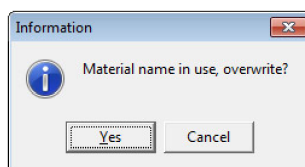


Figure 4.29: Information window

4.2.4.3 Materials – Soil Groups

This option is available only if the *Pseudo values* shear strength model with *Global* measurements in the *Model* window is enabled (section 4.1.1) or when the *Reliability analysis* option is selected. On the menu bar, click *Materials* in the *Soil* menu (see Figure 4.30). This window is the same as for fixed parameters (section 4.2.4.1) except that it is now possible to define *Soil Groups*. Inside a soil group, correlation factors between the soil materials are used for the calculation of the pseudo Tau value. For background information, refer to section 19.5.2.

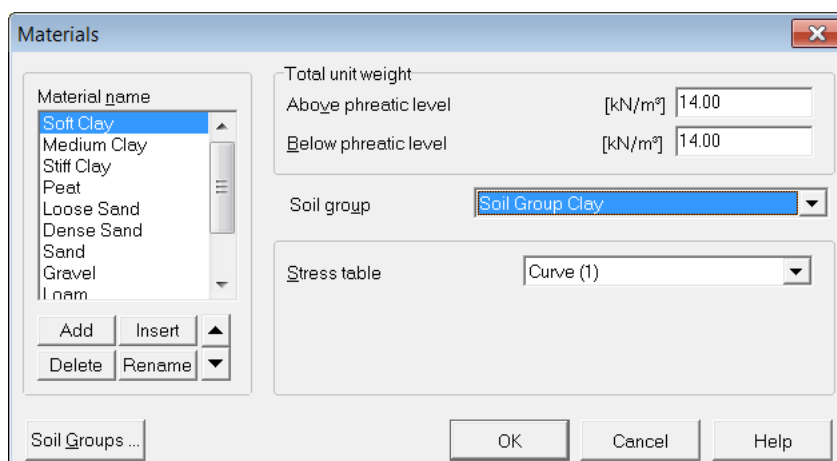


Figure 4.30: Materials window for *Pseudo values* shear strength model with *Global* measurements

Soil Groups ...

Click the *Soil Groups* button at the bottom of the *Materials* window to open the *Soil Groups* window (see Figure 4.31).

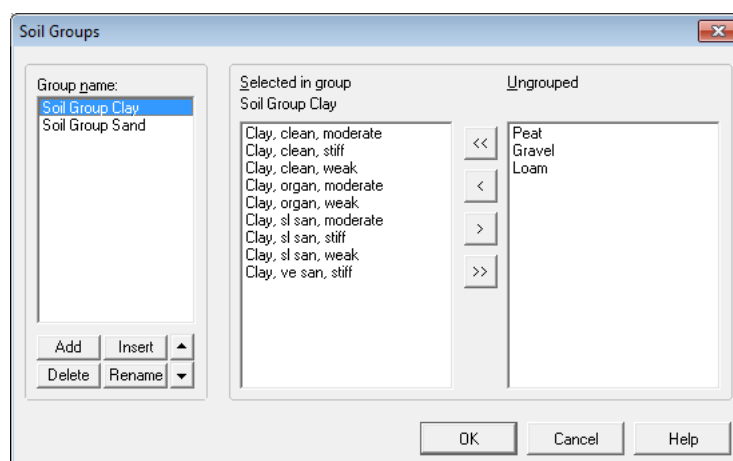
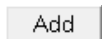






Figure 4.31: Soil Groups window

In this window it is possible to define soil groups.

	Click on the <i>Add</i> button to create a new <i>Soil Group</i> . Select a material in the available list of soil materials called <i>Ungrouped</i> at the right side of the window.
	Click on the <i>Select highlighted material</i> button to add the selected material to the selected soil group.
	Click on the <i>Select all materials</i> button to add all the available materials in the selected soil group.
	Click the <i>Unselect highlighted material</i> button to delete the selected material from the selected soil group.
	Click the <i>Unselect all material</i> button to delete the selected material from the selected soil group.

A soil material can be part of only one soil group. Therefore, when selected in a group, the soil material disappears from the *Ungrouped* list.

4.2.4.4 Materials – Reliability Analysis

If the *Reliability analysis* in the *Model* window is enabled ([section 4.1.1](#)), D-GEO STABILITY uses stochastic values for its calculations. On the menu bar, click *Materials* in the *Soil* menu (see [Figure 4.32](#)). In this window it is possible to enter material parameters and their statistical descriptions.

By default, the *Standard* option is selected and allows inputting standard stochastic parameters.

Materials

Material name: **Soft Clay**
 Medium Clay
 Stiff Clay
 Peat
 Loose Sand
 Berm Sand
 Sand
 Gravel
 Loam
 Muck
 Undetermined

Total unit weight
 Above phreatic level [kN/m³]: 14.00
 Below phreatic level [kN/m³]: 14.00

Soil group: none

Shear strength model: Default (C phi) Standard Advanced

Shear strength input: Default (Mean) Use probabilistic defaults

Shear strength parameters

	Mean	Design	Std. dev.	Distribution
Cohesion (c) [kN/m ²]	8.00	4.14	2.00	Log normal
Friction angle (phi) [deg]	20.00	14.06	3.00	Log normal
Dilatancy (psi) [deg]	22.00			

PI pore pressure parameters

	Std. dev.	Distribution
Hydraulic pressure [kN/m ²]	0.50	Log normal

Add Insert ▲
 Delete Rename ▼

Soil Groups ... OK Cancel Help

Figure 4.32: Materials window for Standard stochastic input

Only the stochastic parameters are described in the paragraph. For the description of the material parameters, refer to *Materials – Input of fixed parameters* (section 4.2.4.1).

<i>Shear strength model</i>	Selected a shear strength model from the drop-down list.
<i>Shear strength input</i>	Use one of the following type of input parameters, either by default (as defined in section 4.1.1), or by specific selection: <i>Mean</i> values or <i>Design</i> values.
<i>Use probabilistic defaults</i>	Select this option when D-GEO STABILITY should allow user-defined values for stochastic data (section 4.1.1). Also unselect this option when D-GEO STABILITY should derive stochastic data from the last two columns of a stress table. When the option is reselected, the defaults will overwrite all user-defined stochastic data for this soil type.
<i>Standard / Advanced</i>	Select the advanced button to access both regular and special shear strength parameters.
<i>Mean</i>	The mean value of a parameter (section 20.3.1).
<i>Design</i>	The design value of a parameter (section 20.3.6).
<i>Std. dev.</i>	The standard deviation of a parameter (section 20.3.2).
<i>Distribution</i>	The distribution type of a parameter: <i>Normal</i> , <i>Log normal</i> or <i>None</i> (section 20.2). A distribution type <i>None</i> is equivalent to a zero standard deviation.

Hydraulic pressure The hydraulic pressure, defined by PL-lines (section 20.4.3).

Stochastic – Cohesion and friction angle (c, ϕ)

Select the *Advanced* button to access both regular and special shear strength parameters.

Parameter	Mean	Design	Std. dev.	Distribution
Cohesion (c) [kN/m ²]	25.00	12.92	6.25	Log normal
Friction angle (ϕ) [deg]	17.50	12.30	2.63	Log normal
Dilatancy (ψ) [deg]	17.50			

Figure 4.33: C-phi – Standard stochastic input

Cohesion The cohesion c .

Friction Angle The internal friction angle ϕ .

Dilatancy The dilatancy angle ψ , in degrees. Note that this parameter is not a stochast.

Figure 4.34: C-phi – Advanced stochastic input

Correlation coefficient cohesion and $\tan(\phi)$ The correlation coefficient defines the dependency between variations of cohesion and $\tan(\phi)$. A value of 1 means that both parameters will vary equally, with respect to the mean value. A zero value means that the parameters can vary independently. A zero value is a safe assumption.

Design value factors - Partial The partial factor f_{partial} used by D-GEO STABILITY to reduce the unfavorable characteristic value of cohesion and friction angle to a safe lower limit (section 20.3.6).

Design value factors - Std. dev. The value of the standard normal parameter u_{charac} used by D-GEO STABILITY to calculate the unfavorable characteristic value of cohesion and friction angle (section 20.3.4 and section 20.3.5).

Stochastic – Stress table (Sigma-Tau)

Figure 4.35: Stress table (sigma-tau) – Standard stochastic input

Stress table	Select a previously defined or imported stress table (see also section 4.2.1 , section 19.2 and section 20.3.3).
Distribution	The distribution type of the shear strength: <i>Normal</i> , <i>Log normal</i> or <i>None</i> (section 20.2). The distribution type <i>None</i> is equivalent to a zero standard deviation.

Figure 4.36: Stress table (sigma-tau) – Advanced stochastic input

Design value factors – Partial	The partial factor f_{partial} used by D-GEO STABILITY to reduce the unfavorable characteristic value of the shear strength to a safe lower limit (section 20.3.6).
Design value factors – Std. dev.	The value of the standard normal parameter u_{charac} , used by D-GEO STABILITY to calculate the unfavorable characteristic value of cohesion and friction angle (section 20.3.4 and section 20.3.5).

Stochastic – Calculated undrained shear strength (S_u)

Note: A stochastic analysis is available only for the *Su-calculated with POP* model, not for the *Su-calculated with yield stress* model.



Figure 4.37: Su-calculated with POP – Standard stochastic input

<i>Undrained shear strength ratio S</i>	The ratio between the undrained shear strength s_u and the vertical yield stress σ'_y (section 19.4). Values range typically between 0.18 and 0.40. Average values for horizontal orientation of the slip plane are derived from example from Direct Simple Shear (DSS) tests.
<i>POP</i>	The pre-overburden pressure. D-GEO STABILITY uses this value to calculate the yield stress σ'_y from the effective vertical stress: $\sigma'_y = \max(\sigma'_{v.ref} + POP, \sigma'_v)$ The reference value of the vertical stress $\sigma'_{v.ref}$ is determined from a reference level of the historic ground surface, see section 4.4.5.

Figure 4.38: *Su calculated with POP – Advanced stochastic input*

<i>Uniform ratio S</i>	Unselect this option to define stress induced anisotropy for over-consolidated soil (section 19.4).
<i>Mean</i>	The mean value of the ratio (section 20.3.1).
<i>Design</i>	The design value of the ratio (section 20.3.6).
<i>Undrained shear strength ratio S – Passive (low, TE)</i>	The low value of the undrained shear strength ratio, resulting from Triaxial Extension tests.
<i>Undrained shear strength ratio S – Active (high, TC)</i>	The high value of the undrained shear strength ratio, resulting from Triaxial Compression tests.
<i>Design value factors - Partial</i>	The partial factor f_{partial} used by D-GEO STABILITY to reduce the unfavorable characteristic value of the undrained shear strength ratio (S) and pre-overburden pressure (POP) to a safe lower limit (section 20.3.6).
<i>Design value factors – Std. dev.</i>	The value of the standard normal parameter u_{charac} used by D-GEO STABILITY to calculate the unfavorable characteristic value of the undrained shear strength ratio (S) and pre-overburden pressure (POP) (section 20.3.4 and section 20.3.5).

Stochastic – Measured undrained shear strength (S_u)

	Mean	Design
Top	6.00	3.37
Bottom	8.00	4.50
Std. dev.	1.75	
Distribution	Log normal	

Figure 4.39: S_u measured – Standard stochastic input

<i>Horizontal undrained strength S_u (DSS)</i>	Undrained shear strength for a horizontal slip plane, derived from Direct Simple Shear (DSS) tests (section 19.3).
<i>Top</i>	The apparent undrained shear strength s_u at the top of the layer.
<i>Bottom</i>	The apparent undrained shear strength s_u at the bottom of the layer.
<i>Std. dev.</i>	The value of the standard normal parameter u_{charac} used by D-GEO STABILITY to calculate the unfavorable characteristic value of the undrained shear strength (section 20.3.4 and section 20.3.5).

	Mean	Design
Passive undrained strength Su (low, TE) - Top	6.00	3.37
Passive undrained strength Su (low, TE) - Bottom	8.00	4.50
Active undrained strength Su (high, TC) - Top	7.00	3.93
Active undrained strength Su (high, TC) - Bottom	9.00	5.06
Su design value factors - Partial	1.15	
Su design value factors - Std. dev.	-1.65	

Figure 4.40: S_u measured – Advanced stochastic input

<i>Uniform S_u</i>	Select this option to define stress induced anisotropy for over-consolidated soil (section 19.3).
---------------------------------	---

<i>Passive undrained strength S_u (low, TE)</i>	The low value of the undrained shear strength at the passive side of the slip plane, derived from Triaxial Extension (TE) tests.
<i>Active undrained strength S_u (high, TC)</i>	The high value of the undrained shear strength at the active side of the slip plane, derived from Triaxial Compression (TC) tests.
<i>Top</i>	The apparent undrained shear strength s_u at the top of the layer.
<i>Bottom</i>	The apparent undrained shear strength s_u at the bottom of the layer.
<i>Design value factors - Partial</i>	The partial factor f_{partial} used by D-GEO STABILITY to reduce the unfavorable characteristic value of the undrained shear strength to a safe lower limit (section 20.3.6).
<i>Design value factors – Std dev.</i>	The value of the standard normal parameter u_{charac} , used by D-GEO STABILITY to calculate the unfavorable characteristic value of the undrained shear strength (section 20.3.4 and section 20.3.5).

Stochastic – Gradient undrained shear strength (S_u)

Shear strength model	Su gradient				
Shear strength input	Default (Mean)	<input checked="" type="checkbox"/> Use probabilistic defaults			
Horizontal undrained strength S_u (DSS)					
		Mean	Design	Std. dev.	Distribution
Top	[kN/m ²]	6.00	3.37	1.50	Log normal
Gradient	[kN/m ² /m]	0.50	0.28	0.13	Log normal

Figure 4.41: S_u gradient – Standard stochastic input

<i>Horizontal undrained strength S_u (DSS)</i>	Undrained shear strength for a horizontal slip plane, derived from Direct Simple Shear (DSS) tests (section 19.3).
<i>Top</i>	The apparent undrained shear strength s_u at the top of the layer.
<i>Gradient</i>	The apparent gradient in undrained shear strength s_u over the depth of the layer (per meter).
<i>Std. dev.</i>	The value of the standard normal parameter u_{charac} used by D-GEO STABILITY to calculate the unfavorable characteristic value of the undrained shear strength (section 20.3.4 and section 20.3.5).

4.2.4.5 Materials – Bishop probabilistic random field method

If the *Bishop probabilistic random field* method in the *Model* window is enabled ([section 4.1.1](#)), D-GEO STABILITY uses stochastic values for its calculations. On the menu bar, click *Soil* and then select the *Materials* option to open the *Materials* window (see [Figure 4.42](#)). In this window all data related to the soil type is entered. Note that in this method the dilatancy angle is not used. See [section 21.5.1](#) for background.

Figure 4.42: Materials window for Bishop probabilistic random field method

<i>Cohesion</i>	Bishop prob. random field Mean value of the cohesion.
<i>Friction angle</i>	Mean value of the friction angle.
<i>Std dev c</i>	Standard deviation of the cohesion.
<i>Std dev phi</i>	Standard deviation of the tangent of the friction angle.
<i>Cor c-phi</i>	Correlation coefficient between cohesion and friction angle, ranging between -1 and 1. A1. A zero value means that parameter values can vary independently. A value of 1 means that the values of cohesion and friction vary identically on normalized scale. A value of -1 means that the increase of one value causes an identical decrease in the other value, again on normalized scale.
<i>Std press pn</i>	Standard deviation of the hydraulic pore pressure per material. This hydraulic pressure is derived from the input of PL-lines per layer (<i>Geometry</i> menu, <i>Water</i> menu). See section 20.4.3 .
<i>Dh c</i>	Bishop prob. random field correlation length of the cohesion. See section 21.5.1 Equation 21.3 .
<i>Dv c</i>	The vertical correlation length of the cohesion. See section 21.5.1, Equation 21.3 .
<i>N tests c</i>	Number of tests used to determine the cohesion. The model uses this value to modify the auto-correlation function. See section 21.5.1, Equation 21.5 .
<i>Vert/tot var c</i>	The ratio α between vertical and total variance (variance is the square of the standard deviation) of the cohesion. See section 21.5.1, Equation 21.3 .
<i>dh phi</i>	The horizontal correlation length of the friction angle. See section 21.5.1 Equation 21.2 .
<i>dv phi</i>	The vertical correlation length of the friction angle. See section 21.5.1, Equation 21.2 .
<i>N tests phi</i>	Number of tests used to determine the friction angle. The model uses this value to modify the auto-correlation function. See section 21.5.1, Equation 21.4 .
<i>Vert/tot var phi</i>	The ratio α between vertical and total variance (variance is the square of the standard deviation). See section 21.5.1, Equation 21.4 .

4.2.4.6 Materials – Nails

If the *Use soil parameters c, phi / Su* option in the *Soil Resistance* window is selected (section 4.1.1), D-GEO STABILITY uses the following soil parameters to determine:

- ◇ the ultimate lateral stress at the interface soil/nail p_u using either the friction angle φ or the undrained shear strength s_u of the soil, depending on the *Shear Strength* model of the soil:

$$p_u = 3 \times \sigma'_v \times K_p \quad \text{with} \quad K_p = \frac{1 + \sin \varphi}{1 - \sin \varphi} \quad \text{for c-phi models}$$

$$p_u = 9 \times s_u \quad \text{for Su models}$$

- ◇ the Young's modulus of the soil E_s using the compression ratio of the soil ($CR = \frac{C_c}{1 + e_0}$) and the rheological coefficient of the soil α .

See section 16.2.2.3 for background information.

Figure 4.43: Materials window for nails with option *Use soil parameters c, phi / Su*

<i>Use soil type</i>	If this check-box is marked, the <i>Soil type</i> must be specified. D-GEO STABILITY will automatically determine the compression ratio and the rheological coefficient using the values according to Ménard and given in Table 4.1.
<i>Compression ratio (Cc/1+eo)</i>	Enter the compression ratio of the soil $CR = C_c / (1 + e_0)$.
<i>Rheological coefficient (alpha)</i>	Enter the rheological coefficient of the soil (α), empirical parameter used by Ménard to relate the modulus of deformation E_s to the pressuremeter modulus E_{pm} : $E_s = E_{pm} / \alpha$
<i>Bond stress</i>	Select a previously defined bond stress diagram (section 4.2.2) from the list.

Table 4.1: Rheological coefficient and compression ratio for different soil types

Soil type	Rheological coefficient α	Compression ratio $CR = C_c/(1 + e_0)$
Gravel	1/4	0.0023884
Sand	1/3	0.0039806
Loam	1/2	0.0495100
Clay	2/3	0.1287400
Peat	1	0.8991000

4.2.5 Model Factor

This option is available only if the *Bishop probabilistic random field* method in the *Model* window is enabled (section 4.1.1). On the menu bar, click *Soil* and then select the *Model Factor* option in order to open the *Model Factor* window (see Figure 4.44). In this window, all general stochastic data can be entered. See section 21.5.3 for background.

Figure 4.44: Model Factor window

<i>Limit value stability factor</i>	The required value for the safety factor F_{required} .
<i>Standard deviation for the limit value stability factor</i>	This value expresses the uncertainty caused by the Bishop model assumptions.
<i>Reference standard deviation for degree of consolidation</i>	The standard deviation of the reference excess pore pressure at a degree of consolidation of 50%. See Equation 20.22 in section 20.4.3.
<i>Length of section</i>	The length of the considered section in the out-of-plane direction.
<i>Use contribution of end section</i>	Select this button to include the stability increase caused by the resistance at the edges of a sliding section in the out-of-plane direction, see section 21.5.3.
<i>Lateral stress ratio</i>	The model assumes a single value for the earth pressure coefficient K_0 of all layers during calculation of the resistance at the edges. A common value is 0.5. Lateral stress ratio
<i>Coefficient of variation contribution edge</i>	The ratio for the moment at the edges of a section. See Equation 21.9 in section 21.5.3.

4.3 Geometry menu

The Geometry menu can be used to enter geometry specifications for the analysis.

4.3.1 New

Select this option to display the *View Input (Geometry)* window, showing only the geometry limits (with their default values) of the geometry. It is possible to now start modeling the geometry. However, it is possible to create a new geometry faster and easier using the Geometry Wizard. This wizard involves a step-by-step process for creating a geometry.

4.3.2 New Wizard

Use this option to start the wizard, which will guide the user step-by-step through the process of creating a geometry. For a detailed description see Tutorial 1 ([chapter 8](#)). Using this wizard significantly reduces time and effort required to enter data.

4.3.3 Import

This option displays a standard file dialog for selecting an existing geometry stored in a geometry file. Existing input files for D-SETTLEMENT (formerly known as MSettle), D-GEO STABILITY, D-GEO PIPELINE (formerly known as MDrill) or MSeep are also supported. For a full description of these programs and how to obtain them, visit www.deltaressystem.com.

When selecting the geometry, it is imported into the current project, replacing the current geometry. The imported geometry is displayed in the *View Input (Geometry)* window. It is also possible to use this option to analyze the settled geometry at different stages, as all other input is retained.

Click *Import* in the *Geometry* menu. The *Import Geometry From* dialog will appear, see [Figure 4.45](#). Choose the desired geometry and click *Open*.

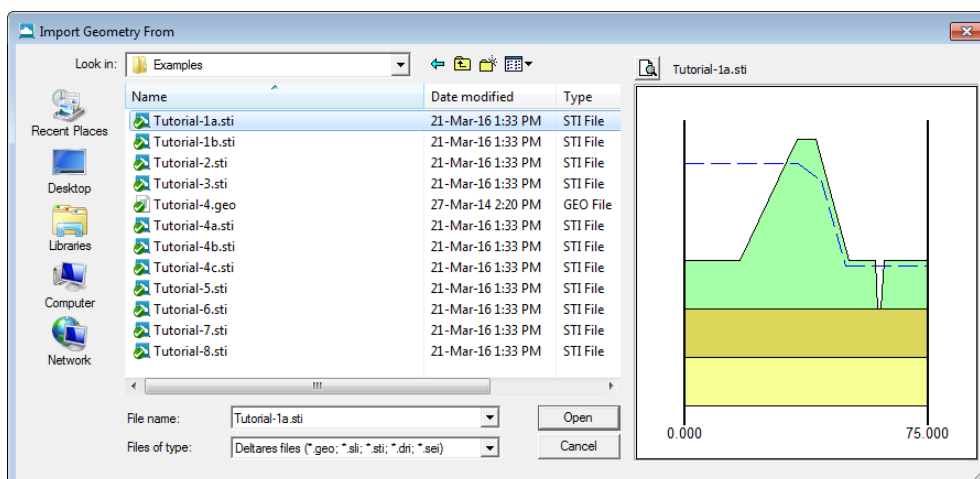


Figure 4.45: Import Geometry From window

4.3.4 Import geometry from database

To be able to import a geometry from a database, this option has to be provided with the purchased version of D-GEO STABILITY.

To import a geometry from a database, click *Import from Database* in the *Geometry* menu. The *Select Geometry* dialog will appear. Again, the imported geometry will replace the current one and will be displayed in the *View Input (Geometry)* window.

Note: This option is only available when the correct database directory has been specified using the *Locations* tab in the *Program Options* menu (see [section 4.2.4](#)). For more information on MGeobase, visit www.deltaressystems.com.



4.3.5 Export

This option displays a standard *Save As* dialog that enables the user to choose a directory and a file name and format in which to save the current geometry file. The file will be saved in the standard geometry format for the Deltares Systems Geo-tools (*.geo). Files in this format can be used in a multitude of Deltares Systems geo-programs, such as D-GEO STABILITY, D-SETTLEMENT (formerly known as MSettle), MSeep and D-GEO PIPELINE (formerly known as MDrill). For a full description of these programs and how to obtain them, visit: www.deltaressystems.com.

4.3.6 Export as Plaxis/DOS

This option displays the *Save As Plaxis/DOS* dialog that enables the user to choose a directory and a file name in which to save the current geometry. The file will be saved using the old DOS-style geometry format for the Deltares systems geo-tools. Files in this format can be used by the finite element program Plaxis and in old DOS-based versions of Deltares Systems programs such as D-GEO STABILITY (DOS) and MZet.

Saving files of this type will only succeed, however, if the stringent demands imposed by the old DOS style are satisfied:

- ◇ number of layers = 20
- ◇ number of PL-lines = 20
- ◇ number of lines per boundary < 50
- ◇ total number of points = 500

To be able to differentiate between an old DOS-style file and a normal geometry file, the file dialog that prompts for a new file name for the old DOS-style geometry file provides a default file name, prefixing the current file name with a 'D'.

4.3.7 Limits

Use this option to edit the geometry limits.

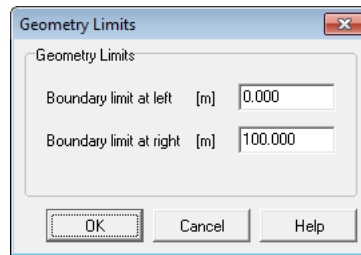


Figure 4.46: Geometry Limits window

A limit is a vertical boundary defining the 'end' at either the left or right side of the geometry. It is defined by an X coordinate only.



Note: The values entered in the *Geometry Limits* window are ignored if they resulted in an invalid geometry.

4.3.8 Points

Use this option to add or edit points that can be used as part of layer boundaries or PL-lines (section 4.3.10). A point is a basic geometry element defined by its coordinates. Since the geometry is restricted to two dimensions, it allows the user to define an X and Y coordinates, respectively in horizontal and vertical directions.

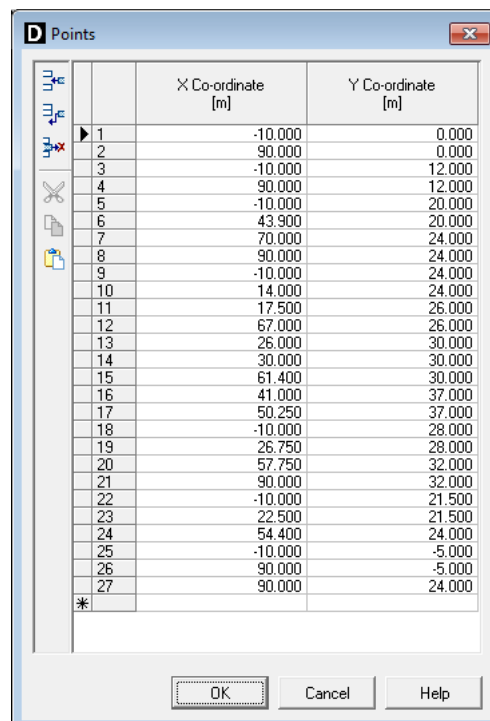


Figure 4.47: Points window



Note: When a point is to be deleted, D-GEO STABILITY will check whether the point is used as part of a PL-line or layer boundary. If so, a message will be displayed.

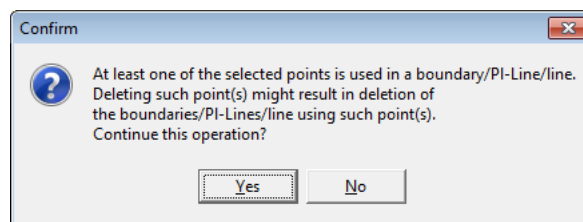


Figure 4.48: Confirm window for deleting used points

When *Yes* is clicked, all layer boundaries and/or PL-lines using the point will also be deleted.

Every change made using this window (Figure 4.47) will only be displayed in the underlying *View Input (Geometry)* window after closing this window using the *OK* button. When this button is clicked, a validity check is performed on the geometry. Any errors encountered during this check are displayed in a separate window. Of course, it is always possible to close the window using the *Cancel* button, but this will discard all changes.

4.3.9 Import PL-line

Use this option to display the *Import PL-line* dialog for importing a Piezometric Level (PL) line from an existing MPL file. Such file is made using the WATEX program of Deltares: in tab *Head-Location Plot*, click on the button “Export...” and fill in a file name in the “Export Water Pressure Line” window.

4.3.10 PL-lines

Use this option to add or edit Piezometric Level lines (PL-lines) to be used in the geometry. A PL-line represents the pore pressures in the soil. A file can contain more PL-lines as different soil layers can have different piezometric level. In the next section it is described how different PL-lines are assigned to different layers.

It is possible to add, insert edit and delete PL-lines (see Figure 4.49).

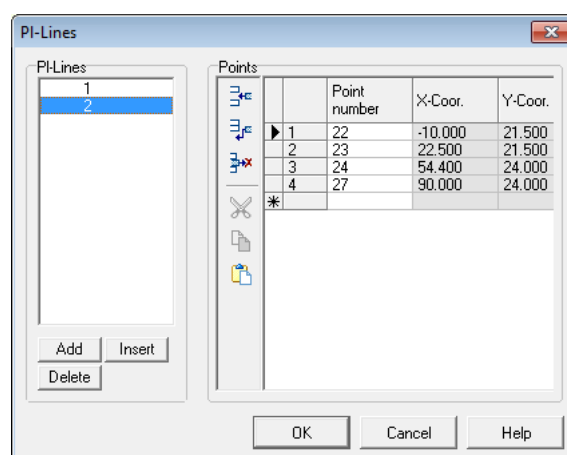


Figure 4.49: PL-lines window

In the lower left part of the window it is possible to use the buttons to add, insert and delete PL-lines. The selection box on the left can be used to navigate between PL-lines that have already been defined.

Use the table to add/edit the points identifying the PL-lines. It is only possible to select points that are not attached to layer boundaries ([section 4.3.12](#)).



Note: It is only possible to manipulate the *Point number* column – that is, the coordinate columns are purely for informative purposes. To manipulate the coordinates of the points, select the *Points* option from the *Geometry* menu (see [section 4.3.8](#)).

Every change made using this window will only be displayed in the underlying *View Input (Geometry)* window after closing this window using the *OK* button. When clicking this button, a validity check is performed on the geometry. Any errors encountered during this check are displayed in a separate window. These errors must be corrected before closing this window using the *OK* button. Of course, it is always possible to close the window using the *Cancel* button, but this will discard all changes.

4.3.11 Phreatic Line

Use this option to select the PL-line that acts as a phreatic line (see [Figure 4.50](#)). The phreatic line (or groundwater level) is used to mark the border between dry and wet soil.

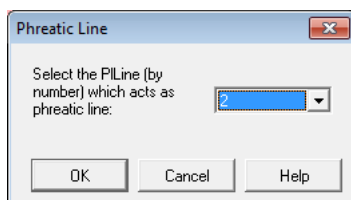


Figure 4.50: Phreatic Line window

Select the appropriate line number from the drop-down list and click the *OK* button. At least one PL-line has to be defined to be able to pick a Phreatic Line.

4.3.12 Layers

This option enables the user to add or edit layers to be used in the geometry. A layer is defined by its boundaries and its material. Use the *Boundaries* tab (seen here in [Figure 4.51](#)) to define the boundaries for all layers by choosing the points that identify each boundary.

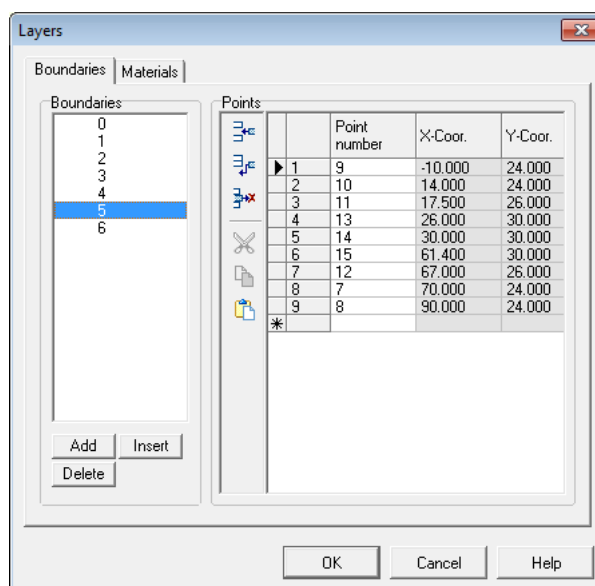


Figure 4.51: Layers window, Boundaries tab

On the left-hand side of the window, it is possible to add, insert, delete or select a boundary. In the table on the right, it is possible to modify or add the points that identify the selected boundary.

Note: It is only possible to select points that are not attached to PL-lines ([section 4.3.10](#)).



Note: It is only possible to manipulate the *Point number* column, because the coordinate columns are purely for informative purposes. To manipulate the coordinates of the points, select the *Points* option in the *Geometry* menu (see [section 4.3.8](#)).



Note: When inserting or adding a boundary, all points of the previous boundary (if this exists) are automatically copied. By default, the material of a new layer is set equal to the material of the existing layer just beneath it.



The *Materials* tab (see [Figure 4.52](#)) enables the user to assign materials to the layers.

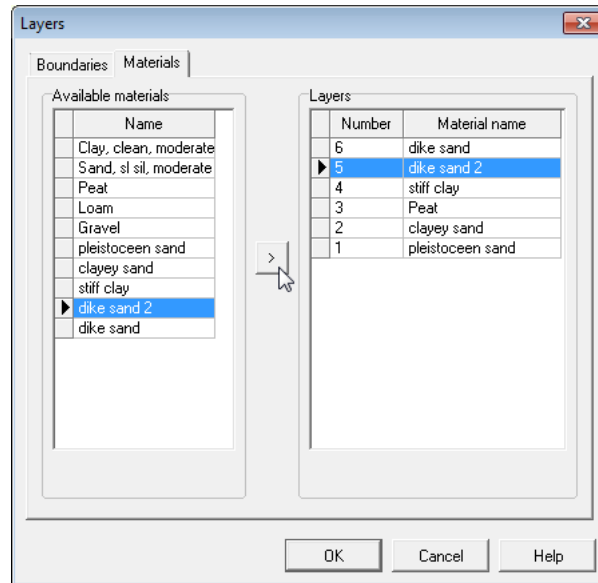



Figure 4.52: Layers window, Materials tab

On the left of the screen, a list containing all defined materials (see the *Materials* option in the *Soil* menu [section 4.2.4.1](#)) is displayed. On the right, a list of all defined layers together with their assigned materials (if available) is displayed. Note that the layers are listed from top to bottom as displayed in the *View Input (Geometry)* window.

To assign a material to a layer, first select that layer on the right of the window. Then select the required material on the left of the window. Finally, click the *Assign*  button.

4.3.13 PL-lines per Layer

Use this option to define the top and bottom PL-lines for the defined layers. The PL-lines represent the pore pressure in a soil layer. For each soil layer (except the deepest layer), two PL-line numbers can be entered – one that corresponds to the top of the soil layer, and one that corresponds to the bottom.

Therefore, different PL-lines can be defined for the top and bottom of each soil layer (see [section 4.3.13](#)).

To do this, select the appropriate PL-line at top / PL-line at bottom field and enter the appropriate number, see [Figure 4.53](#).



Note: D-GEO STABILITY has reserved two numbers for special cases. Also use the special values 0 and 99.

D-GEO STABILITY's Darcy model expects only input for layers with fixed head, as it will calculate by itself the distribution inside clusters of compressible layers.

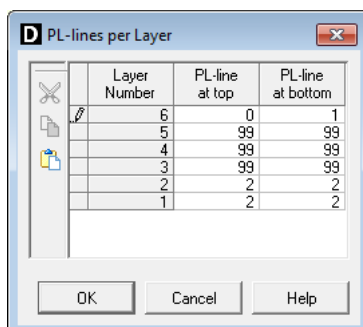


Figure 4.53: PL-lines per Layer window

Note: For the deepest soil layer, no second PL-line number is required. For this layer a hydrostatic increase of the pore pressure is automatically assumed from the pore pressure at the top of the layer downwards.



The following values can be used as PL-line numbers (N):

0 < N < 99	The number corresponds to one of the PL-lines defined during the geometry input. Capillary water pressures are not used – that is, if a negative water pressure is calculated for a point above the phreatic line, the water pressure in that point is defined as 0.
N=0	Each point within the layer has a water pressure equal to 0. (Define 0 for PL-line at top of layer).
N=99	It is possible to have a number of overlying soil layers with a non-hydrostatic pore pressure (for example, a number of layers consisting of cohesive soil). In this case, a large number of PL-lines would have to be calculated, one or two for each layer. To avoid this, D-GEO STABILITY is able to interpolate across layer boundaries. For layers with a non-hydrostatic pore pressure, 99 can be entered as the PL-line number. For this layer, the interpolation will take place between the PL-line belonging to the first soil layer above with a real PL-line number, and the PL-line belonging to the first soil layer below with a real PL-line number. The first and the last soil layer must therefore always have a real PL-line number. Note: A real PL-line number is not equal to 99. Water pressures above the phreatic line are set to zero. An example can be seen in Figure 4.54 .

D-GEO STABILITY has a special input option, if a PL-line number 99 is given for the top and/or bottom of any soil layer, the nearest soil layer with thickness > 0.0 meter and with a PL-line number unequal to 99 above and/or below the point is searched for. In this layer, the pore pressure is calculated. Using this pressure, together with the corresponding vertical co-ordinate, the pore pressure along the slip circle arc is calculated by interpolation. If the interpolation point is located above the phreatic line, the pore pressure is assumed to be zero or a negative capillary pressure, depending on the sign of the given PL-line number. An example using two different PL-lines is given in [Figure 4.54](#) showing how the pore pressure varies in the vertical.

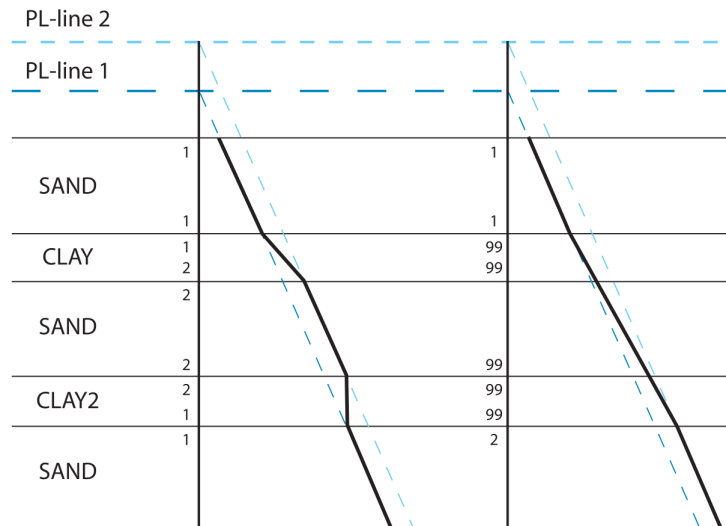


Figure 4.54: PL-lines and vertical pressure distribution

4.3.14 Check Geometry

Select this option to verify the validity of the geometry. All requirements are checked. If the geometry complies with all the requirements, a message will confirm this, see [Figure 4.55](#).

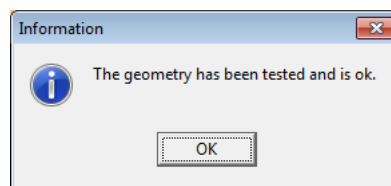


Figure 4.55: Information window on confirmation of a valid geometry

If any errors are encountered during this check, they are displayed in a separate window.

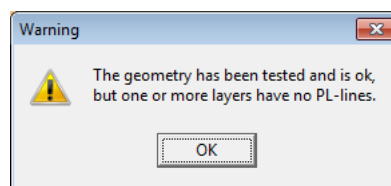


Figure 4.56: Warning window on confirmation of a valid geometry

4.4 Definitions menu

The *Definitions* menu can be used to enter definitions slip plane geometry specifications.

4.4.1 Slip Plane Definition

To open the input window for slip plane definition, click the button at the left of the *View Input* window ([section 2.2.3](#)) or use the menu bar ([section 2.2.1](#)) (open the *Definitions* menu and choose *Slip Plane*).

Depending on the selected model in the *Model* window ([section 4.1.1](#)), the content of the window will be different:

- ◇ Refer to [section 4.4.1.1](#) for Bishop and Fellenius models;
- ◇ Refer to [section 4.4.1.2](#) for Uplift Van and Uplift Spencer models;
- ◇ Refer to [section 4.4.1.3](#) for Spencer model.

4.4.1.1 Slip Circle Definition (Bishop or Fellenius)

The following applies when the *Bishop* or *Fellenius* method is selected ([section 4.1.1](#)).

D-GEO STABILITY determines the critical slip circle in an iterative way. The trials that D-GEO STABILITY performs are based on a grid of center points and a set of horizontal tangent lines. Both the grid and the tangent lines can move towards the direction with the lowest safety factor during the calculation process.

In the input window, the initial location of the grid and the initial location of the horizontal trial tangent lines are supplied. In addition, it is also possible to define a fixed point that the circle must pass.

To find the global position of the critical slip plane, it is possible to use a rather coarse grid with a sufficiently large horizontal range, and also a rather coarse distribution of tangent lines with a sufficiently large vertical range. To find a more accurate value for the safety factor, it is possible to reduce the range and refine the distribution of the grid and tangent lines, while locating them around the position of the global slip circle.

For more information on the theory on slip circles, see [section 16.2](#). For an example of usage, see the Tutorial 1 ([section 8.6](#)).

Figure 4.57: Slip Circle Definition window (Bishop and Fellenius methods)

Grid	
<i>X-left</i>	The initial horizontal coordinate of the leftmost center point in the (moving) trial grid.
<i>X-right</i>	The initial horizontal coordinate of the rightmost center point in the (moving) trial grid.
<i>Number</i>	The number of grid points in horizontal direction.
<i>Y-top</i>	The initial vertical coordinate of the highest center point in the (moving) trial grid.
<i>Y-bottom</i>	The initial vertical coordinate of the lowest center point in the (moving) trial grid.
<i>Number</i>	The number of grid points in vertical direction.

Tangent Line

<i>Y-top</i>	The initial vertical coordinate of the highest tangent line of a trial slip circle.
<i>Y-bottom</i>	The initial vertical coordinate of the lowest tangent line of a trial slip circle.
<i>Number</i>	The number of tangent lines in vertical direction.

Fixed Point

<i>Use Fixed Point</i>	Enforce a slip circle through a particular point.
<i>X-fixed</i>	The horizontal coordinate of the fixed point.
<i>Y-fixed</i>	The horizontal coordinate of the fixed point. This coordinate must be above the <i>Y-bottom</i> coordinate of the tangent lines.

4.4.1.2 Slip Plane Definition (Uplift Van, Uplift Spencer)

The following applies when the *Uplift Van* or *Uplift Spencer* method is selected ([section 4.1.1](#)).

The plane for uplift stability consists of a horizontal part, bounded by a circle at the active side, and a circle (Uplift Van) or a straight plane (Uplift Spencer) at the passive side. D-GEO STABILITY determines the critical plane in iterative way. The trials that D-GEO STABILITY performs are based on two grids of center points and one horizontal tangent line. The grids can move towards the direction with the lowest safety factor during the calculation process. The position of the tangent line is fixed and should be located at the interface between impermeable weak layers and underlying sand layer.

In the input window, the initial location of the grids and the fixed location of the horizontal tangent line are supplied. It is possible to use a rather coarse grid with a sufficiently large horizontal range. D-GEO STABILITY will refine the grid automatically around the area with the lowest safety factor.

For more information on Van's theory, see [section 16.3](#). For more information on Spencer's theory, see [section 16.4](#). For an example of usage, see Tutorial 5 ([section 12.6](#)).

Figure 4.58: Slip Plane Definition window (*Uplift Van* and *Uplift Spencer* methods)

<i>Grid left/right</i>	
<i>X-left</i>	The initial horizontal coordinate of the leftmost center point in the (moving) trial grid
<i>X-right</i>	The initial horizontal coordinate of the rightmost center point in the (moving) trial grid
<i>Number</i>	The number of grid points in horizontal direction
<i>Y-top</i>	The initial vertical coordinate of the highest center point in the (moving) trial grid
<i>Y-bottom</i>	The initial vertical coordinate of the lowest center point in the (moving) trial grid
<i>Number</i>	The number of grid points in vertical direction
<i>Tangent Line</i>	
<i>Y-top</i>	The initial vertical coordinate of the highest tangent line of a trial slip circle.
<i>Y-bottom</i>	The initial vertical coordinate of the lowest tangent line of a trial slip circle.
<i>Number</i>	The number of tangent lines in vertical direction.
<i>Automatic at boundary</i>	Mark this check-box to define tangent lines at the boundaries between the different layers.

4.4.1.3 Slip Plane Definition (Spencer)

The following applies only when the *Spencer* method is selected ([section 4.1.1](#)).

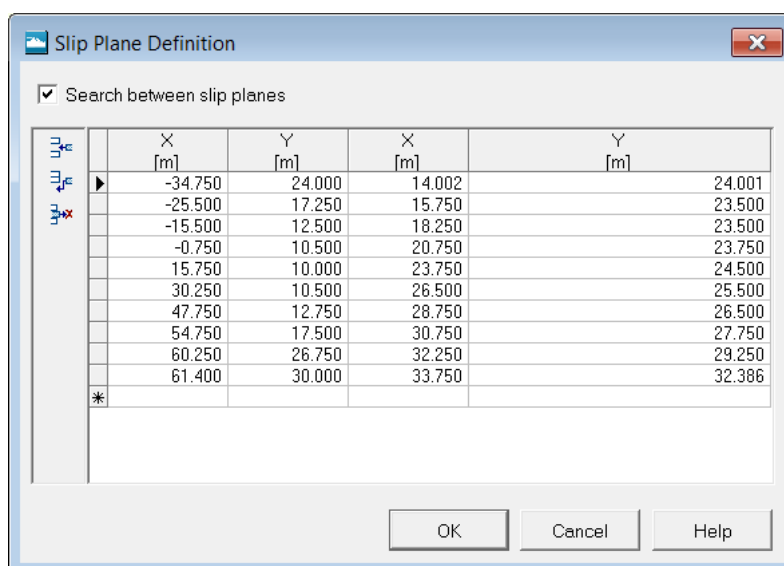


Figure 4.59: Slip Plane Definition window (*Spencer* method)

It is possible to generate a single slip plane by entering X and Y coordinates into the table. This is possible when the *Search between slip planes* option in this window is not selected. The table will then only contain two columns.

It is also possible to input a range of slip planes by entering the X and Y coordinates of two slip planes in the table. The slip planes used in the calculation will all lie between these two planes. This is possible when the *Search between slip planes* option is selected. The table contains four columns in this case. Both planes should contain the same number of points. Therefore, empty input fields are not allowed.

4.4.2 Calculation Area Definition

The following applies only when the *Horizontal Balance* method is selected (section 4.1.1). Click *Definitions* and then choose *Calculation Area*.

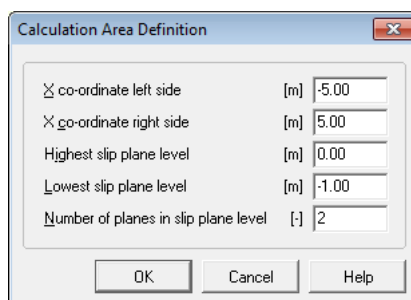


Figure 4.60: Calculation Area Definition window (*Horizontal Balance* method)

<i>X coordinate left side</i>	The horizontal coordinate of the left side of the calculation area.
<i>X coordinate right side</i>	The horizontal coordinate of the right side of the calculation area.
<i>Highest slip plane level</i>	The vertical coordinate of the highest slip plane level.
<i>Lowest slip plane level</i>	The vertical coordinate of the lowest slip plane level.
<i>Number of planes in slip plane level</i>	The number of planes in vertical direction between the highest and the lowest slip plane levels.

4.4.3 Forbidden lines

It is possible to open the input window for forbidden lines either using the button at the left of the *View Input* window (section 2.2.3) or from the Menu bar (section 2.2.1) (click *Definitions* and then choose *Forbidden Lines*). D-GEO STABILITY uses forbidden lines as a constraint during the automatic determination of the critical slip circle. The slip circle is not allowed to intersect with the forbidden line. A forbidden line can be used, for example, to model a sheet piling. By clicking *Forbidden Lines* in the *Definitions* menu, the *Forbidden Lines* window (see Figure 4.61) will allow the addition of a forbidden line in the geometry. This is done by entering the relevant coordinates in the right part of the window. It is also possible to modify existing forbidden lines.

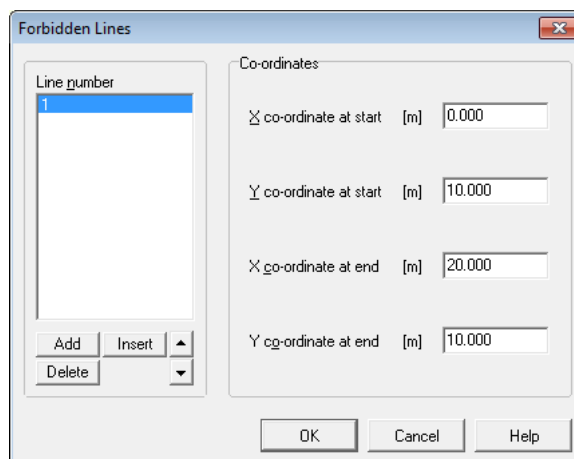


Figure 4.61: Forbidden Lines window

4.4.4 Zone Areas for Safety

This option is available only if the *Enable* check-box in the *Zone Plot* sub-window of the *Model* window is marked (section 4.1.1). The *Zone Plot* option allows defining different zones in the dike body with a different safety factor. The limits of those different zones and there corresponding safety factor can be inputted in the *Zone Areas for Safety* window.

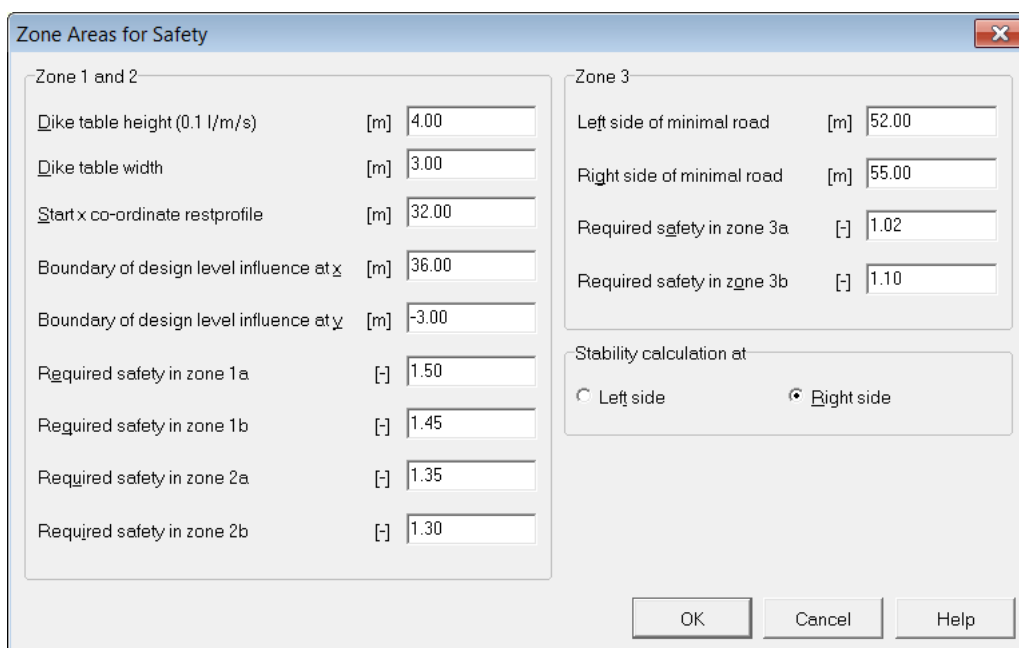


Figure 4.62: Zone Areas for Safety window

<i>Dike table height (0.1 l/m/s)</i>	Level (Z coordinate) of the dike table [m].
<i>Dike table width</i>	Width of the dike table [m].
<i>Start x coordinate rest profile</i>	X coordinate of the starting point of the rest profile [m].
<i>Boundary of design level influence at x</i>	Vertical boundary of the design high water level [m].

<i>Boundary of design level influence at y</i>	Horizontal boundary of the design high water level [m].
<i>Required safety in zone 1a</i>	Required safety factor in zone 1a of the dike.
<i>Required safety in zone 1b</i>	Required safety factor in zone 1b of the dike.
<i>Required safety in zone 2a</i>	Required safety factor in zone 2a of the dike.
<i>Required safety in zone 2b</i>	Required safety factor in zone 2b of the dike.
<i>Left side minimal road</i>	Left side of the road construction at the polder side of the dike.
<i>Right side minimal road</i>	Right side of the road construction at the polder side of the dike.
<i>Required safety in zone 3a</i>	Required safety factor in zone 3a of the dike.
<i>Required safety in zone 3b</i>	Required safety factor in zone 3b of the dike.
<i>Stability calculation at</i>	Select <i>Left side</i> or <i>Right side</i> to design the polder side of the dike.

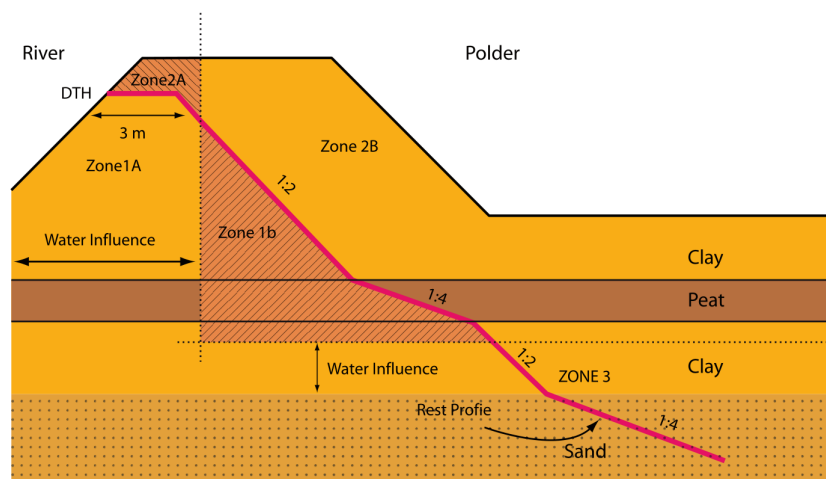


Figure 4.63: Schematization of the zone areas for the Zone Plot model

4.4.5 Reference Level for Ratio S

In this window, it is possible to define a reference surface level. This option applies only to the calculated undrained strength model (section 4.2.4.1 and section 4.2.4.2). It is appropriate to use the reference level, if an embankment or an excavation has been added to initially over-consolidated soil. This reference level will be used to calculate $\sigma'_{v.ref}$, the reference value of the vertical stress, used in Equation 19.5 (section 19.4) for the calculation of the yield stress.

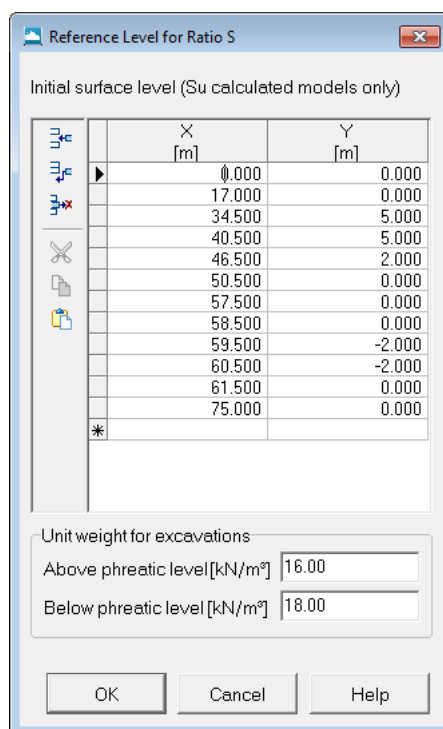


Figure 4.64: Reference Level for Ratio S window

<i>X, Y</i>	Enter the horizontal and vertical coordinates of the different points forming the reference level. Tip: To easily define a reference level, coordinates can be copied from the layers menu and copied into this window.
<i>Unit weight for excavations</i>	Enter the unit weight of the excavated material. Only used in case the Reference Line is situated above the actual surface level (see Figure 4.66). <i>Above phreatic level</i> is the unsaturated unit weight. <i>Below phreatic level</i> is the saturated unit weight.

The reference level is displayed as a green line in the *Input* tab of the *View Input* window. In [Figure 4.65](#), the embankment 'Berm Sand' has been added to initially over-consolidated soil; the reference level is therefore below the actual surface level. In [Figure 4.66](#), part of the ground has been excavated from the initially over-consolidated soil; the reference level is therefore above the actual surface level. Note that in cases where an excavation is defined in the same vertical or section as the yield stresses are defined, this may result in erroneous stresses and strength results.

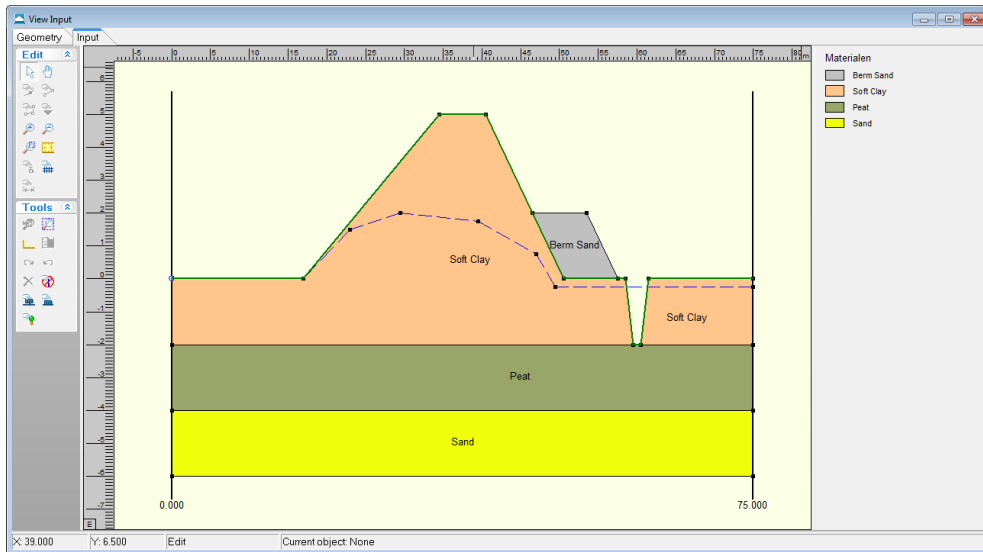


Figure 4.65: View Input window - Reference level (green line) in case of an embankment

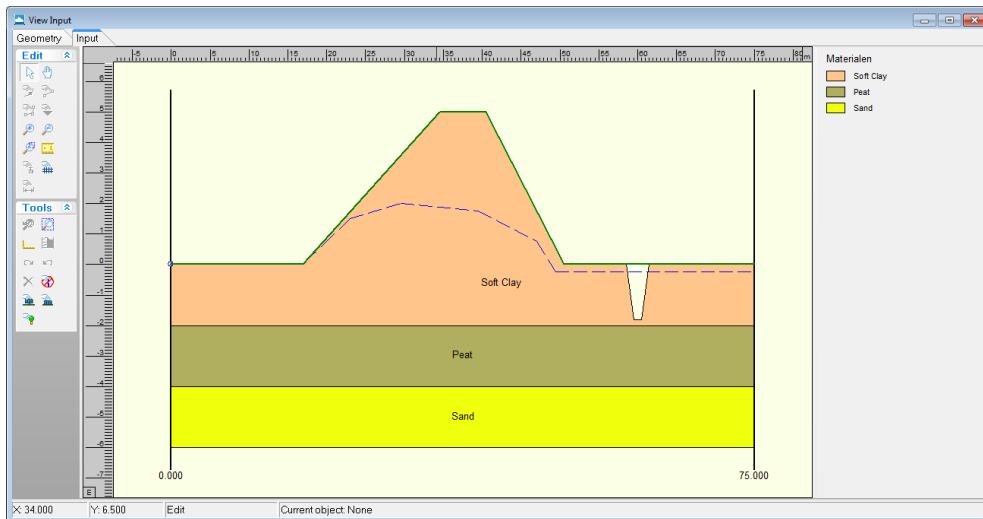


Figure 4.66: View Input window - Reference level (green line) in case of an excavation

4.5 Reinforcements

4.5.1 Geotextiles

In this window (see [Figure 4.67](#)), it is possible to add geotextiles to the cross section. For background information, see [section 16.2.2.2](#).

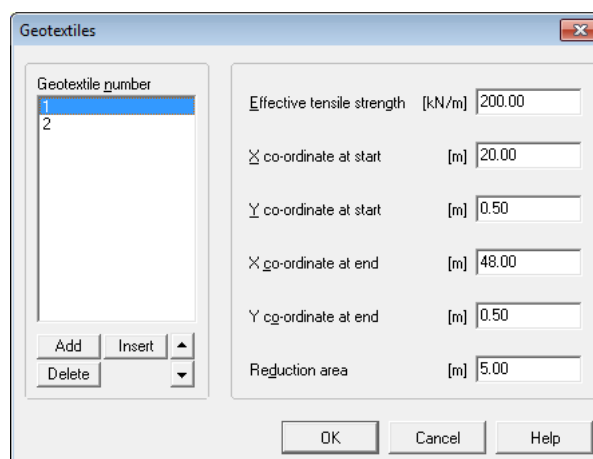


Figure 4.67: Geotextiles window

<i>Effective tensile strength</i>	The amount of tensile strength T_f per unit width of geotextile (kN/m) that is activated at common deformation levels.
<i>X coordinate at start</i>	The horizontal coordinate of the start of the section.
<i>Y coordinate at start</i>	The vertical coordinate of the start of the section.
<i>X coordinate at end</i>	The horizontal coordinate of the end of the section.
<i>Y coordinate at end</i>	The vertical coordinate of the end of the section.
<i>Reduction area</i>	<p>The required transmission length of the geotextile to enable the tensile stress to grow to the full tensile strength. If the length of a side near the intersection with a slip circle is less than the required length, D-GEO STABILITY will assume a tensile stress lower than the effective tensile strength. In that case, D-GEO STABILITY will use a linear dependency between tensile stress and side length.</p> <p>For example: a geotextile has a total length of 5 m, of which 3 m are inside the slip plane. The minimum length is therefore 2 m. If this minimum length is larger than (or equal to) the <i>Reduction Area</i>, then the full tensile strength of the geotextile is taken into account. But if this minimum length is only a quarter of the <i>Reduction Area</i>, then only a quarter of the tensile strength of the geotextile is taken into account.</p> <p>NOTE: This input must be determined by the user and depend on different factors such as the soil weight, the ground structure... According to a geotextile provider, the <i>Reduction area X</i> can be determined using the following formula:</p> $\sigma_y = 2 \tan \varphi \times H \times \gamma \times X$ <p>where σ_y is the effective tensile strength of the geotextile, φ is the friction angle with the soil, H is the soil cover above the geotextile and γ is the unit weight of the soil. In case of non-horizontal surface, the weight of the soil above above the geotextile has to be defined as a function of X.</p>

4.5.2 Nail Type Defaults

In this window, it is possible to define a default type of nail that can be used later in the *Nails* window (section 4.5.3). For background information, see section 16.2.2.3.

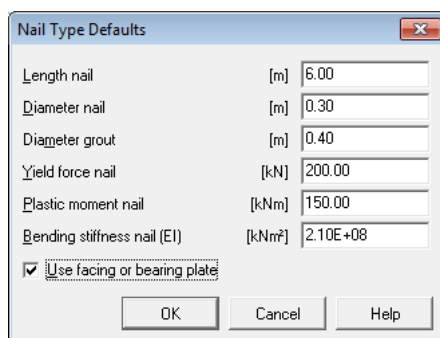


Figure 4.68: Nail Type Defaults window

<i>Length nail</i>	Enter the length of the nail.
<i>Diameter nail</i>	Enter the diameter of the nail.
<i>Diameter grout</i>	Enter the diameter of the grout of the nail.
<i>Yield force nail</i>	Enter the yield force in tension of the nail (F_y), obtained from a uni-axial tensile test.
<i>Plastic moment nail</i>	Enter the plastic moment of the nail.
<i>Bending stiffness nail (EI)</i>	Enter the bending stiffness of the nail.
<i>Use facing or bearing plates</i>	Mark this check-box if a facing or bearing plate is used.

4.5.3 Nails

In this window, the characteristic's of the nail and the lateral and shear stresses curves at the interface soil/nails can be defined. For background information, see section 16.2.2.3.

Options for all nails:

<i>Critical angle</i>	The critical angle of the nail $\alpha_{critical}$. Depending on the value of α , the angle between the nail and the tangent line along the circle where the nail intersects the slip circle, compared to $\alpha_{critical}$, the lateral or shear forces of the nail can be neglected. For more information, refer to Equation 16.18 and Equation 16.19.
-----------------------	---

4.5.3.1 Nails – Geometry

Options for all nails

Critical angle [deg] 5.00

Nail name

Nail 1
Nail 2
Nail 3

Add Insert
Delete Rename

Geometry | Nail Type | Lateral Stress | Shear Stress

X co-ordinate head [m] 4.000

Y co-ordinate head [m] 11.000

Horizontal spacing [m] 1.000

Angle with x-axis [deg] -150.00

OK Cancel Help

Figure 4.69: Nails window, Geometry tab

<i>X coordinate head</i>	The horizontal coordinate of the head of the section.
<i>Y coordinate head</i>	The vertical coordinate of the head of the section.
<i>Horizontal spacing</i>	The horizontal spacing between two nails.
<i>Angle with x-axis</i>	The angle with the vertical axis.

4.5.3.2 Nails – Nail Type

Options for all nails

Critical angle [deg] 5.00

Nail name

Nail 1
Nail 2
Nail 3

Add Insert
Delete Rename

Geometry | Nail Type | Lateral Stress | Shear Stress

Use defaults

Length nail [m] 20.00

Diameter nail [m] 0.04

Diameter grout [m] 0.13

Yield force nail [kN] 1000000.00

Elastic moment nail [kNm] 5.30

Bending stiffness nail (EI) [kNm²] 2.64E+01

Use facing or bearing plate

OK Cancel Help

Figure 4.70: Nails window, Nail Type tab

<i>Use defaults</i>	Mark this check-box to use the nail type defaults previously defined in the <i>Nail Type Defaults</i> window (section 4.5.2).
<i>Length nail</i>	Enter the length of the nail.
<i>Diameter nail</i>	Enter the diameter of the nail.
<i>Diameter grout</i>	Enter the diameter of the grout of the nail.
<i>Yield force nail</i>	Enter the yield force in tension of the nail (F_y), obtained from a uni-axial tensile test, and used in Equation 16.31 and Equation 16.32.
<i>Plastic moment nail</i>	Enter the plastic moment of the nail.
<i>Bending stiffness nail (EI)</i>	Enter the bending stiffness of the nail.
<i>Use facing or bearing plates</i>	Mark this check-box if a facing or bearing plate is used. This input is used for the calculation of the distance L_{shear} used to determine τ_{max} , the ultimate frictional resistance to pull-out between ground and bonded length in Equation 16.22.

4.5.3.3 Nails – Lateral Stress

The *Lateral Stress* tab is available only if the option *Input of ultimate lateral stress along nail* was selected in the *Soil Resistance* window (section 4.1.1).

In this tab, the lateral stress curve along the nail can be defined (ultimate lateral stress vs. distance from nail head).

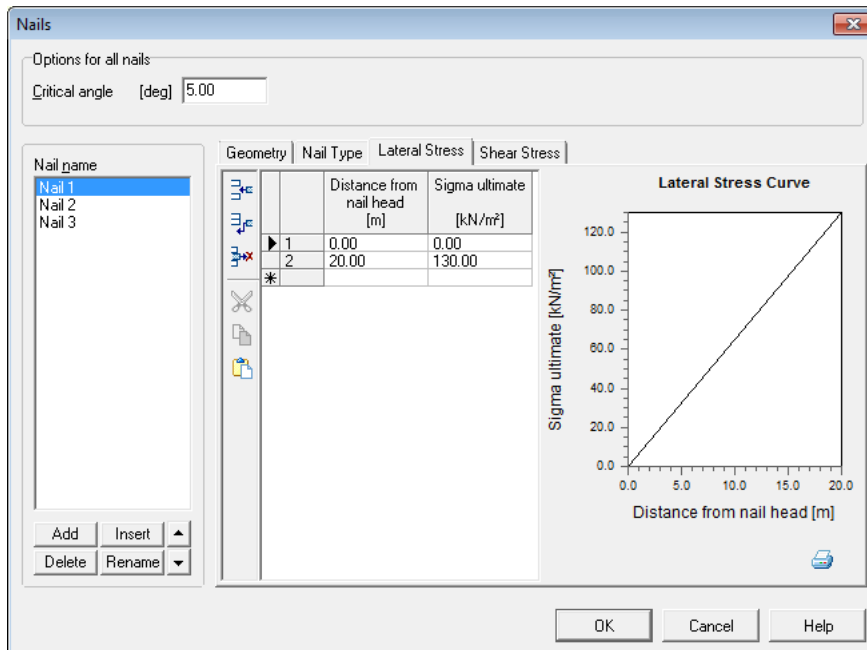


Figure 4.71: Nails window, Lateral Stress tab

4.5.3.4 Nails – Shear Stress

The *Shear Stress* tab is available only if the option *Input of ultimate shear stress along nail* was selected in the *Soil Resistance* window (section 4.1.1).

In this tab, the shear stress curve along the nail can be defined (ultimate shear stress vs. distance from nail head).

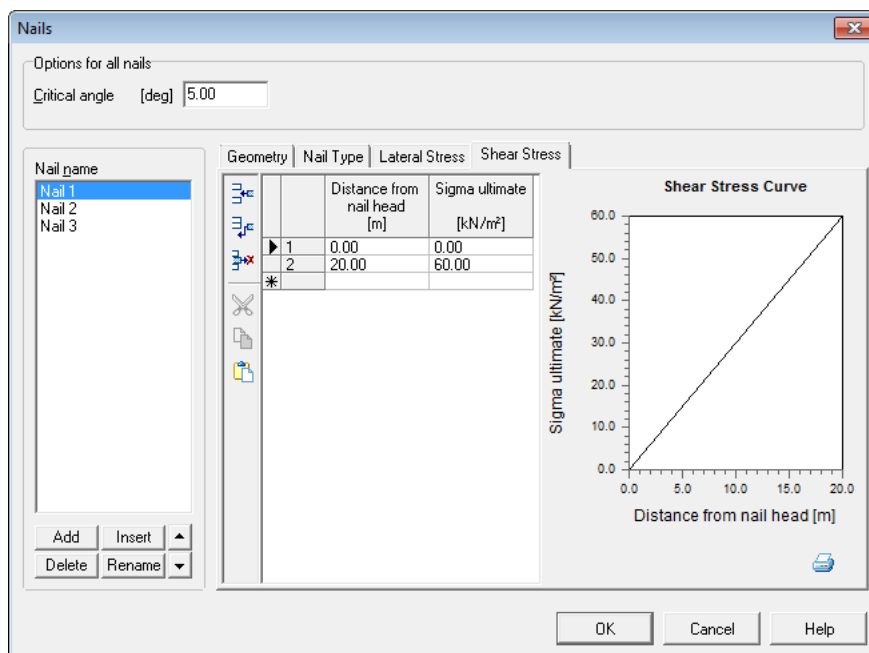


Figure 4.72: Nails window, Shear Stress tab

4.6 Water menu

The *Water* menu can be used to make specifications concerning water related properties in the project.

4.6.1 Unit Weight

Choose the *Unit Weight* option from the *Water* menu to modify the default unit weight of water (see Figure 4.73).

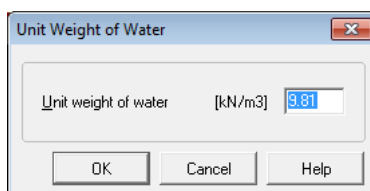


Figure 4.73: Unit Weight of Water window

4.6.2 External Water Levels

Input of external water levels is only required for stochastic modeling of external water level and the associated hydraulic pore pressure field, in combination with either the *Reliability Module*, or the *Bishop probabilistic random field* module.

On the menu bar, click *Water* and then select the *External Water Levels* option to open the *External Water Levels* window, see Figure 4.74. In the window that appears, mark the *Use water data* check-box in order to activate the option for stochastic modeling. After that, it is possible to enter all the required data.

D-GEO STABILITY can determine the conditional probability of failure for a maximum of five different external water levels, and then apply a Gumbel distribution assumption for the water level in order to determine the integrated probability. This probability is determined at a certain

external level, called the design point. See [section 20.4.5](#) for background information.

The screenshot shows the 'External Water Levels' dialog box. It is divided into several sections. At the top left, there is a checked checkbox for 'Use water data'. Below it, the 'Water level' section contains two input fields: 'Design level' with a value of 4.00 [m] and 'Decimate height' with a value of 0.30 [m]. To the right, the 'Exceeding frequency' section has four radio button options: 1/10000, 1/2000 (which is selected), 1/4000, and 1/1250. Below these are two lists: 'Water data_name' containing 'MHW' and 'MLW', and 'P-lines' containing a dropdown for 'Phreatic line number' set to 3 and an input for 'Level' set to 3.00 [m]. A table with two columns, both labeled 'P-line at top', contains five rows with values 5, 4, 3, 2, and 1. Below the table is a 'Copy from Geometry' button. At the bottom of the dialog are 'Add', 'Insert', 'Delete', and 'Rename' buttons, and 'OK', 'Cancel', and 'Help' buttons.

Figure 4.74: External Water Levels window

In the top part of the *External Water Levels* window, the design level itself is entered, together with the exceeding frequency for that same level. D-GEO STABILITY expects that the associated hydraulic field for this level via the *PL-lines per layer* option from the *Geometry* menu is already defined.

The lower part of the *External Water Levels* window enables the user to define a maximum of four additional levels and associated fields. It is possible to add, modify or delete the names of fields at the left hand side. At the right hand side the external level can be entered, together with the associated PL-lines at the edges of all soil layers. A value of 99 yields a linear interpolation between the PL-lines at the outside of the cluster.

The *Copy from Geometry* button allows the user to define a new field by modification of a copy of the design level field.

A further description of nontrivial input fields is given below.

<i>Design level</i>	The design level h_{design} , corresponding to the hydraulic field that has been specified via the PL-lines per layer option from the Geometry menu. See section 20.4.5 , Equation 20.23 .
<i>Decimate height</i>	The increase in the external water level B that reduces the exceeding frequency with a factor 10. This value varies in the Netherlands roughly from 0.3 m to 1 m. See section 20.4.5 , Equation 20.23 .
<i>Exceeding frequency</i>	The exceeding frequency for the design level $P(h > h_{\text{design}})$. See section 20.4.5 , Equation 20.23 .
<i>Level</i>	The external level connected to the hydraulic field that is defined by the PL-lines at the top and bottom of each layer.

4.6.3 Degree of Consolidation

Choose the *Degree of Consolidation* option from the *Water* menu to model excess pore pressures by soil weight, see [Figure 4.75](#).

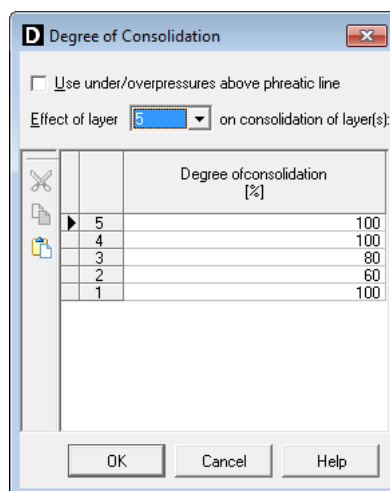


Figure 4.75: Degree of Consolidation window (consolidation by soil weight)

<i>Use under/ overpressures above the phreatic line</i>	Activate this check-box to use positive or negative excess pore pressures above the phreatic line.
<i>Effect of layer</i>	Select the layer that causes excess pore pressures in the layers below.
<i>Degree of consolidation</i>	Specify the relative degree of consolidation ΔU_i per layer i . This is the relative amount of the total vertical stress by the weight of the selected layer that is assumed to be carried as effective vertical stress by the soil skeleton. A degree of consolidation of 0% means no additional effective stress. A degree of consolidation of 100% means no additional excess pore pressures. See section 18.3 for background information.

4.6.4 Use MSeep net

Choose the *Use MSeep Net* option from the *Water* menu to import hydraulic pore pressures from a previous MSeep analysis. MSeep software (stationary groundwater flow calculations) calculates water pressures and phreatic lines. When using this option, MSeep and D-GEO STABILITY should share the same geometry, so that D-GEO STABILITY can use the MSeep dump file (*.SED) to obtain the water pressures. The MSeep dump file contains a list of nodes with their X and Y coordinates and the calculated water pressure at each node. The file also contains information on the position of the phreatic line, which in D-GEO STABILITY forms the boundary between dry and wet soil. All nodes in the MSeep dump file are drawn as dots, and should cover the D-GEO STABILITY geometry at all places below the phreatic line. In some cases, MSeep calculates negative water pressures when a phreatic block becomes too thin (see MSeep for more information). If negative water pressures are present, the D-GEO STABILITY user can select whether these should be equal to zero.

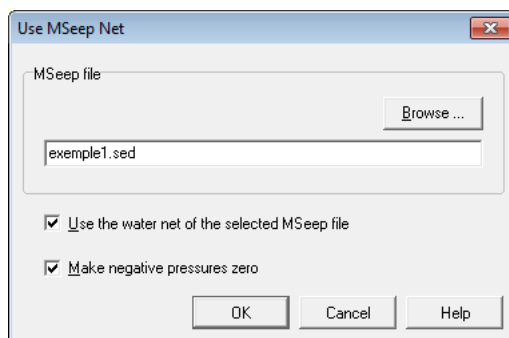


Figure 4.76: Use MSeep Net window

<i>Use the water net of the selected MSeep file</i>	Mark this check-box to confirm the use of the pressures in the selected file.
<i>Make negative pressures zero</i>	Mark this check-box to avoid contribution of pore pressures in unsaturated areas.

4.7 Loads menu

The *Loads* menu can be used to define loads in the geometry.

4.7.1 Line Loads

The *Line Loads* option in the *Loads* menu displays an input window in which the line load per unit length in the direction perpendicular to the cross section are defined. For background information, see [section 17.1](#).

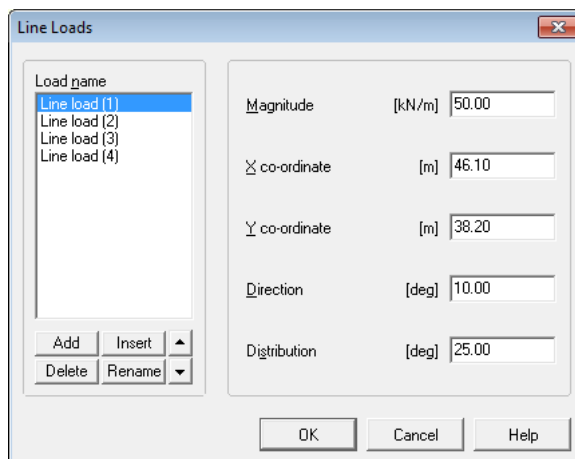


Figure 4.77: Line Loads window

<i>Magnitude</i>	The load size per unit of length
<i>X coordinate</i>	The horizontal coordinate
<i>Y coordinate</i>	The vertical coordinate
<i>Direction</i>	The angle θ between the load and the vertical axis
<i>Distribution</i>	The angle δ that defines the assumed load distribution relative to the direction of the load ($0 < \delta < 90^\circ$).

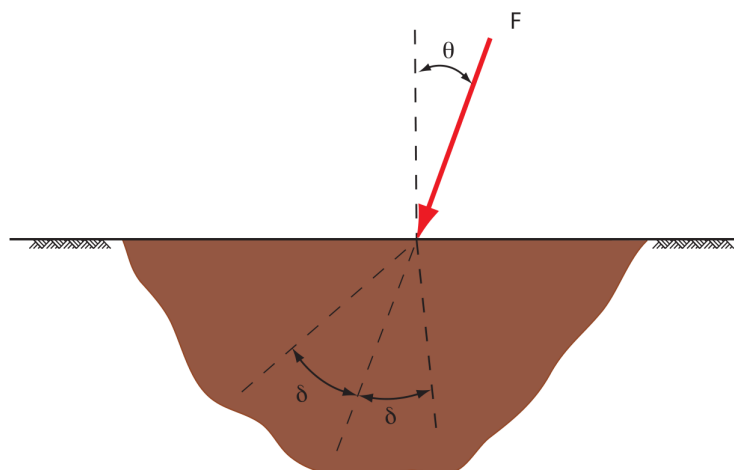


Figure 4.78: Schematization of the angles θ and δ for the definition of a line load

4.7.2 Uniform Loads

The *Uniform Loads* option in the *Loads* menu displays an input window in which a uniformly distributed vertical surface load per unit of area are defined. The part of the load acting between entry and exit point of the slip circle is taken into account in the load moment. For background information, see [section 17.2](#).

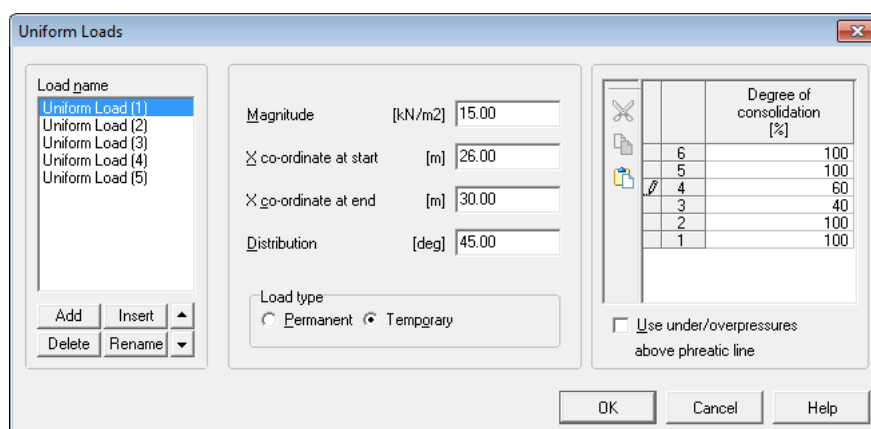


Figure 4.79: Uniform Loads window

<i>Magnitude</i>	The load size for each unit of area.
<i>X coordinate at start</i>	The X coordinate of the starting point of the distributed vertical load.
<i>X coordinate at end</i>	The upper X coordinate of the ending point of the distributed vertical load.
<i>Distribution</i>	The angle δ that defines the assumed load distribution relative to the vertical direction of the load ($0 < \delta < 90^\circ$)
<i>Load Type</i>	Select <i>Permanent</i> if this load should not cause any excess pore pressures. Select <i>Temporary</i> if it does do.

<i>Degree of consolidation</i>	In case of <i>Temporary</i> load: specify the relative degree of consolidation per layer. This is the relative amount of the total vertical stress by loading that is assumed to be carried as effective vertical stress by the soil skeleton. A degree of consolidation of 0% means no additional effective stress. A degree of consolidation of 100% means no additional excess pore pressures. See section 18.3 for background information.
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4.7.3 Earthquake

The *Earthquake Loads* option in the *Loads* menu displays an input window in which a horizontal and an additional vertical acceleration are defined. For background information, see [section 17.3](#).

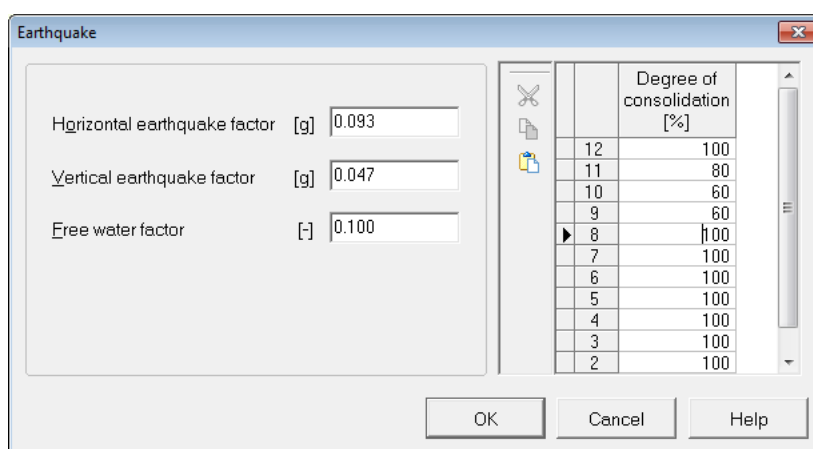


Figure 4.80: Earthquake window

<i>Horizontal earthquake factor</i>	Horizontal acceleration relative to gravity, causing additional moment. The direction of acceleration with positive sign is equal to the X-direction.
<i>Vertical earthquake factor</i>	Additional vertical acceleration relative to gravity, causing temporary additional weight and moment. The direction of acceleration with positive sign is equal to the direction of gravity. The additional weight will also yield additional total vertical stress and additional hydraulic pore pressure.
<i>Free Water Factor</i>	A reduction factor f on the moment caused by free water ($0 < f < 1$, default $f = 0$). This factor can be used to simulate the drag down of free water by earthquake loading.
<i>Degree of consolidation</i>	The relative degree of consolidation r per layer ($0 < r < 100$, default $r = 100$). This is the relative amount of the total vertical stress by vertical earthquake loading that is assumed to be carried as effective vertical stress by the soil skeleton. A degree of consolidation of 100% means no excess pore pressures. For background information, see section 18.3 .

4.7.4 Tree on Slope

The *Tree on Slope* option in the *Loads* menu displays an input window in which the effect of the wind in the trees can be inputted. For background information, see [section 17.4](#).

Figure 4.81: *Tree on Slope* window

<i>Force</i>	Enter the magnitude of the wind force.
<i>Point of application X</i>	Enter the horizontal coordinate of the application point.
<i>Point of application Y</i>	Enter the vertical coordinate of the application point.
<i>Width of root zone</i>	Enter the horizontal width of the root zone.
<i>Angle of distribution</i>	Enter the angle of distribution of the effect of the root zone.

5 Calculations

5.1 Calculation Options

On the *Menu* bar, click *Calculation* and then choose *Options* to modify a number of settings for the analysis: the number of slices, the minimum slice depth and the start value safety factor.

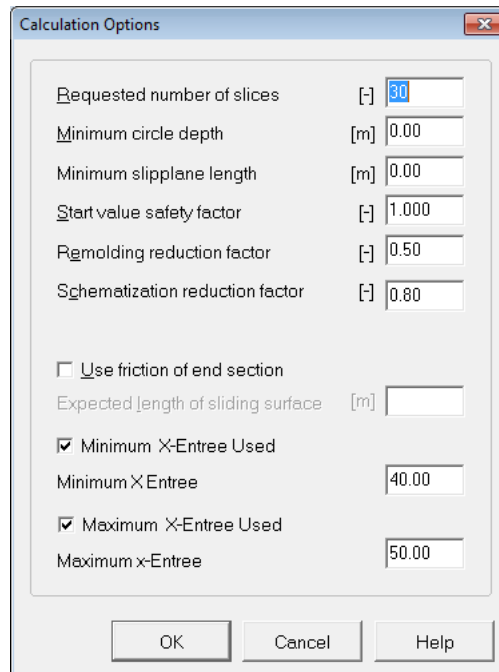


Figure 5.1: Calculation Options window

<i>Requested number of slices</i>	D-GEO STABILITY uses the requested number of slices to determine the maximum width of a slice. At first, slice boundaries are put on points such as geometry points or intersections between circle and layers. Slices exceeding the maximum width will then be divided into smaller ones. The default number of slices is 30. This is a reasonable number for a calculation.
<i>Minimum circle depth</i>	Only available for <i>Bishop</i> , <i>Uplift Van</i> and <i>Bishop Probabilistic Random Fields</i> models (section 4.1.1). In order to avoid slip circles with near-zero soil volumes, it is possible to enter a significant value for the minimum vertical depth. D-GEO STABILITY will only consider the slip circles with a depth exceeding this minimum.
<i>Start value safety factor</i>	Only available for <i>Bishop</i> and <i>Uplift Van</i> models (section 4.1.1). D-GEO STABILITY uses this value as the start value for the iterative determination of the final safety factor.
<i>Remolding reduction factor</i>	Only available for <i>Zone Plot</i> model (section 4.1.1). Reduction factor applied on the sliding force of the ground to take into account the ground deformation due to the deformed slip surface. For background information, refer to section 22.2. Based on tests and literature, the default value is set to 0.5.
<i>Schematization reduction factor</i>	Only available for <i>Zone Plot</i> model (section 4.1.1). Extra model factor used for the calculation of the stability of the deformed slip surface. For background information, refer to section 22.2. Its default value is set to 0.8.

<i>Use friction of end section</i>	Only available for <i>Bishop</i> model (section 4.1.1). Select this button to include the stability increase caused by the resistance at the edges of a sliding section in the out-of-plane direction. For background information, refer to section 16.2.2.4 .
<i>Expected length of sliding surface</i>	Only available for <i>Bishop</i> model (section 4.1.1). If the option <i>Use friction of end section</i> is enabled, enter the length of the considered section in the out-of-plane direction.
<i>Minimum X-entree used</i>	Select this button to used a minimum X-coordinate for the entry point of the slip plane. Slip planes with an entry point situated at the left of this point will not be retained during the search procedure of the critical slip plane.
<i>Minimum X-entree</i>	If the option <i>Minimum X-entree used</i> is enabled, enter a minimum X-coordinate for the entry point of the slip plane.
<i>Maximum X-entree used</i>	Select this button to used a maximum X-coordinate for the entry point of the slip plane. Slip planes with an entry point situated at the right of this point will not be retained during the search procedure of the critical slip plane.
<i>Maximum X-entree</i>	If the option <i>Maximum X-entree used</i> is enabled, enter a maximum X-coordinate for the entry point of the slip plane.

5.2 Start Calculation

On the *Menu* bar, click *Calculation* and then choose *Start* to open the *Start* window ([Figure 5.2](#)) in which some settings can be adjusted before the start of the calculation. Two optimization techniques are available to find the representative slip surface:

- ◇ [section 5.2.1](#) – The grid method calculates all combinations of center points and tangent lines.
- ◇ [section 5.2.2](#) – The genetic algorithm is an advanced optimization procedure that can find either the representative slip circle with Bishops or Vans method or an unconstrained slip plane using Spencer's method. The genetic algorithm is a generally accepted optimization method. Default values are sufficient for most problems to converge. In specific cases, advanced options need to be adjusted. Sufficient literature on this algorithm is available to understand the parameters used.

5.2.1 Grid based calculation

By clicking *OK* the calculation is started. If the input contains no errors, the calculation is started. If the input data contains any errors, a message is displayed.

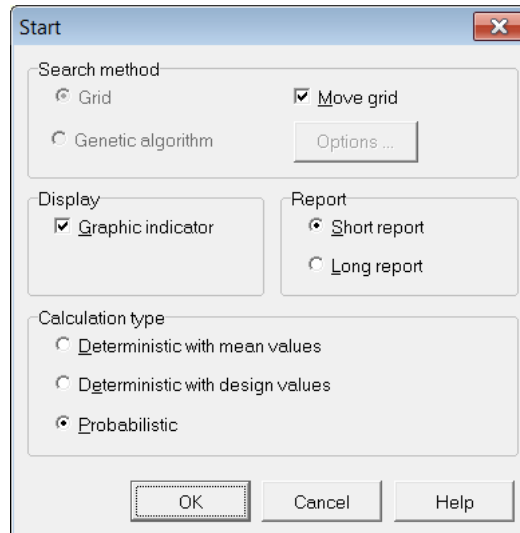


Figure 5.2: Start window, Grid method

<i>Move grid</i>	Activate this check-box if D-GEO STABILITY should move the grid in the direction of the minimum safety factor. Deactivate if D-GEO STABILITY should only calculate the minimum safety factor with the initial grid.
<i>Graphic indicator</i>	Activate if D-GEO STABILITY should graphically display the progress of the automatic slip circle search.
<i>Report type</i>	Select the report type. The long report will contain all available results. The short report will contain only key data.
<i>Calculation type</i>	Only in combination with reliability analysis (section 4.1.1). Select the calculation type: a mean value analysis, a design value analysis or a probabilistic design with random parameter values.

5.2.2 Genetic Algorithm based calculation

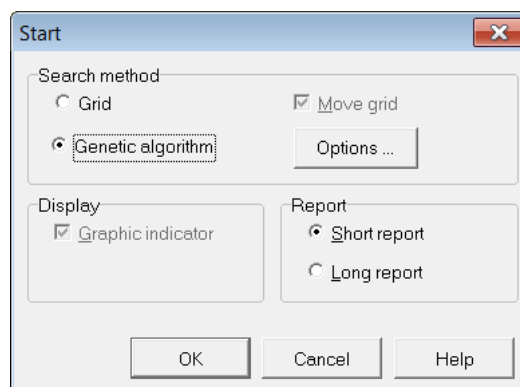


Figure 5.3: Start window, Genetic algorithm method

A genetic algorithm is an advanced optimization method that is particularly good in finding a solution in a large and complex search space. It searches the same space as the calculation grid, without analyzing every possible grid point. With the right options it is much more efficient. The Genetic Algorithm is only implemented in combination with the following limit equilibrium methods:

- ◇ Bishop
- ◇ Spencer
- ◇ Fellenius
- ◇ Uplift Van
- ◇ Uplift Spencer



Note: Some features like Fmin in grid don't work after a genetic algorithm based calculation.



Note: It is possible to find only so called “zone 1” circles using the genetic algorithm, but one needs to take care when using this method. One can do so by checking “enable” under “zone plot” in the model window. This option gives a penalty of 3 to each zone 2 or zone 3 circle. If a safety factor higher than 3 is returned, chances exist no zone 1 circle is found.

The search space must be defined in the same way as by the grid-based method. The shown grid is not used, instead, the slip plane with the lowest resistance is found with the genetic algorithm. A very large search area may be used with Bishop's method, as the optimization technique is very efficient.

Click the *Options* button to open the *Options Genetic Algorithm* window and view the default options (Figure 5.4). Those advanced options are chosen automatically, based on the chosen limit equilibrium method and the size of the search space. If these defaults do not lead to the desired optimum, the advanced options must be set differently. Some knowledge of genetic algorithms is required in order to do this.

Population		
Population count	[:]	30
Generation count	[:]	30
Elite count	[:]	2
Mutation rate	[:]	0.200

CrossOver method		Fraction
Scatter	[:]	1.000
Single Point	[:]	0.000
Double Point	[:]	0.000

Mutation method		Fraction
Jump	[:]	1.000
Creep	[:]	0.000
Inverse	[:]	0.000
		Creep Reduction
		[:] 0.050

Figure 5.4: Options Genetic Algorithm window

Population

The product of the population- and the generation count determines the precision of the calculation result. A larger elite can increase the convergence speed, but increases the risk of finding a local minimum. A different mutation rate can change the convergence speed and the smoothness of the solution.

<i>CrossOver method</i>	Scatter implies a random combination of genes from both parents. This fraction can be 100% in case of a relatively simple solution space like Bishop or Uplift-Van. With Spencer's method, the slip planes become too chaotic and single- or double point crossover will result in much better convergence.
<i>Mutation method</i>	A jump mutation causes a gene to get another, uniformly drawn value, between the boundary conditions of the value. A creep mutation draws another value in a smaller range: the change will be no more than the creep reduction factor. An inversion inverts all values in a chromosome. Jump mutations are efficient in a simple search space like Bishops method and Uplift-Van. With Spencer's method, creep- and inverse mutations are more likely to produce good offspring.

Note: Spencer's limit equilibrium method cannot always produce a valid result. Searching in a space with a relative large number of invalid results requires a large population- and generation count in order to find a good solution and will require much more calculation time. Only solutions with the thrust line inside the soil body are accepted.



5.3 Error messages

If the input contains any errors, a message is displayed. A description of the errors that must be corrected is located in the output file or in the error file. The output file contains an echo of the input, and messages concerning all errors that were found. This file can be viewed with the *Report* option in the *Results* menu. The *Error messages* option in the *Help* menu allows the user to display the error messages for the last calculation performed for the current project.

Note: To keep the messages, it is only possible to print them, as they will be overwritten the next time a calculation is started.



5.4 Progress of Calculation

Critical circle search

If the input contains no errors, the program will start calculating all circles in the initial grid. The screen displays a progress overview and the minimum safety factor found so far in the *Progress of Calculation* window ([Figure 5.5](#)).

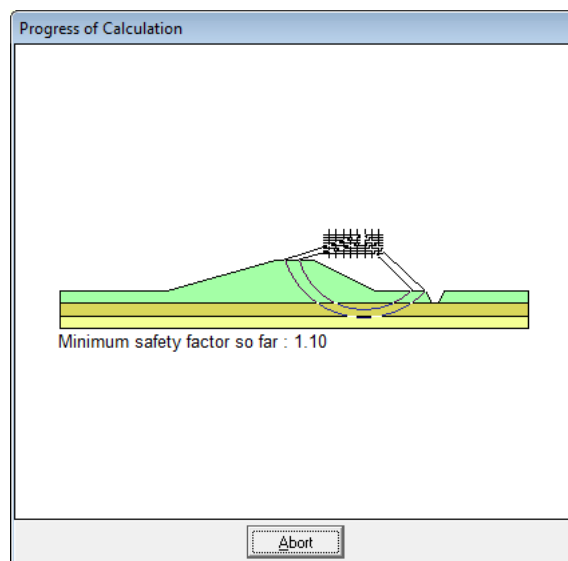


Figure 5.5: Progress of Calculation window

Once the entire initial grid has been calculated for all tangent lines, the program checks whether the center point grid needs to be moved (only if larger than 2x2) if the option *Move Grid* in the *Start* window was enabled. If the critical circle is located along either the top or bottom tangent line, then D-GEO STABILITY will also shift the tangent lines, in order to find the real minimum safety factor. It is possible to do this using the *View Input* window ([section 2.2.3](#)) or the *Slip Circle Definition* option in the *Definitions* menu ([section 4.4.1.1](#)).



Note: It is possible to abort the calculation by clicking the *Abort* button in the *Progress of Calculation* window. This stops the calculation and an empty graphic dump file (*.STD) is created, indicating that no graphical results are available. A message is appended to the output file (*.STO) and only the data is saved for the slip circles calculated before the calculation was aborted.


6 View Results

The options in the *Results* menu can be used to view the results of the performed calculations.

6.1 Report

On the menu bar, click *Results* and then choose *Report* to view a window displaying a table of the most recent calculation results.

Click the *Print active window*  to print the report.

Note: It is possible to export the report to a text file. To do so, click *Export Active Window* in the *File* menu. 

The output file consists of the following elements:

- ◇ general section
- ◇ program name and version, update, company name, license and copy number
- ◇ title of the problem
- ◇ names of the used files
- ◇ echo of the input
- ◇ the safety factor table for each center point and for each tangent line and/or fixed point ([section 6.1.1](#))
- ◇ information about the critical slip circle ([section 6.1.2](#))
- ◇ extensive information about the critical slip circle (optional) ([section 6.1.3](#))

The following sections describe the output in more detail. The calculation process can be aborted, after which a message is appended to the output file and the file is closed. All results until the moment the calculation was aborted remain stored in the file.

6.1.1 Report – Safety factor table (long report)

If the *Long report* option is selected when starting a calculation ([section 5.2](#)), a table with the X and Y coordinates of the center point, the radius and the safety factor is presented for each calculated circle. If the grid has moved during the calculation, the new grid position is displayed, followed by a new table with information on the circles and factors of safety for the new grid. Messages may be displayed behind the safety factor column, either indicating that the circle was rejected for some reason or noting anything exceptional about the circle.

The following can be reasons for rejecting a circle:

- ◇ circle cuts the surface less than two times
- ◇ circle cuts the surface an uneven number of times
- ◇ circle cuts a forbidden line
- ◇ circle center point is too low
- ◇ circle center is located within the geometry
- ◇ too many slices
- ◇ driving moment too small (limit = 0.001)
- ◇ resisting moment too small (limit = 0.001)
- ◇ more than maximum number of iterations required

The following are possible output notes about a slip circle:

- ◇ “circle cuts surface > 2 times => piece X = ... till ... taken” to indicate which part of the



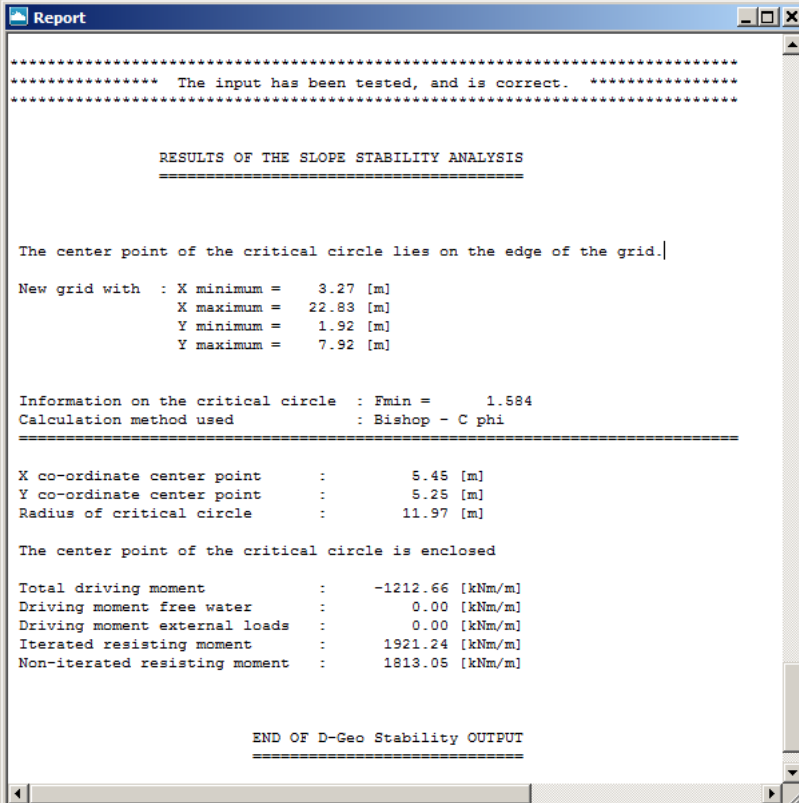
slip circle is used if the circle intersects the surface more than two times

- ◇ “occurrence of negative effective stress”
- ◇ “evaluated earlier” (in former grid position)

This table can become very long, depending on the number of circles for each grid and the number of times the grid is moved in search of a minimum safety factor.

6.1.2 Report – Information about critical slip plane

If a slip plane was found with a minimum safety factor, the following information is displayed about that slip plane:



```

Report
-----
***** The input has been tested, and is correct. *****
-----

RESULTS OF THE SLOPE STABILITY ANALYSIS
=====

The center point of the critical circle lies on the edge of the grid.

New grid with : X minimum = 3.27 [m]
               X maximum = 22.83 [m]
               Y minimum = 1.92 [m]
               Y maximum = 7.92 [m]

Information on the critical circle : Fmin = 1.584
Calculation method used          : Bishop - C phi
=====

X co-ordinate center point      : 5.45 [m]
Y co-ordinate center point      : 5.25 [m]
Radius of critical circle       : 11.97 [m]

The center point of the critical circle is enclosed

Total driving moment           : -1212.66 [kNm/m]
Driving moment free water      : 0.00 [kNm/m]
Driving moment external loads  : 0.00 [kNm/m]
Iterated resisting moment      : 1921.24 [kNm/m]
Non-iterated resisting moment  : 1813.05 [kNm/m]

END OF D-Geo Stability OUTPUT
=====

```

Figure 6.1: Report window for Bishop method

The calculated minimum safety factor and the position of the circle are displayed. If the center point is enclosed, this is noted. If not, the side of the grid where the minimum safety factor was found is displayed.

An iterative process determines the resisting moment in the Bishop method. The non-iterated resisting moment is the resisting moment in the first iteration with $F = 1.0$. With the changing of F in each iteration, the resisting moment also changes and the moment in the last iteration is given by the iterated resisting moment. This moment should be approximately equal to the absolute value of the total driving moment.

There is no iterative process for the s_u and Fellenius methods. In such cases, therefore, only the total available resisting moment is displayed. Division of this moment by the total driving moment immediately produces the safety factor.

If geotextiles were used and were active for the critical slip circle, extra information is displayed about the contribution of the geotextile(s) to the resisting moment.

In case of a probabilistic design, the probability of failure and the corresponding reliability index are written, additionally to the mean value of the safety factor.

In case of a probabilistic design with different water levels, the results for all separate levels are first presented, followed by the integrated probability of failure at the design point level.

6.1.3 Report – Extensive information about critical planes (long report)

If the *Long report* option is selected when starting a calculation (section 5.2), a large number of calculated values for the slices of the critical slide plane are displayed in three tables. The values presented in these tables depend on the calculation method used.

The following column headings are possible:

<i>Slice</i>	[-]	Slice number
<i>X-coor</i>	[m]	Horizontal coordinate at center of slice
<i>Y-bot</i>	[m]	Vertical coordinate at the center of the bottom of slice
<i>Y-top</i>	[m]	Vertical coordinate at the center of the top of slice (= geometry surface)
<i>Width</i>	[m]	Width of slice
<i>Angle bottom</i>	[deg]	Average angle slice bottom
<i>Angle top</i>	[deg]	Angle slice top (= at geometry surface)
<i>Arc.len.</i>	[m]	Length of slip circle for the slice (approximated by a straight line)
<i>Cohesion</i>	[kN/m ²]	Cohesion at slice bottom
<i>Phi</i>	[deg]	Internal friction angle at slice bottom
<i>Sw surf</i>	[kN/m ²]	Water pressure at geometry surface at slice top
<i>Fw hor.</i>	[kN]	Horizontal water force on geometry surface at slice top
<i>Fw ver.</i>	[kN]	Vertical water force on geometry surface at slice top
<i>Weight</i>	[kN]	Total weight of the slice
<i>S-tot</i>	[kN/m ²]	Total stress at slice bottom
<i>S-eff.</i>	[kN/m ²]	Effective stress at slice bottom
<i>Sw-hydro</i>	[kN/m ²]	Hydrostatic pore water pressure at slice bottom
<i>Sw-extr</i>	[kN/m ²]	Pore water pressure (positive or negative) at slice bottom due to degree of consolidation and PL-lines at slice bottom
<i>Sw tot</i>	[kN/m ²]	Total water pressure at slice bottom
<i>S shear</i>	[kN/m ²]	Shear stress at slice bottom
<i>Su</i>	[kN/m ²]	Shear strength s_u at slice bottom
<i>Ko</i>	[-]	Horizontal stress ratio at slice bottom
<i>Sig-Vo'</i>	[kN/m ²]	Effective vertical stress before loading at slice bottom
<i>Alf*SigB</i>	[kN/m ²]	Alf is the degree of consolidation to the stress (SigB) resulting from the applied load (Su-calculated)
<i>Sig-Alfa</i>	[kN/m ²]	Normal stress at slice bottom (Bishop stress dependent)

In the case of a Spencer calculation, the value, position and angle of the inter-slice forces are added to the output.

In the case of a probabilistic design, a long report also shows the values of the influence factors and the values of all stochastic parameters at the design point.

If a column does not apply to a particular calculation method, zeros are printed instead.

6.1.4 Report for Bishop Probabilistic Random Field model

On the menu bar, click *Results* and then select the *Report* option to open the *Report* window. Hereafter is only the output in the *Short Report* is described. The output type can be selected in the *Start* window (see [Figure 6.2](#)).

The short report gives the following intermediate data for each of the water levels and each of the circles that were analyzed:

<i>X, Y, Radius</i>	The dimension of the slip circle.
<i>Mean Value</i>	The reliability index β resulting from a linearization at the mean value of all parameters.
<i>Design point</i>	The reliability index β resulting from a linearization at the so-called design point in a FORM analysis.

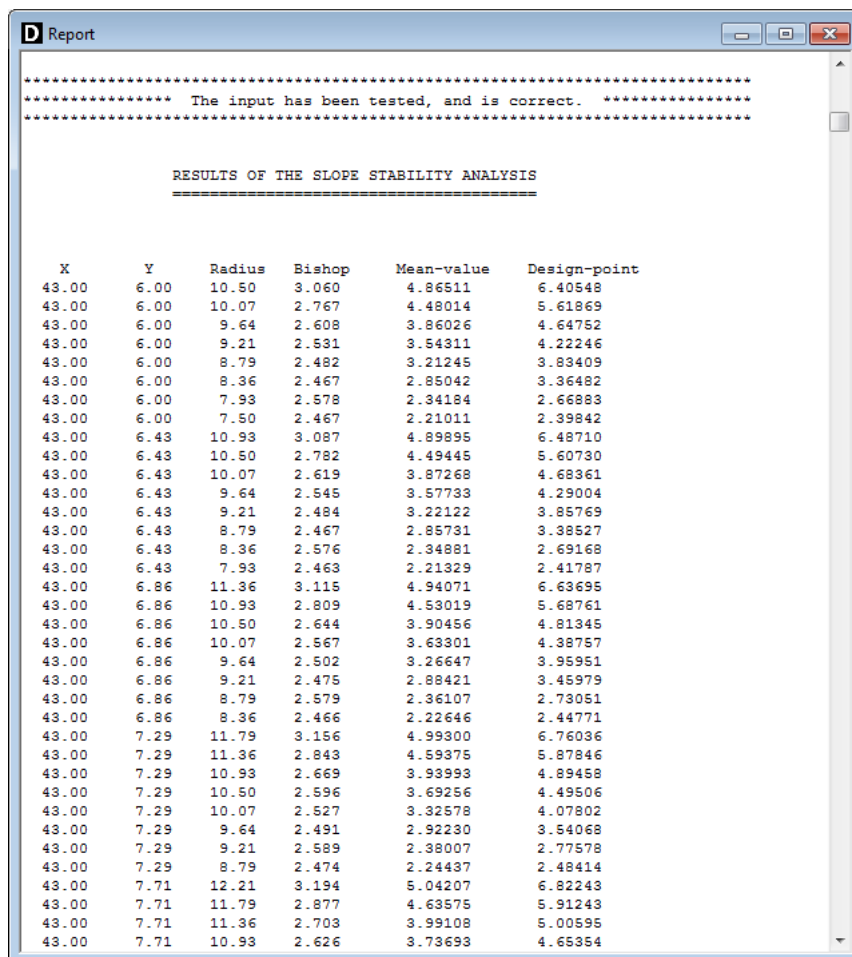


Figure 6.2: Report window, intermediate results

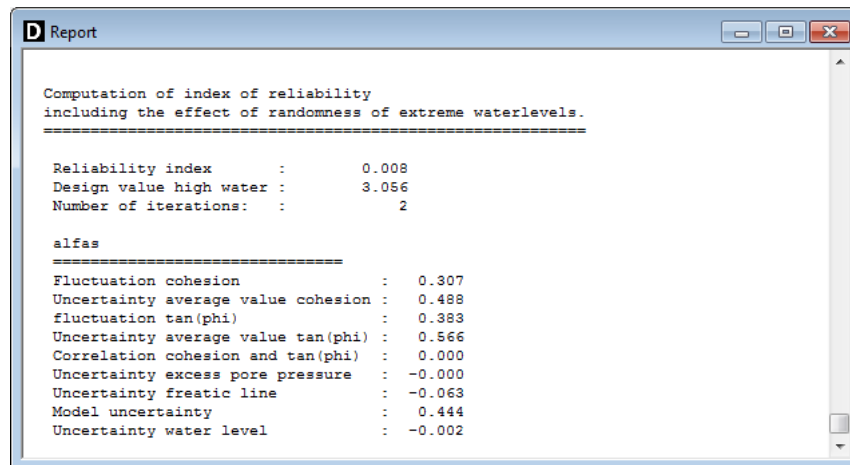


Figure 6.3: Report window, final results

The short report gives the following output of the final analysis results (see [Figure 6.3](#)):

<i>Reliability index</i>	The final value of the reliability index β . In case of a stochastic external water level, this value is the result of the integration of the conditional values for the different water levels.
<i>Design value high water</i>	Only for a stochastic external water level: the value of the water level corresponding to the integrated value of β .
<i>Number of iterations</i>	Only for a stochastic external water level: the number of iterations used for the determination of the integrated β value.
<i>Alfas</i>	<p>The sensitivity coefficient α of parameter x_i indicates the effect of parameter change and parameter uncertainty on the probability of failure for the cross-section:</p> $\alpha = \frac{\sigma [x_i] \frac{dF}{dx_i}}{\sum_{j=1}^n \sigma [x_j] \left(\frac{dF}{dx_j} \right)}$ <p>The sensitivity coefficients for soil parameters result from integration along all soil types. The sum of the sensitivity coefficients equals 1. The values are based on a cross-section analysis only.</p>

6.2 Stresses in Geometry

The *Stresses in Geometry* option in the *Results* menu presents a view of the distribution of pore pressure and effective vertical stress along verticals that can be selected with the mouse pointer.

Clicking the cursor anywhere in the horizontal domain will produce a representation of the stresses in the vertical at that point. It is also possible to manually provide the X coordinate (in the domain) of which to see the stresses in the vertical at that point. This X coordinate can be given in the upper left corner of the screen.

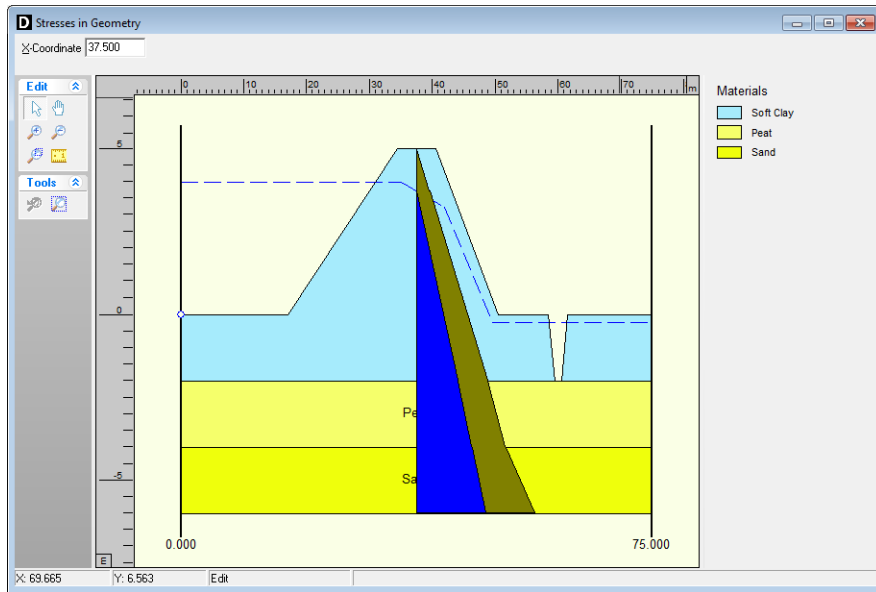


Figure 6.4: Stresses in Geometry window

6.3 Stresses

6.3.1 Critical Circle (Fellenius and Bishop)

On the menu bar, click *Results* and then select the *Stresses* option to open the *Critical Circle* window which gives access to various graphical representations of the calculated results for Fellenius or Bishop method. Key information like the safety factor and the probability of failure are printed in the status panel at the bottom.

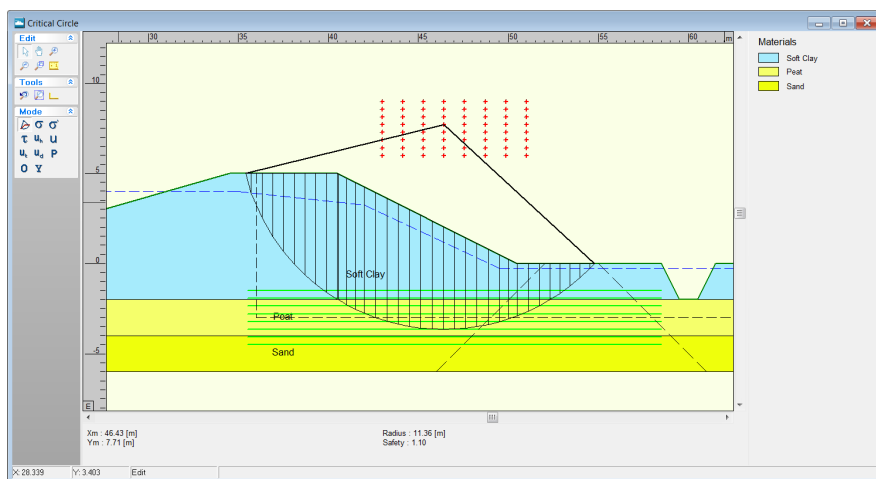


Figure 6.5: Critical Circle window

Click on the following buttons to view:



The critical slip circle, with the initial and final position of the grid.



The distribution of the vertical total stress.



The distribution of the vertical effective stress.

τ	The distribution of the shear stress along the slip plane.
u_h	The hydrostatic pore pressure component along the slip plane (from the phreatic line definition).
U	The hydraulic (piezometric) pore pressure component along the slip plane (from the piezometric lines definition or the MSeep pore pressures).
u_t	The excess pore pressure component along the slip plane, caused by the specified degrees of consolidation by addition of different layers and loads.
u_d	The total pore pressure along the slip plane. Summation of the hydraulic pressure and the excess pore pressure.
P	The pre-overburden pressure (POP) along the slip plane, only relevant for Su-calculated models.
O	The over-consolidation ratio (OCR) along the slip plane, only relevant for Su-calculated models.
Y	The yield stress along the slip plane, only relevant for Su-calculated models.

By double-clicking on a certain slice, a special window is displayed, containing detailed information on that slice, as shown in [Figure 6.6](#).

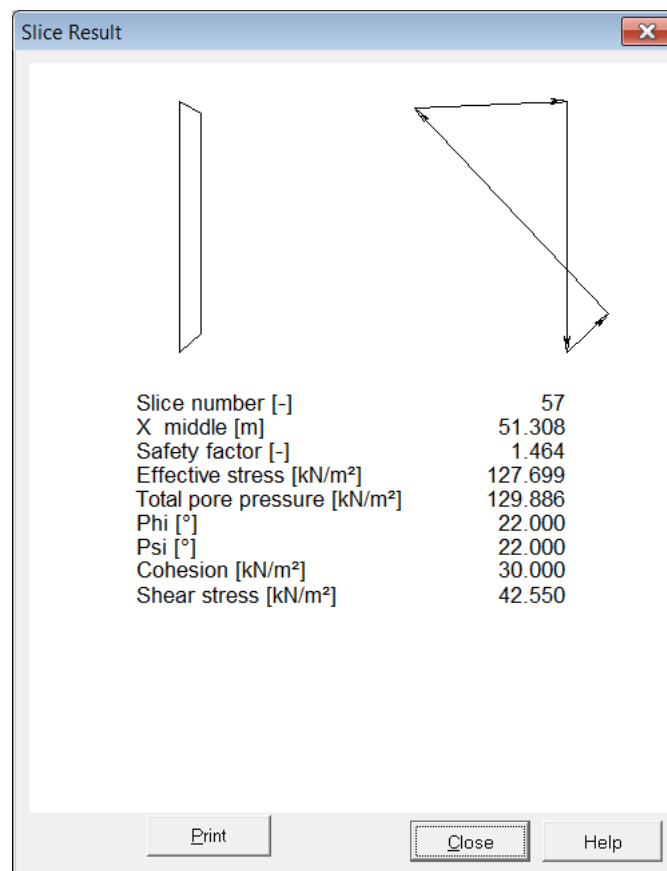


Figure 6.6: Slice Result window

6.3.2 Critical Plane (Uplift-Van and Spencer)

On the menu bar, click *Results* and then select the *Stresses* option to open the *Critical Plane* window which gives access to various graphical representations of the calculated results for Uplift-Van or Spencer method. Key information like the safety factor are printed in the status panel at the bottom.

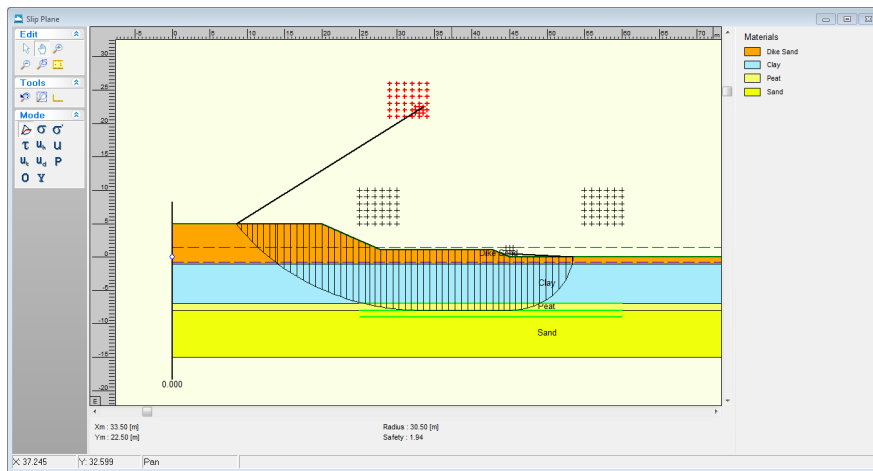


Figure 6.7: Critical Plane window for Uplift-Van method

Refer to [section 6.3.1](#) for a detailed description of this window

6.3.3 Critical Circle for Reliability Analysis

In case of a probabilistic calculation (using the *Reliability analysis* option or the *Bishop probabilistic random field* model in the *Model* window, see [section 4.1.1](#)), complementary information compared to a standard calculation ([section 6.3.1](#)) is given: the value of the reliability index β and the probability of failure (see [Figure 6.8](#)). When using external water levels ([section 4.6.2](#)) for probabilistic design, it is possible to view the results for each level separately, by using the selection list on top.

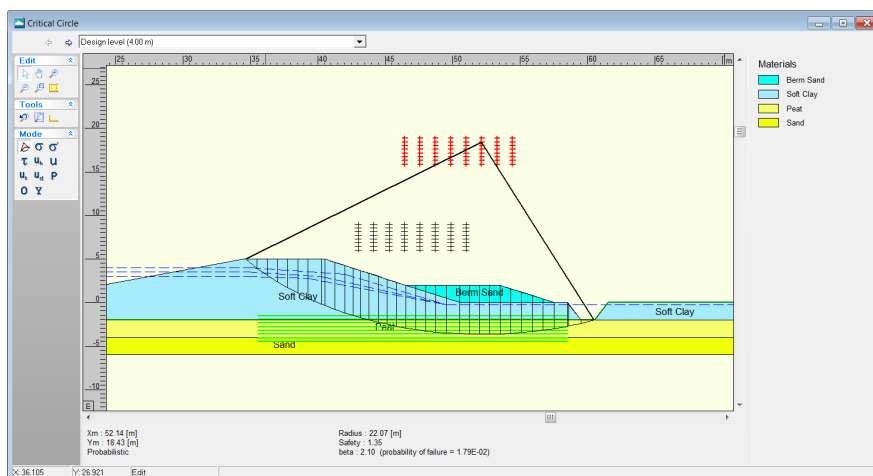


Figure 6.8: Critical Circle window for probabilistic analysis

6.4 FMin Grid

The *FMin Grid* option in the *Results* menu enables the user to view iso-lines of the safety factor distribution on the final grid, provided that the *Point* and/or *Iso-lines* option is activated. This option can be found in the *FMin Grid Results* tab of the *Project Properties* window (section 4.1.3). This plot is only drawn if the number of grid points is less than 11 for both the X and Z directions. For larger grids, only the minimum value is drawn in the grid.

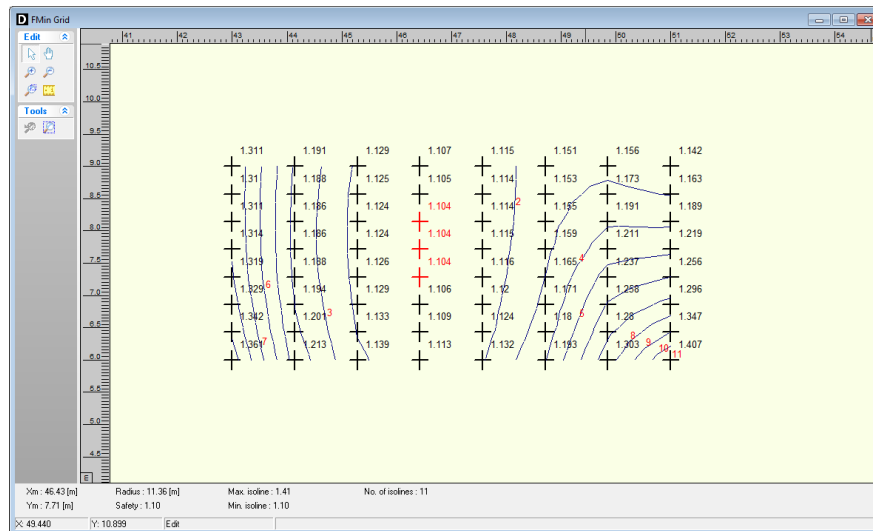


Figure 6.9: textitFMin Grid window

6.5 Safety Factor per Zone

In case of a *Zone plot* calculation (section 4.1.1), click the *Safety Factor per Zone* option in the *Results* menu to open the *Safety Factor per Zone* window. This window shows a diagram of the *Safety factor / Model factor* vs. the *Entry point active circle* (i.e. X coordinate) for the calculated slip circles of each zone.

Mark and unmark the six check-boxes at the right side of the window to show the desired zones (1a, 1b, 2a, 2b, 3a or 3b). The horizontal black lines in the diagram correspond to the required safety factors of each zone as defined in the *Zone Areas for Safety* window (section 4.4.4).

Note: A slip surface passing through zone 1, but with an entrance point in zone 2, is according to the zone plot method defined as a slip surface in zone 2 only if the modified slip surface (deformed situation after rotation) satisfies the required safety factor for zone 1. For background information on the determination of the modified slip surface, refer to section 22.2.



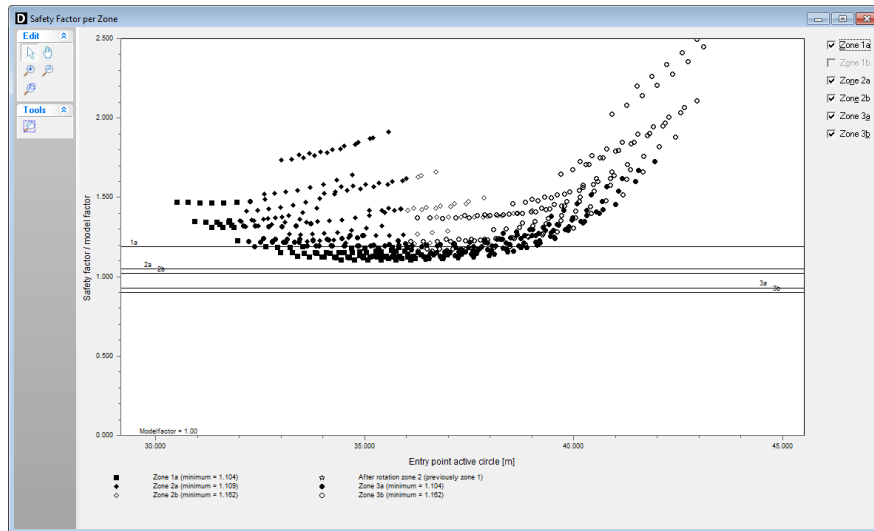




Figure 6.10: Safety Factor per Zone window

6.6 Stresses per Zone

In case of a *Zone plot* calculation (section 4.1.1), click the *Stresses per Zone* option in the *Results* menu to open the *Critical Circle* window (Figure 6.11). Click the *Previous zone* and *Next zone* icons,  , to view various calculated results for each zone:

- ◇ Graphical representations of the critical circle divided into a certain number of slices. By double-clicking on a certain slice, a special window is displayed, containing detailed information on that slice.
- ◇ Key information like the radius and center coordinates of the critical circle and the safety factor are printed in the status panel at the bottom.
- ◇ Graphical representation of the zone areas of the *Zone plot* model:
 - the bold red line represents the rest profile;
 - the vertical and horizontal dotted black lines represent the boundaries of the design level influence respectively at X and Y;
 - the two inclined dotted black lines at the right side of the window represent the limits of the minimal road influence.

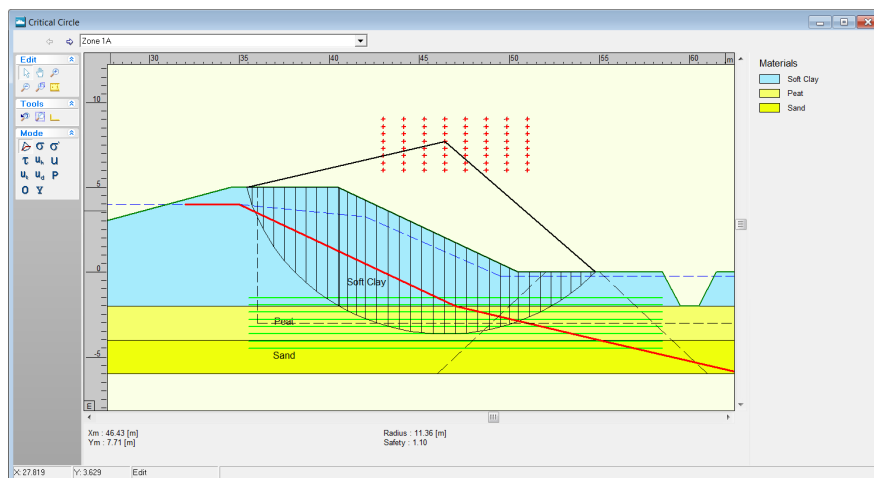


Figure 6.11: Critical circle window for the Zone plot model

For the description of the *Mode* panel, refer to [section 6.3](#).

6.7 Influence Factors

In case of a probabilistic analysis, the *Influence factor* option in the *Results* menu gives access to the *Influence Factors* window. This window shows the influence of variations of uncertain parameters on the probability of failure, see [Equation 20.21](#), page 293.

When using external water levels ([section 4.6.2](#)) for probabilistic design, it is possible to view the results for each level separately, by using the selection list on top. Besides the results for each level, it is also possible to view the integrated influence factors, calculated by D-GEO STABILITY in the design point.

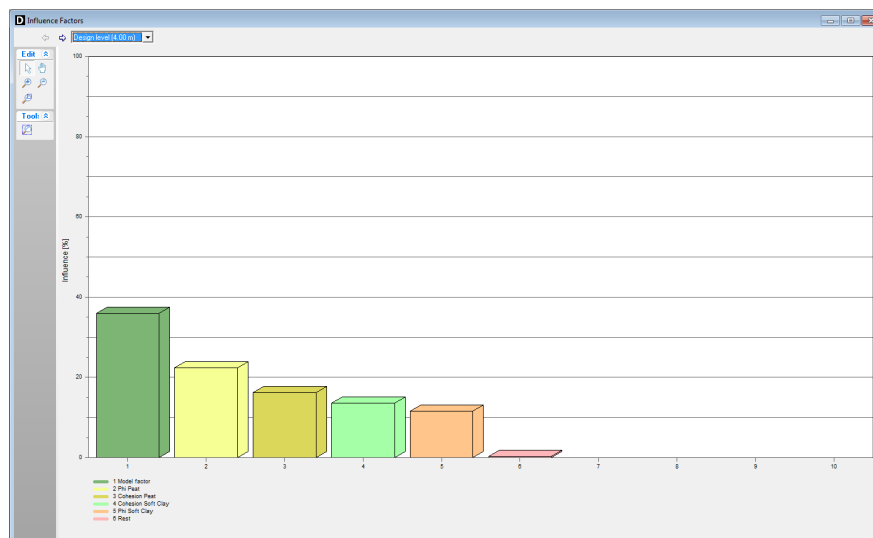


Figure 6.12: Influence Factors window

6.8 Safety Overview

The *Safety Overview* option in the *Results* menu displays the soil region with a safety factor within a certain range, according to the results of the various trials that D-GEO STABILITY performs when determining the critical slip surface. It also displays the regions with a safety value greater and less than the range bounds. The default range bounds (1.15 and 1.35) are defined in the *Safety Results* tab of the *Project Properties* window ([section 4.1.3](#)).

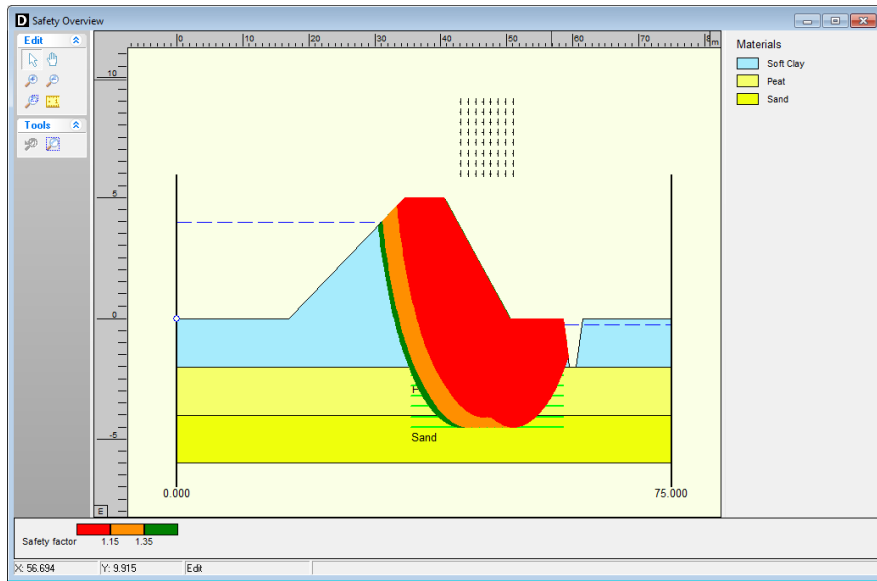


Figure 6.13: Safety Overview window

7 Graphical Geometry Input

This chapter explains how to define the soil layers in a two-dimensional cross section by drawing, using the shared Deltares Systems Geo-tools options for geometry modeling.

- ◇ [section 7.1](#) introduces the basic geometrical elements that can be used.
- ◇ [section 7.2](#) lists the restrictions and assumptions that the program imposes during geometry creation.
- ◇ [section 7.3](#) gives an overview of the functionality of the *View Input* window.
- ◇ [section 7.4](#) describes the creation and [section 7.5](#) describes the manipulation of general graphical geometry using the *View Input* window.

Besides graphical input, the geometry can also be imported or tabular forms can be used (see [section 4.3](#)). See the *MGeobase* manual for a description of special features to create cross-section geometry semi-automatically from CPT and/or boring records.

7.1 Geometrical objects

A geometry can be built step-by-step through the repetitive use of sketching, geometry creation and geometry manipulation. Each step can be started by using line-shaped construction elements (autorefsec:7.1.2) to add line drawings. After converting these drawings to valid geometry parts, the specific geometry elements created can be manipulated ([section 7.1.1](#)).

7.1.1 Geometry elements

A geometry can be composed from the following geometry elements:

Points	A point is a basic geometry element defined by its coordinates. As stated earlier, the geometry is restricted to two dimensions, allowing to define X and Y coordinates only.
Boundary lines	A boundary line is a straight line piece between two points and is part of a boundary.
Boundaries	A boundary is a collection of connected boundary lines that forms the continuous boundary between layers.
PL-lines	A piezometric level line is a collection of connected straight line pieces defining a continuous piezometric level.
Phreatic line	This is a PL-line that acts as phreatic line. The phreatic line (or groundwater level) is used to mark the border between saturated and unsaturated soil.
Layers	A layer is the actual soil layer. Its geometrical shape is defined by its boundaries, and its soil type is defined by its material.
Materials	A material defines the actual soil material (or soil type). It contains the parameters belonging to the soil type, such as its unsaturated weight and its saturated weight. A material can be connected to a layer in order to define the soil type of the layer.
Limits	A limit is a vertical boundary defining the 'end' at either the left or right side of the geometry. It is defined by an X coordinate only. Note that this is the only type of element that cannot be deleted.

Adding, moving and deleting the above-mentioned elements are subject to the conditions for a valid geometry (see [section 7.2](#)). For example, while dragging selected geometry elements, the program can perform constant checks on the geometry validity ([section 7.4.4](#)). Invalid parts will be shown as construction elements (thick blue lines).



7.1.2 Construction elements

Besides the D-GEO STABILITY geometry elements ([section 7.1.1](#)), special construction elements can also be used for sketching the geometry graphically. These elements are not a direct part of the geometry and the restrictions on editing (adding, moving, and deleting); these elements are therefore far less rigid. The only restriction that remains is that these elements cannot be moved and/or defined beyond the limits of the geometry.

Lines	A line consists of a starting point and end point, both defined by a left-hand mouse click in the graphic input screen.
Poly-lines	A poly-line consists of a series of connected lines, all defined by a left-hand mouse click in the graphic input screen.

Construction elements will be displayed as solid blue lines. Valid construction elements are converted to geometry elements as soon as the geometry is (re-) generated. For more information on adding lines and poly-lines, see [section 7.4](#).

7.2 Assumptions and restrictions

During geometrical modeling, the program uses the following assumptions.

- ◇ Boundary number 0 is reserved for the base.
- ◇ A soil layer number is equal to the boundary number at the top of the layer.
- ◇ The boundary with the highest number defines the soil top surface.
- ◇ A material (soil type) must be defined for each layer – except for layer 0 (base). Different layers can use the same material.
- ◇ All the boundaries must start and end at the same horizontal coordinates.
- ◇ Boundaries should not intersect, but they may coincide over a certain length.
- ◇ All horizontal coordinates on a boundary must be ascending – that is, the equation $X[i+1] = X[i]$ must be valid for each following pair of X coordinates (vertical parts are allowed).
- ◇ PL-lines may intersect and may coincide with each other over a certain length.
- ◇ PL lines and layer boundaries may intersect.
- ◇ All PL-lines must start and end at the same horizontal coordinate.
- ◇ All X coordinates on a PL-line must be strictly ascending – that is, the equation $X[i+1] > X[i]$ must be valid for each following pair of X coordinates (no vertical parts allowed).

One way for inputting geometry data is through the *Geometry* menu, as explained in the *Reference* section ([section 4.3](#)). This section describes an other way to create and manipulate geometry graphically using the tool buttons of the *View Input* window.

7.3 View Input Window

7.3.1 General

To use the *View Input* option, click the *Geometry* tab to activate it in the regular *View Input* window or use the menu to select it.

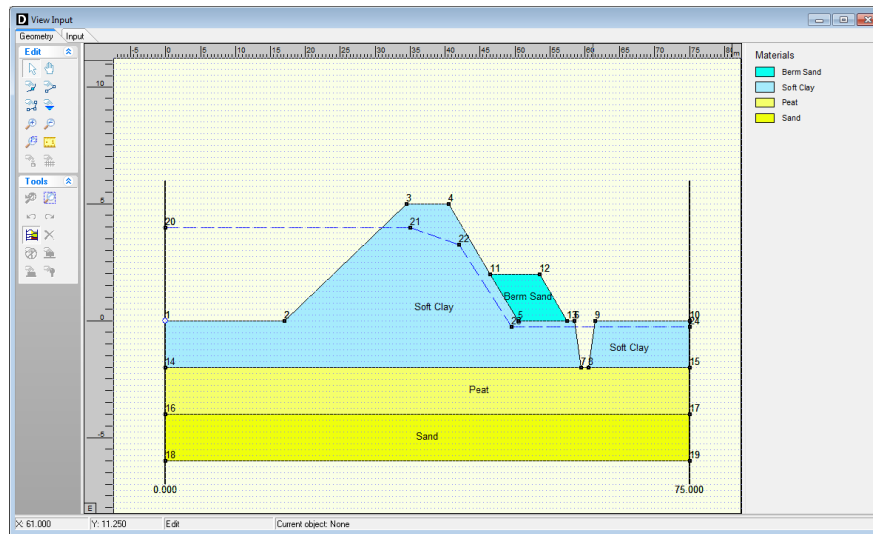


Figure 7.1: *View Input* window, *Geometry* tab

When the *Geometry* tab in the *View Input* window is selected, it displays a graphical representation of only the geometrical data. On the left of the window, the *Edit* and *Tools* buttons are displayed (section 7.3.2). On the right, the legend belonging to the geometry is displayed (section 7.3.3). At the bottom of the window, the title panel and the info bar are displayed. The title panel displays the project titles defined using the *Properties* option in the *Project* menu. The info bar provides information (from left to right) about the current cursor position, the current mode and the object currently selected. The legend, title panel and info bar are optional and can be controlled using the *Properties* option in the *Project* menu (section 4.1.3).

It is possible to use three different modes when working in the *Geometry* tab of the *View Input* window:






<i>Select</i>	The <i>Select</i> mode is the default mode and enables the user to select existing elements in the window.
<i>Add</i>	The <i>Add</i> mode allows the addition of elements using one of the <i>Add</i> buttons. By selecting one of these buttons, one switches to the <i>Add</i> mode. As long as this mode is active, the user can add the type of element which is selected.
<i>Zoom</i>	The <i>Zoom</i> mode allows the user to view the input geometry in different sizes. By selecting one of the <i>Zoom</i> buttons or the <i>Pan</i> button, one activates the <i>Zoom</i> mode. While in this mode, the user can repeat the zoom or pan actions without re-selecting the buttons.













It is possible to change modes in the following ways. When in *Add* or *Zoom* mode, it is possible to return to the *Select* mode by clicking the right-hand mouse button, or by pressing the *Escape* key, or by clicking the *Select mode* button. To activate the *Add* mode, select one of the *Add* buttons. To activate the *Zoom* mode, select one of the *Zoom* buttons or the *Pan* button.










Note: The current mode is displayed on the info bar at the bottom of the *View Input* window.

7.3.2 Buttons

	<p><i>Select and Edit mode</i></p> <p>In this mode, the left-hand mouse button can be used to graphically select a previously defined grid, load, geotextile or forbidden line. Items can then be deleted or modified by dragging or resizing, or by clicking the right-hand mouse button and choosing an option from the menu displayed. Pressing the <i>Escape</i> key will return the user to this <i>Select and Edit</i> mode.</p>
	<p><i>Pan</i></p> <p>Click this button to change the visible part of the drawing by clicking and dragging the mouse.</p>
	<p><i>Add point(s) to boundary / PL-line</i></p> <p>Click this button to add points to all types of lines (e.g. poly-lines, boundary lines, PL-lines). By adding a point to a line, the existing line is split into two new lines. This provides more freedom when modifying the geometry.</p>
	<p><i>Add single lines(s)</i></p> <p>Click this button to add single lines. When this button is selected, the first left-hand mouse click will add the info bar of the new line and a “rubber band” is displayed when the mouse is moved. The second left-hand mouse click defines the end point (and thus the final position) of the line. It is now possible to either go on clicking start and end points to define lines, or stop adding lines by selecting one of the other tool buttons, or by clicking the right-hand mouse button, or by pressing the <i>Escape</i> key.</p>
	<p><i>Add polyline(s)</i></p> <p>Click this button to add poly-lines. When this button is selected, the first left-hand mouse click adds the starting point of the new line and a “rubber band” is displayed when the mouse is moved. A second left-hand mouse click defines the end point (and thus the final position) of the first line in the poly-line and activates the “rubber band” for the second line in the poly-line. Every subsequent left-hand mouse click again defines a new end point of the next line in the poly-line. It is possible to end a poly-line by selecting one of the other tool buttons, or by clicking the right-hand mouse button, or by pressing the <i>Escape</i> key. This also stops adding poly-lines altogether.</p> <p>A different way to end a poly-line is to double-click the left-hand mouse button. Then the poly-line is extended automatically with an ‘end line’. This end line runs horizontally from the position of the double-click to the limit of the geometry in the direction the last line of the poly-line was added. Therefore, if the last line added was defined left to right, the ‘end line’ will stop at the right limit. Note that by finishing adding a poly-line this way, it is possible to start adding the next poly-line straight away.</p>

	<p><i>Add PL-line(s)</i></p> <p>Click this button to add a piezometric level line (PL-line). Each PL-line must start at the left limit and end at the right limit. Furthermore, each consecutive point must have a strictly increasing X coordinate. Therefore, a PL-line must be defined from left to right, starting at the left limit and ending at the right limit. To enforce this, the program will always relocate the first point clicked (left-hand mouse button) to the left limit by moving it horizontally to this limit. If trying to define a point to the left of the previous point, the rubber band icon indicates that this is not possible. Subsequently clicking on the left side of the previous point, the new point will be added at the end of the rubber band icon instead of the position clicked.</p> <p>As with poly-lines, it is also possible to end a PL-line by double-clicking the left-hand mouse button. In this case, the automatically added 'end line' will always end at the right limit.</p> <p>To stop adding PL-lines, select one of the other tool buttons, or click the right-hand mouse button, or press the <i>Escape</i> key.</p>
	<p><i>Measure the distance between two points</i></p> <p>Click this button, then click the first point on the View Input window and place the cross on the second point. The distance between the two points can be read at the bottom of the View Input window. To turn this option off, click the escape key.</p>
	<p><i>Zoom in</i></p> <p>Click this button to enlarge the drawing, then click the part of the drawing which is to be at the center of the new image. Repeat if necessary.</p>
	<p><i>Zoom out</i></p> <p>Click this button, then click on the drawing to reduce the drawing size. Repeat if necessary.</p>
	<p><i>Zoom rectangle</i></p> <p>Click this button then click and drag a rectangle over the area to be enlarged. The selected area will be enlarged to fit the window. Repeat if necessary.</p>
	<p><i>Add geotextile</i></p> <p>In this mode, it is possible to use the left mouse button to graphically define the starting and end point of a geotextile section. The stability of a slope will increase if a slip plane crosses a geotextile.</p>
	<p><i>Add nail</i></p> <p>In this mode, it is possible to use the left mouse button to graphically define the starting and end point of a nail. The resistance of the soil will increase.</p>
	<p><i>Add fixed point</i></p> <p>Click this button to graphically define the position of a point that will be part of the critical slip circle.</p>
	<p><i>Add calculation grid</i></p> <p>Click this button to graphically define the initial position of the trial grid with slip-circle center points and the corresponding positions of the trial horizontal tangent lines of the slip circle.</p>
	<p><i>Undo zoom</i></p> <p>Click this button to undo the zoom. If necessary, click several times to retrace each consecutive zoom-in step that was made.</p>
	<p><i>Zoom limits</i></p> <p>Click this button to display the complete drawing.</p>
	<p><i>Undo</i></p> <p>Click this button to undo the last change(s) made to the geometry</p>

	<p><i>Redo</i> Click this button to redo the previous Undo action</p>
	<p><i>Automatic regeneration of geometry on/off</i> When selected, the program will automatically try to generate a new valid geometry whenever geometry modifications require this. During generation, (poly)lines (solid blue) are converted to boundaries (solid black), with interjacent layers. New layers receive a default material type. Existing layers keep the materials that were assigned to them. Invalid geometry parts are converted to construction elements. Automatic regeneration may slow down progress during input of complex geometry, because validity will be checked continuously.</p>
	<p><i>Delete</i> Click this button to delete a selected element. Note that this button is only available when an element is selected. See section 7.5.2 for more information on how using this button.</p>
	<p><i>Add forbidden lines</i> Click this button to display a window in which it is possible to add, modify or delete lines. Slip circles are not allowed to cross forbidden lines.</p>
	<p><i>Add line loads</i> Click this button to display a window in which it is possible to add, modify or delete point loads per unit of length.</p>
	<p><i>Add uniform loads</i> Click this button to display a window in which it is possible to add, modify or delete uniform loads per unit of area.</p>
	<p><i>Edit tree on slope</i> Click this button to display a window in which it is possible to define the position of trees on the slope and the magnitude of wind.</p>

7.3.3 Legend

At the right side of the *View Input* window ([Figure 7.2](#)) the legend belonging to the geometry is shown. This legend is present only if the *Legend* check-box in the *View Input* tab of the *Project Properties* window is activated (see [section 4.1.3](#)).

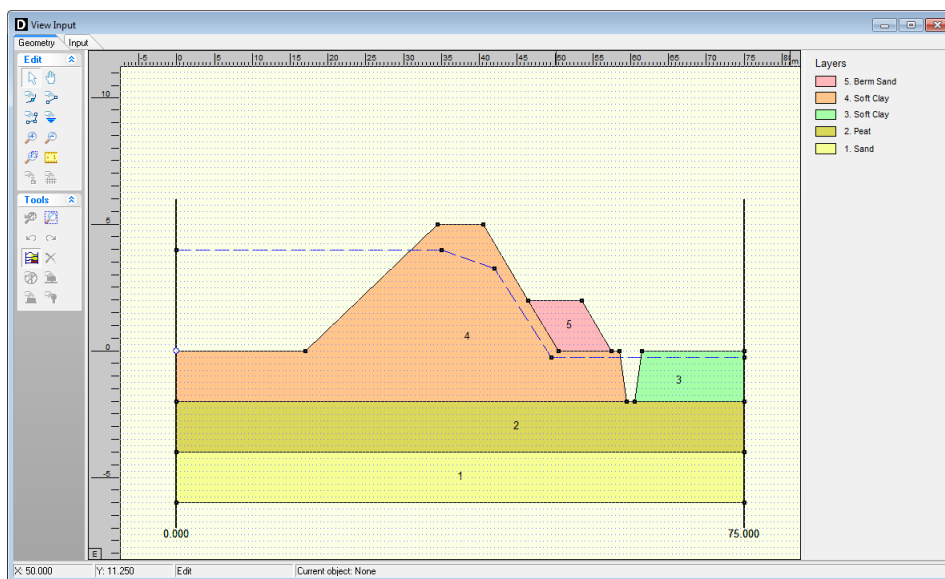


Figure 7.2: *View Input* window, *Geometry* tab (legend displayed as *Layer Numbers*)

In the *Geometry* tab of the *View Input* window, it is possible to change the type of legend. When a soil type box in the legend is right clicked, the menu from [Figure 7.3](#) is displayed.

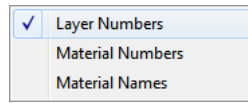


Figure 7.3: Legend, Context menu

With this menu, there are three ways to display the legend of the layers:

- ◇ As *Layer Numbers*: the legend displays one box for each layer. Each layer (and therefore each box) is displayed in a different standard color. Next to each box, the layer number and the material name are displayed, corresponding to the color and number of the layer in the adjacent *Geometry* window (see [Figure 7.2](#)).
- ◇ As *Material Numbers*: the legend displays one box for each material. Each material (and therefore each box) is displayed in a different color which can be changed by the user (see below). Next to each box, the material number and name are displayed, corresponding to the color and number of the material in the adjacent *Geometry* window (see [Figure 7.4](#)).

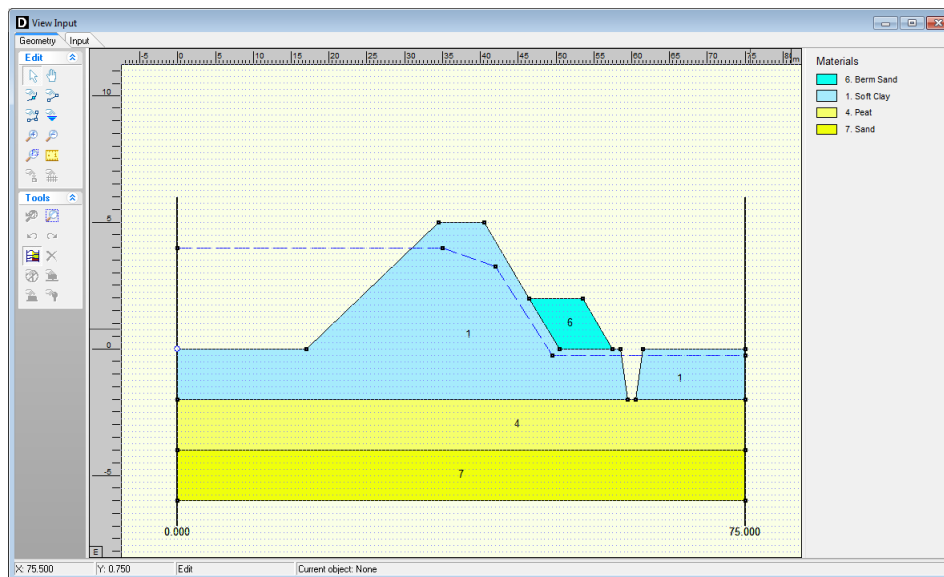


Figure 7.4: View Input window, *Geometry* tab (legend displayed as Material Numbers)

- ◇ As *Material Names*: the legend displays one box for each material. Each material (and therefore each box) is displayed in a different color which can be changed by the user (see below). Next to each box, only the material name is displayed, corresponding to the color and name of the material in the adjacent *Geometry* window (see [Figure 7.5](#)).

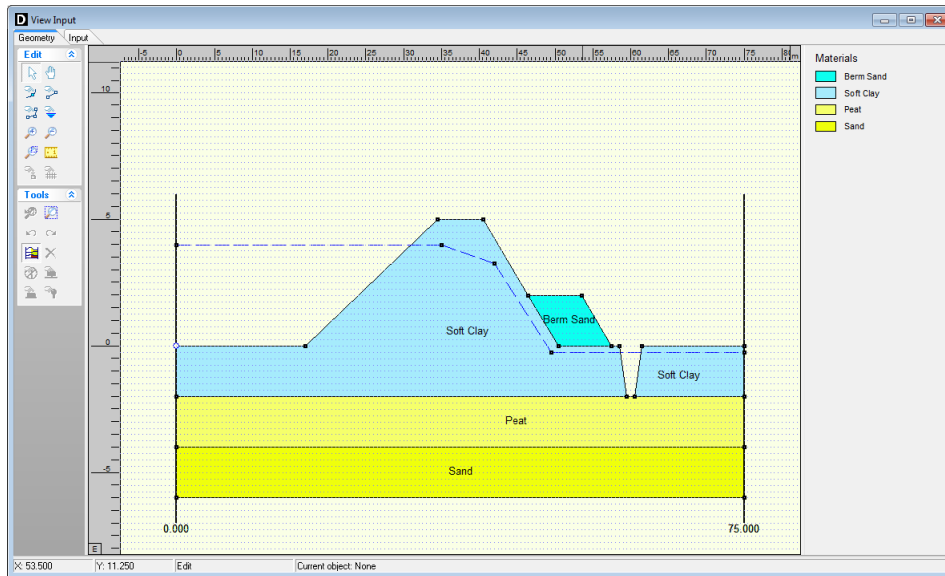


Figure 7.5: View Input window, Geometry tab (legend displayed as Material Names)

Unlike the standard colors used to display layers with their layer colors, it is possible to define different colors used when displaying materials. To change the color assigned to a material, right click the material box. The menu from Figure 7.6 is displayed.

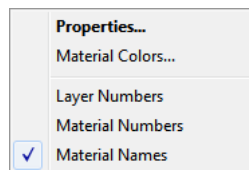


Figure 7.6: Legend, Context menu (for legend displayed as Materials)

When selecting *Material Colors* the *Color* window appears (Figure 7.7), in which the user can pick a color or even define customized colors himself (by clicking the *Define Custom Colors* button).

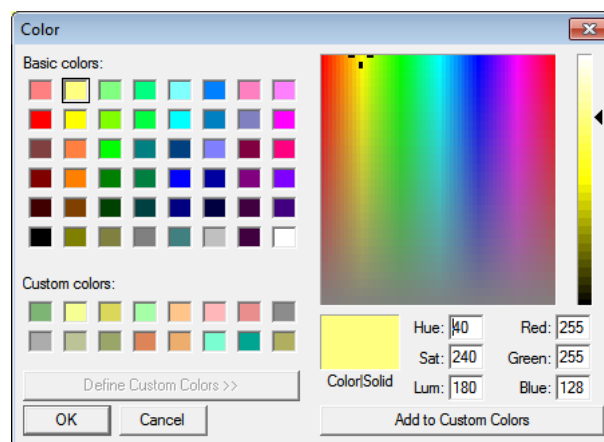


Figure 7.7: Color window

7.4 Geometry modeling

7.4.1 Create a new geometry

There are two ways to create a new geometry without the wizard:

- ◇ Open the *Geometry* menu and choose *New*.
- ◇ Open the *File* menu and choose *New*. In the *New File* window displayed, select *New geometry* and click *OK* (see [section 3.1](#)).

In both cases, the *Geometry* tab of the *View Input* window is displayed ([Figure 7.8](#)) with the default limits of the geometry (from 0 to 100 m).

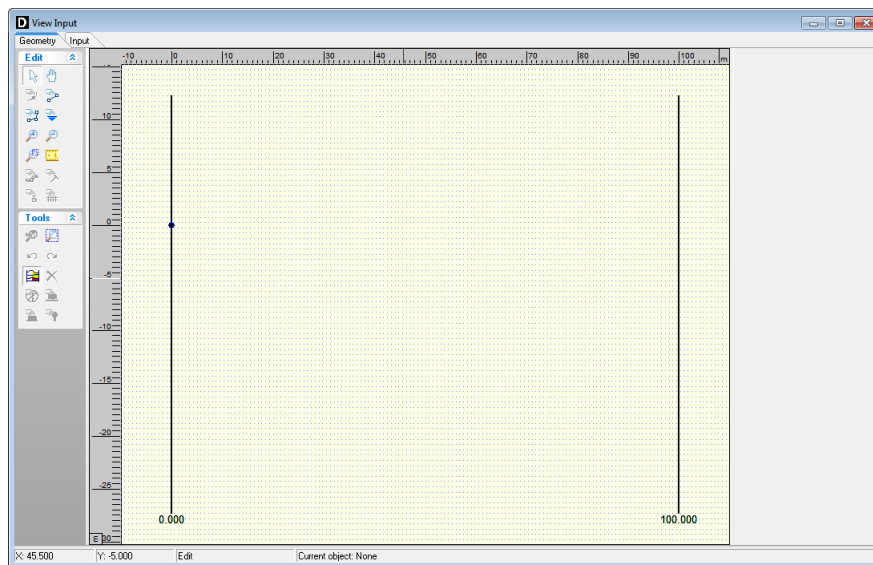


Figure 7.8: View input window, Geometry tab

7.4.2 Set limits

The first thing to do when creating new geometry is to set the model limits. This is possible by selecting and then dragging the limits to their proper place one by one. It is also possible to select a limit and edit its value by clicking the right-hand mouse button after selecting the limit and then choosing the *Properties* option in the pop-up menu. The property window belonging to the selected limit is displayed ([Figure 7.9](#)), enabling to define the new X coordinate for this limit.

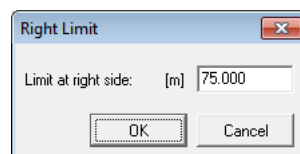


Figure 7.9: Right Limit window

7.4.3 Draw layout

It is possible to use the *Add single line(s)*, *Add polyline(s)* and *Add point(s) to boundary / PL-line* buttons to draw the layout of the geometry. See [section 2.2.3](#) for more information's on how using those buttons.

Add single line(s)  and *Add polyline(s)* 

Each (poly)line is displayed as a solid blue line, and each point as a small black rectangle ([Figure 7.10](#)).

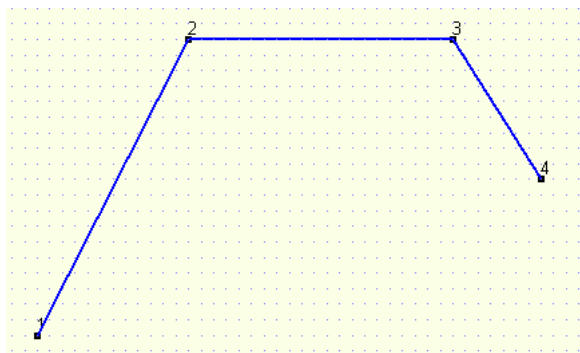


Figure 7.10: Representation of a polyline

The position of the different points of a (poly)line can be modified by dragging the points as explained in [section 7.5.4](#) or by editing the (poly)line. This is done by clicking the right-hand mouse button after selecting the (poly)line and then choosing the *Properties* option in the pop-up menu ([section 7.5.3](#)).

The underlying grid helps the user to add and edit (poly)lines. Use the *Properties* option in the *Project* menu to adjust the grid distance and force the use of the grid by activating *Snap to grid* ([section 4.1.3](#)). When this option is activated, each point is automatically positioned at the nearest grid point.

The specified line pieces must form a continuous line along the full horizontal width of the model. This does not mean that each line piece has to be connected exactly to its predecessor and/or its successor. Intersecting line pieces are also allowed, as shown in the examples of [Figure 7.11](#).

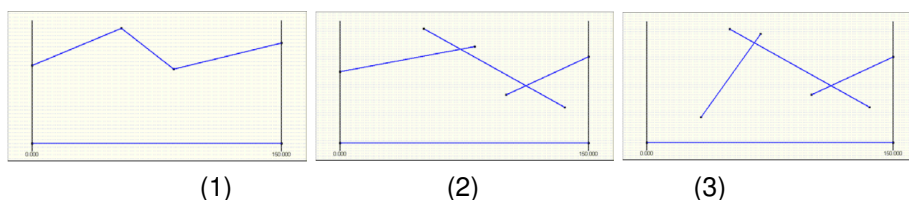


Figure 7.11: Examples of configurations of (poly)lines

- ◇ Configuration (1) is allowed. The different lines are connected and run from boundary to boundary
- ◇ Configuration (2) is also allowed. The different are connected. They are defined as being connected because they intersect. The line construction runs from boundary to boundary.
- ◇ Configuration (3) is illegal, as there is no connection with the left boundary.

Add point(s) to boundary / PL-line 

Use this button to add extra points to lines (lines, polylines, boundary lines, PL-lines). By adding a point to a line, the existing line is split into two new lines. This provides more freedom when modifying the geometry.

For example, the shape of the berm of [Figure 7.12 \(1\)](#) needs to be modified. Two points are added to the outer lines of the berm as shown in [Figure 7.12 \(2\)](#). Then, the middle point is selected and dragged to the position that completes the new geometry as shown in [Figure 7.12 \(3\)](#).

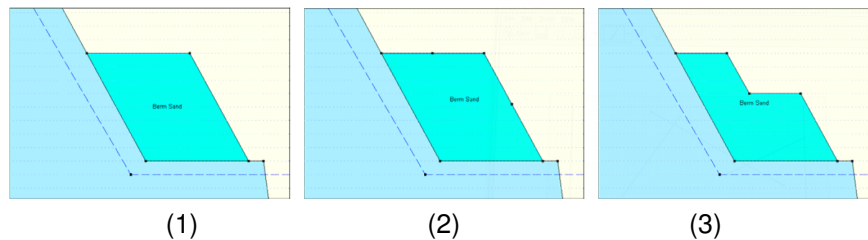



Figure 7.12: Modification of the shape of a berm

Note: When the *Add point(s) to boundary / PL-line* button is clicked, each left-hand mouse click adds a new point to the nearest line until one of the other tool buttons is selected, or click the right-hand mouse button, or press the *Escape* key.



7.4.4 Generate layers

Use the *Automatic regeneration of geometry on/off* button  to start or stop the automatic conversion of construction elements to actual boundaries and layers. Valid (poly)lines are converted to boundaries, which are displayed as black lines. Invalid lines remain blue.

Layers are generated between valid boundaries, and default soil types are assigned.

It is possible to modify the soil type assigned to a layer by first selecting the layer and then clicking the right-hand mouse button and choosing the *Layer Properties* option in the pop-up menu to display the *layer* window (see [Figure 7.21](#) in [section 7.5.3](#)). Once a material has been assigned to a layer, this material will continue to be associated to that layer in subsequent conversions of construction elements as long as the layer is not affected by those conversions.

The most common cause of invalid (poly)lines is that they are not part of a continuous poly-line running from limit to limit. Sometimes, lines appear to start/end at a limit without actually being on a limit. [Figure 7.13](#) gives an example: on the left geometry (1), the end of the line seems to coincide with the boundary. However, zooming in on the point (geometry (2) on the right) reveals that it is not connected to the boundary. Therefore the geometry is considered invalid.

It is possible to correct this by dragging the point to the limit while the specific area is zoomed in or by selecting the point, clicking the right-hand mouse button, choosing the *Properties* option in the pop-up menu ([section 7.5.3](#)) and making the X coordinate of the point equal to the X coordinate of the limit.

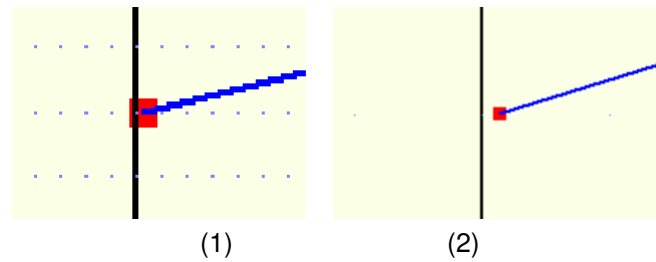



Figure 7.13: Example of invalid point not connected to the left limit

7.4.5 Add piezometric level lines

It is possible to use the *Add PL-line(s)*  button to add PL-lines. When adding a PL-line, D-GEO STABILITY imposes the limitation that the subsequent points of the PL-line have an increasing X coordinate. Furthermore the first point of a PL-line is to be set on the left boundary and the last point on the right boundary.

It is possible to change the position of the different points of a PL-line by dragging the points as explained in [section 7.5.4](#) or by editing the PL-line. This is done by selecting the PL-line, clicking the right-hand mouse button and choosing the *Properties* option in the pop-up menu ([section 7.5.3](#)).

7.5 Graphical manipulation

7.5.1 Selection of elements

After selecting a geometry element it is possible to manipulate it. In order to be able select a geometry element, the select mode should be active. Then it is possible to select an element by clicking the left-hand mouse button. To select a layer, click on the layer number, material number or material name, depending on the option chosen in the *Properties* dialog in the *Project* menu. When successfully selected, the element will be displayed highlighted (for example, a point will be displayed as a large red box instead of a small black box).

The following remarks are relevant to selection accuracy and ambiguity.

Accuracy

The program draws a circular selection area around the mouse pointer. If the element falls within this circle, it will be selected when click the left-hand mouse button is clicked ([Figure 7.14](#)).



Figure 7.14: Selection accuracy as area around cursor

The *Selection accuracy* determines the required distance between the mouse pointer and the geometrical element for selection. It is possible to use the *Properties* option in the *Project* menu to modify the accuracy ([section 4.1.3](#)). This is defined in percentages of the screen size and its default value is 2%. If a larger percentage is defined, this increases the selection area. However, if the percentage is set to a relatively high value, the accuracy required for the selection of certain geometry items may be inaccurate. In other words, it will most likely

result in too many 'ambiguous' selections (see the following section), or will make it difficult to perform an intentionally empty selection.

Ambiguous selection

A selection of geometrical elements can be ambiguous. Figure 7.15 gives an example: a user may want to select a point, a boundary line, a boundary or a PL-line. As several elements are in close proximity to each other, D-GEO STABILITY does not automatically select an element.

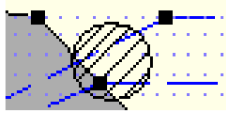


Figure 7.15: Selection accuracy as area around cursor

In this case D-GEO STABILITY requires the user to assign the element that is to be selected by displaying a pop-up menu (Figure 7.16) with the available types of elements within the range of the selection click. It is possible to select the element from this menu.

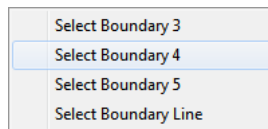



Figure 7.16: Selection accuracy as area around cursor

Clear selection

It is possible to clear a selection by clicking in an area without geometry elements in the direct area.

7.5.2 Deletion of elements

Click the *Delete*  button to delete a selected element. This button is only available when an element is selected. When a point is selected and deleted, it and all lines connected to it are deleted as shown in Figure 7.17.

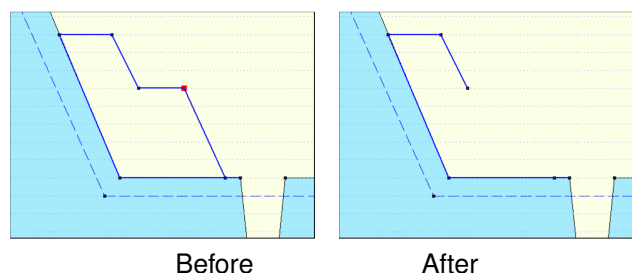


Figure 7.17: Example of deletion of a point

When a geometry point (a point used in a boundary or PL-line) is selected and deleted, the program deletes the point and its connected boundary lines as shown in Figure 7.18. It then inserts a new boundary that reconnects the remaining boundary lines to a new boundary. Deletion of a geometry element (boundary, boundary line, geometry point, PL-line) can result in automatic regeneration of a new valid geometry, if the *Automatic regeneration* option is switched on.

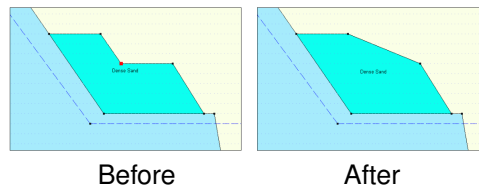


Figure 7.18: Example of deletion of a geometry point

When a line is selected and then deleted, the line and its connecting points are deleted as shown in [Figure 7.19](#). In addition the layer just beneath that boundary is deleted. All other line parts that are not part of other boundaries will be converted to construction lines.

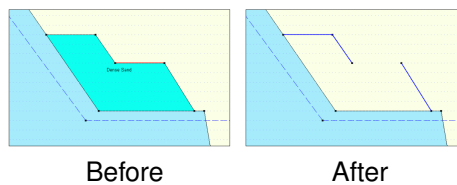


Figure 7.19: Example of deletion of a line

7.5.3 Using the right-hand mouse button

When using the mouse to make geometrical manipulations, the right mouse button enables full functionality in a pop-up menu, while the left button implies the default choice. The options available in the pop-up menu depend on the selected geometrical element and the active mode.

When the *Select* mode is active and the right-hand mouse button is clicked, the pop-up menu of [Figure 7.20](#) is displayed.

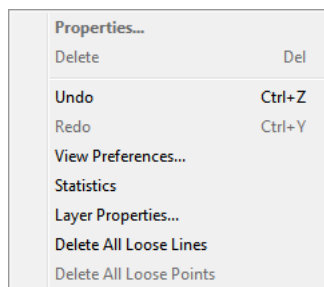


Figure 7.20: Pop-up menu for right-hand mouse menu (*Select* mode)

<i>Properties...</i>	When this option is clicked, the property editor for the selected object is displayed. This procedure is performed by first selecting an object by clicking on it with the left-hand mouse button. Then clicking the right-hand mouse button anywhere in the graphic window will display the pop-up menu. It is possible to use the property editor to quickly adapt the values (properties) of the selected object. Each type of element requires its own properties and therefore its own property editor as shown from Figure 7.22 to Figure 7.25 below.
<i>Delete</i>	This option deletes the element that has been selected (see the comments for the <i>Delete</i> button in section 7.5.2).
<i>Undo</i>	This option will undo the last change(s) made to the geometry.

<i>Redo</i>	This option will redo the previous <i>Undo</i> action.
<i>View Preferences</i>	This option opens the <i>Properties</i> dialog in the <i>Project</i> menu as displayed in.
<i>Statistics</i>	It is possible to use this option to view a window displaying all the vital statistics of the input data. Note that in the window construction lines are called free lines.
<i>Layer Properties...</i>	This option is a special feature that edits the material properties of layers. It is possible to click anywhere in a layer and directly choose this option to edit its properties (Figure 7.21). Clicking outside the geometry layers will display the menu with the <i>Layer Properties</i> option disabled, as there is no layer for which properties can be displayed.
<i>Delete All Loose Lines</i>	This option will delete all loose lines. Loose lines are actually construction lines that are not part of the boundaries or PL-lines (therefore, all lines displayed as solid blue lines). With this option, it is possible to quickly erase all the “leftover bits” of loose lines that may remain after converting lines to a geometry.
<i>Delete All Loose Points</i>	This option will delete all loose points.

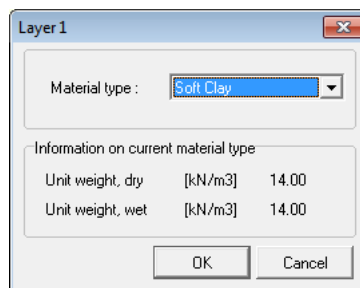


Figure 7.21: layer window (Property editor of a layer)

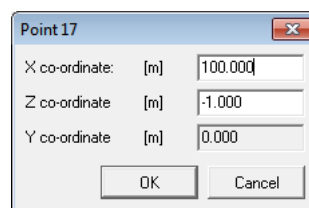


Figure 7.22: Point window (Property editor of a point)

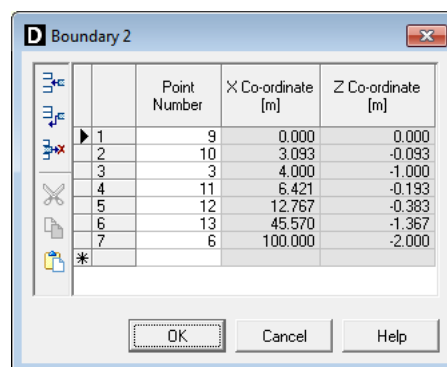


Figure 7.23: Boundary window (Property editor of a polyline)

Boundary Line 8

Point 5
 X co-ordinate [m] 14.000
 Z co-ordinate [m] -1.000

Point 13
 X co-ordinate [m] 45.570
 Z co-ordinate [m] -1.367

Length [m] 31.572
 Slope [%] 1.2

OK Cancel

Figure 7.24: Boundary window (Property editor of a line)

PL-Line 2

	Point Number	X Co-ordinate [m]	Z Co-ordinate [m]
▶	16	0.000	0.000
▶	17	100.000	-1.000
*			

OK Cancel Help

Figure 7.25: PL-line window (Property editor of a PL-line)



Note: In the *Boundary* and *PL-line* properties windows, only the point's number can be modified, not the X and Y coordinates.

7.5.4 Dragging elements Drag and drop

One way to modify elements is to drag them to other locations. To drag an element, first select it. Once the element has been selected, it is possible to drag it by pressing and holding down the left-hand mouse button while relocating the mouse cursor. Dragging of geometry elements can result in automatic regeneration of geometry, if this option is switched on [section 7.4.4](#) as shown in the example of [Figure 7.26](#): when the selected point is moved upwards, a new geometry will be created. D-GEO STABILITY creates new layers according to this new geometry.

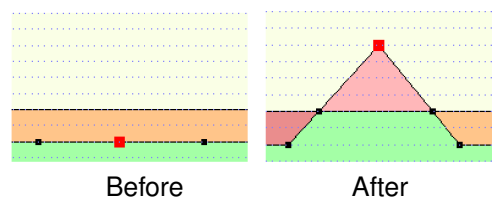


Figure 7.26: Example of dragging of a point

8 Tutorial 1: Dike reinforced with berm

In this first tutorial the safety factor of a dike body which is part of a water retaining reservoir is determined and shows that the dike body doesn't meet the safety requirement. Therefore, a berm have to be added to stabilize it.

The objectives of this exercise are:

- ◇ To learn the steps needed to set up a model geometry and calculation.
- ◇ To learn to create soil layers and attach properties (like shear strength and friction angle).
- ◇ To perform a simple slip plane calculations using the Bishop method and to determine the minimum safety factor.
- ◇ To learn to change the existing geometry in the project.

For this example, the following D-GEO STABILITY module is needed:

- ◇ D-GEO STABILITY Standard module (Bishop and Fellenius).

This tutorial is presented in the files Tutorial-1a.sti and Tutorial-1b.sti.

8.1 Introduction to the case

The dike (Figure 8.1) has a high water level on the left and a low water level on the right. The slope on the right side of the dike is relatively steep. There are three different soil layers. These circumstances result in the fact that the dike, in its current geometry, does not meet the required safety criterion. A situation like this might occur when river water levels rise. It will be seen that placing a berm on the right side of the dike shall result in a more satisfactory safety factor. D-GEO STABILITY is able to use the geometry, water levels, and soil layer properties to calculate the minimum safety factor for the dike.

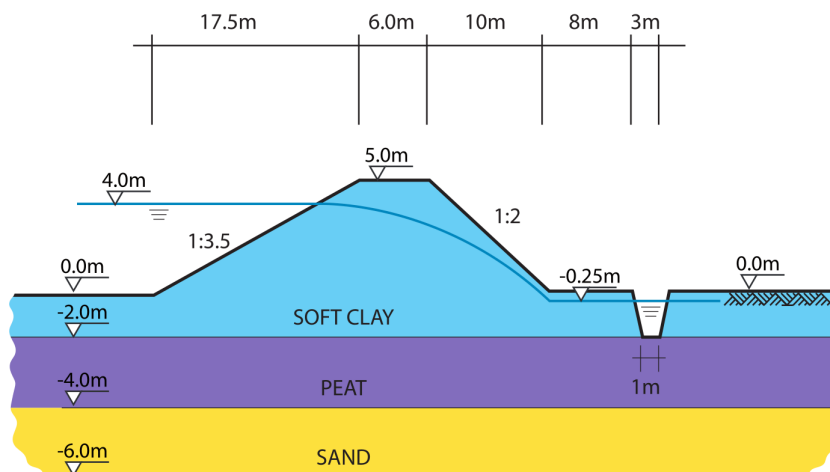


Figure 8.1: Water retaining dike (Tutorial 1)

The relevant values of the soil types used in this tutorial are given in Table 8.1. The properties of 'Berm sand' are also given as this soil type will be used to construct the berm later on. This berm will help to increase the safety factor.

Note: In general safety factors are described in Design Codes (which may vary from country)



to country). Safety factors usually depend on the type of soil structure and its location. In the tutorials in this manual soil structures with a safety factor lower than 1.15 are considered unsafe. Soil structures with a safety factor higher than 1.35 are considered safe.

Table 8.1: Soil properties (Tutorial 1)

	Cohesion [kN/m ²]	Friction angle [deg]	Unsaturated unit weight [kN/m ³]	Saturated unit weight [kN/m ³]
Soft Clay	8	20	14	14
Peat	5	15	12	12
Berm Sand	2	32	19.5	21
Sand	0	29	18	20



Note: The dilatancy ψ is set equal to the friction angle φ .

8.2 Creating a new file using the Geometry Wizard

Firstly, the geometry of [Figure 8.1](#) needs to be inputted in D-GEO STABILITY. This basis of geometry can easily be created in D-GEO STABILITY using the *Geometry Wizard*. In the *Wizard*, also, basic soil layer properties can be assigned. When the *Wizard* is completed, modifications to complete the geometry can be made using the *Edit* toolbox which will be available in the *View Input* window. This will make the geometry complete.

To create a new file, follow the steps described below:

1. Start D-GEO STABILITY from the Windows taskbar (Start/Programs/Deltares Systems/D-GEO STABILITY/D-GEO STABILITY).
2. Click *File* and choose *New* on the D-GEO STABILITY menu bar.
3. Select *New geometry wizard* ([Figure 8.2](#)) to use the geometry wizard to create the dike geometry and click *OK*.

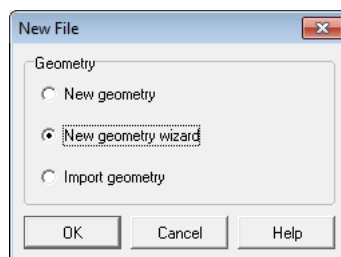


Figure 8.2: New File window

The *Wizard* will now go through the steps needed to set up the basic geometry of the project. Later in this tutorial, the user shall also make slight alterations to the geometry manually.

8.2.1 Wizard – Basic Layout

The first *Wizard* window sets the basic geometrical properties of the project (Figure 8.3).

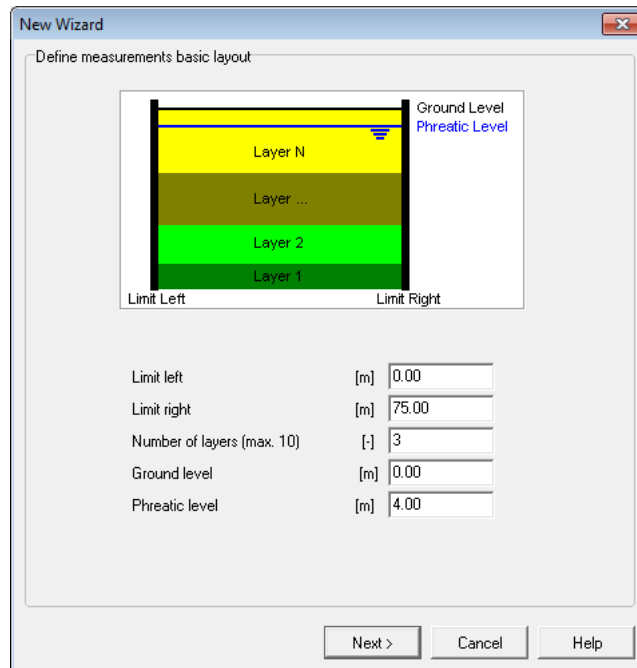



Figure 8.3: New Wizard window, Basic geometrical properties

4. Determine the boundaries of the calculation domain by checking if the left and right limits are $<0\text{ m}>$ and $<75\text{ m}>$ respectively.
5. Set the number of layers to $<3>$.
6. Leave the ground level at 0 m.
7. In this tutorial there is a higher water level left of the dike. Set the phreatic level to $<4\text{ m}>$. This will set the phreatic level to 4 m across the whole domain. Later it will be modified manually according to Figure 8.1.
8. Click *Next*.

Note: Usually the left limit is 0 m and the right limit is in the order of two times the width of the soil structure to be modeled. 

8.2.2 Wizard – Shape selection

In the next window (Figure 8.4), several basic geometric situations can be selected. In this tutorial, a dike structure without berm, but with a dewatering channel on the right must be selected to be in accordance with Figure 8.1.

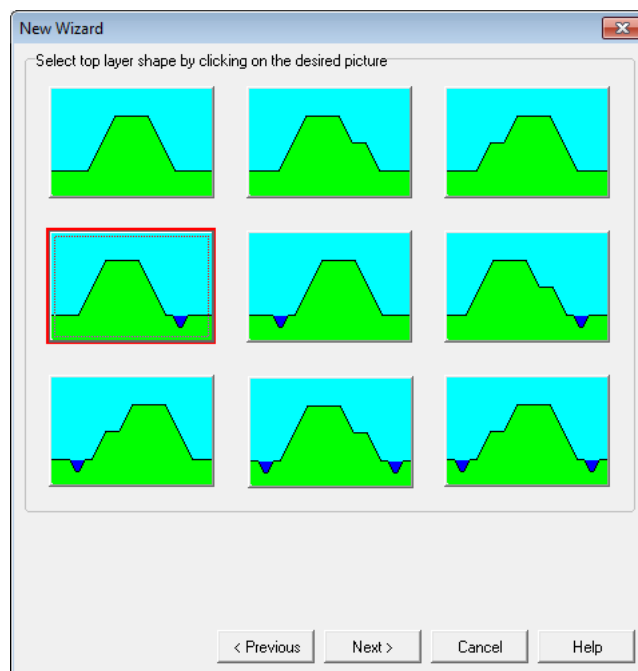


Figure 8.4: New Wizard window, Basic geometric situation

9. Select the option with a dike with a dewatering channel on the right (also indicated in [Figure 8.4](#)).
10. Click *Next*.



Note: Within the *Wizard* it is always possible to navigate between the wizard windows using the *Previous* and *Next* buttons.

8.2.3 Wizard – Shape definition

In the next window ([Figure 8.5](#)), the geometric values of the dike body and the dewatering channel can be set.

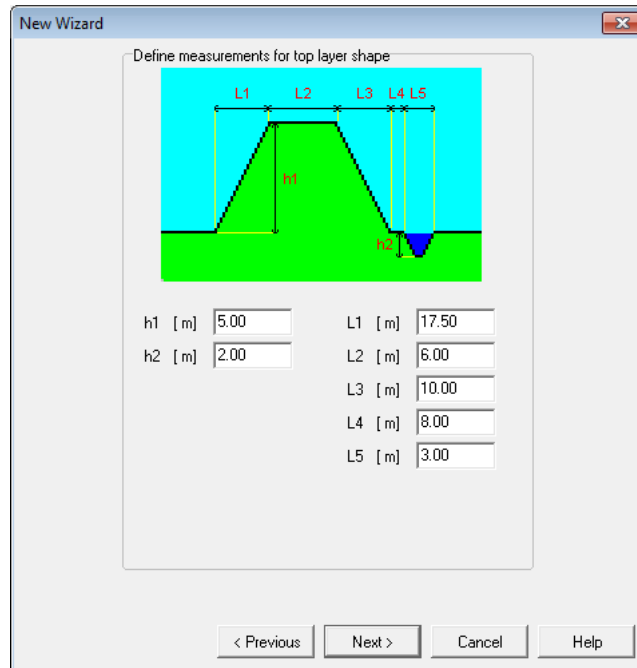


Figure 8.5: New Wizard window, Top layer measurements

In [Figure 8.1](#), the measurements of the dike and the dewatering channel have been depicted.

11. Fill in the values in [Figure 8.5](#) to provide the measurements for the top layers.
12. Click *Next*.

8.2.4 Wizard – Material types

The next window ([Figure 8.6](#)) allows choosing a soil type for each layer from the drop-down menus beside the layer numbers. Later it is possible to modify properties, including strength properties, of the soil types.

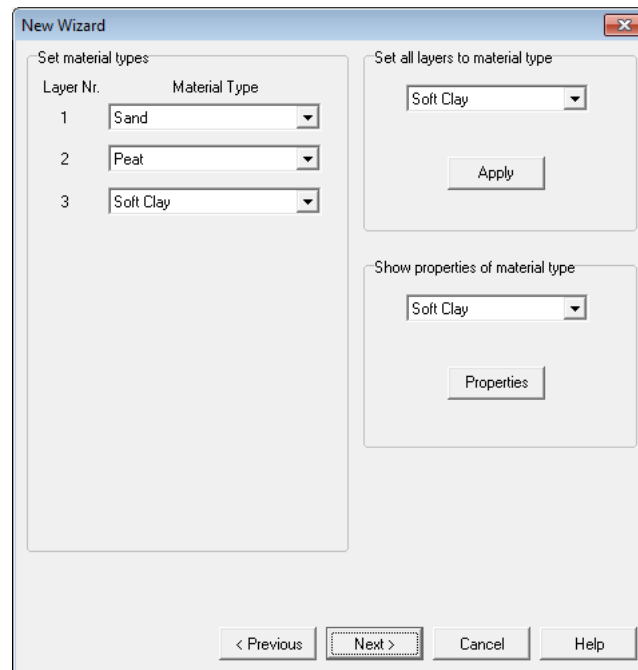


Figure 8.6: New Wizard window, Soil selection

13. Set Layer Nr. 1 to *Sand*.
14. Set Layer Nr. 2 to *Peat*.
15. Set Layer Nr. 3 to *Soft Clay*.
16. Click *Next*.

8.2.5 Wizard – Checking

The last window of the *Geometry Wizard* (Figure 8.7) presents an overview of the entered geometry. The user can check whether it is as desired. If not, the *Previous* button can be used to modify the values in the previous *Wizard* windows.

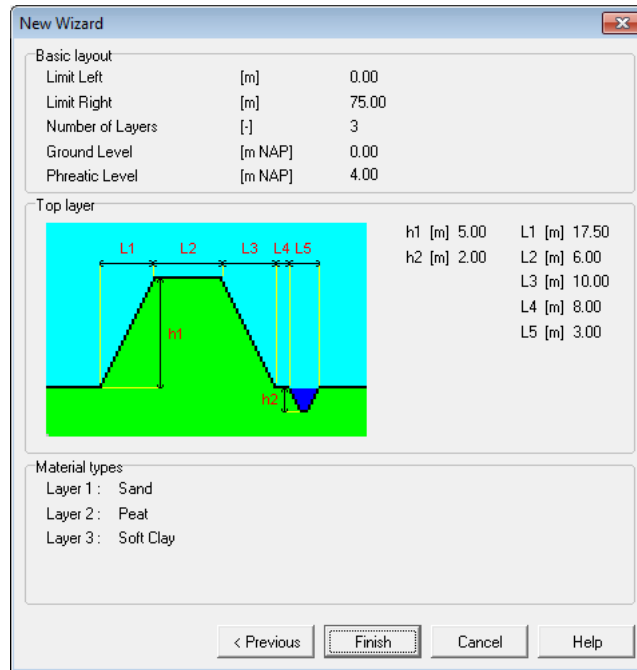


Figure 8.7: New Wizard window, Geometry overview

17. Click *Finish*.

8.2.6 View Input

A *View Input* window appears (Figure 8.8) with the D-GEO STABILITY geometry that has been created so far. At this point the geometry needs to be saved.

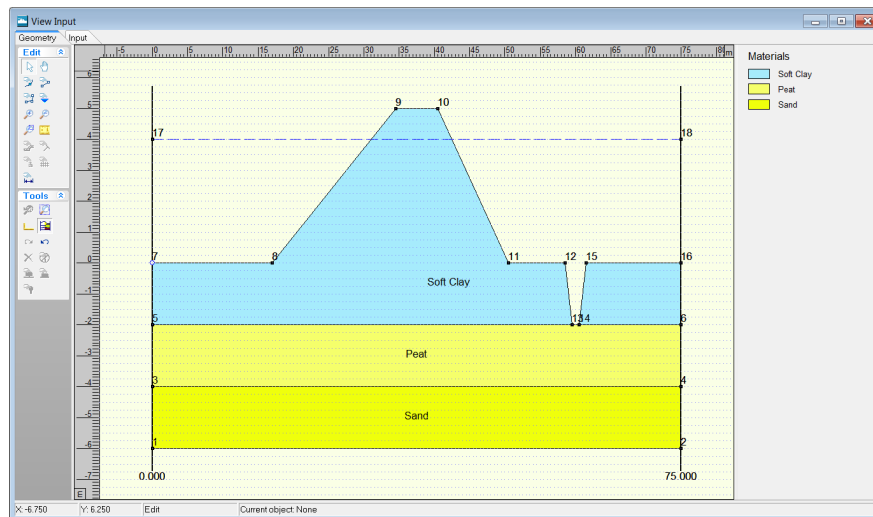


Figure 8.8: View Input window

18. Click *Save as* in the *File* menu.
19. Enter <Tutorial-1a> as file name.
20. Click *Save*.

8.3 Project

8.3.1 Model

At this point the calculation model is to be set. In this tutorial, the minimum safety factor for the dike structure must be determined. This can be done by assessing the stability of the dike via one of its possible failure mechanisms, namely a slip circle. The Bishop method performs calculations on such a slip circle therefore the *Bishop* model is used in this tutorial. Later, in [Definitions \(section 8.6\)](#), it will be described how D-GEO STABILITY uses the Bishop method to determine the minimum safety factor for the soil structure.

21. Choose *Model* from the *Project* menu to open the *Model* window ([Figure 8.9](#)).

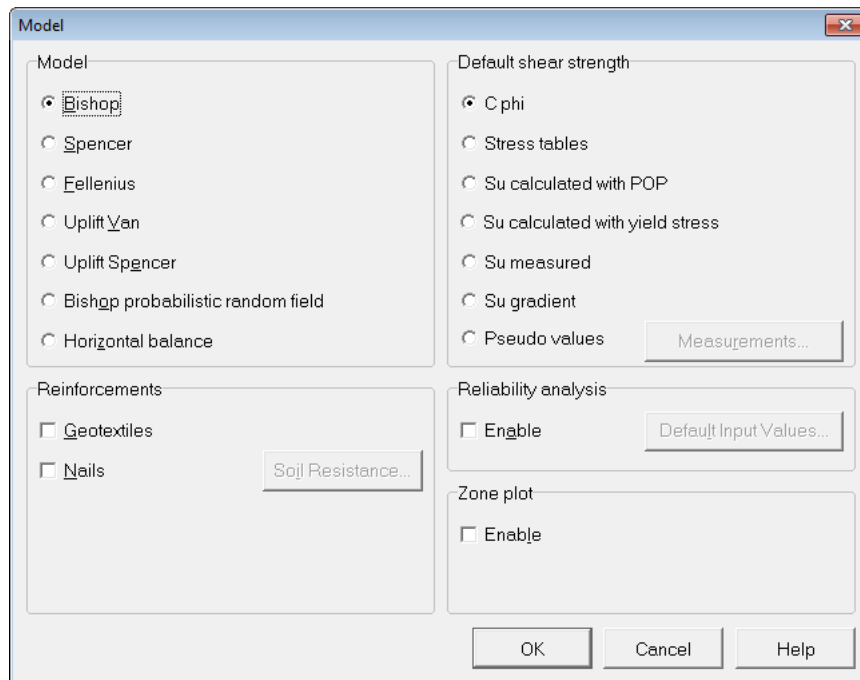


Figure 8.9: Model window

22. Select the *Bishop* model (using a circular slip plane).
23. From the *Soil* menu, select *Materials* and set the *Default shear strength* to *C phi*.
24. Set the cohesion and friction angle for each layer (see [Table 8.1](#)).
25. Unmark the *Geotextiles* and *Nails* check-boxes as no geotextile or nail is used in this tutorial.
26. Click *OK* to confirm.

See [section 4.1.1 "Model"](#) for a detailed description of this window.

8.3.2 Project Properties

To give the project a meaningful description, follow the steps described below:

27. On the menu bar, click *Project* and then choose *Properties* to open the *Project Properties* window (Figure 8.10).
28. Fill in <Tutorial 1 for D-GEO STABILITY > and <Dike reinforced with berm> for *Title 1* and *Title 2* respectively in the *Identification* tab. The settings of the others tabs of the *Project Properties* window are set to their default values.

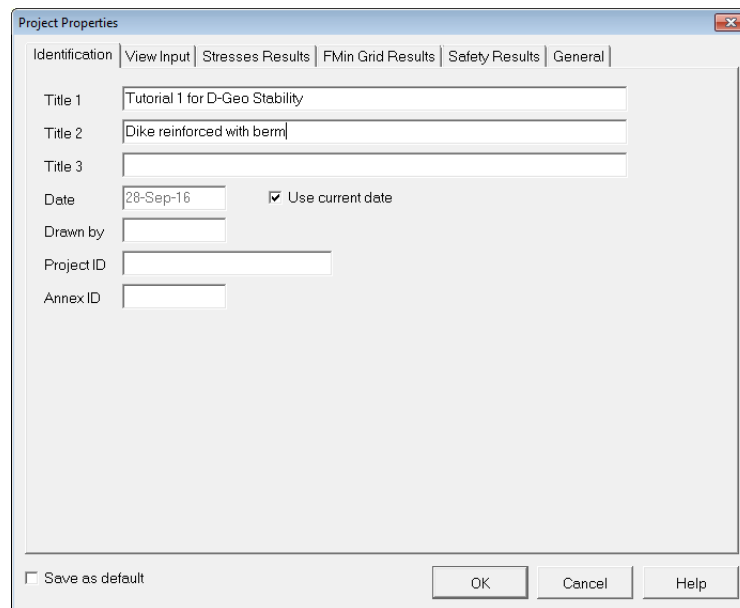


Figure 8.10: *Project Properties* window, *Identification* tab

In the other tabs of the *Project Properties* window, some default values are modified in order to make the graphical geometry input (section 8.9.1) and the view results (section 8.8) more understandable.

29. Select the *View Input* tab (Figure 8.11) to change the settings of the *View Input* window.
30. Mark the *Points* check-box of the *Labels* sub-window in order to display the point's number.
31. In the *Layers* sub-window, select *As material names* to display the material name of the different layers.
32. In the *Grid* sub-window, enter a *Grid distance* of 0.25 m and mark the *Snap to grid* check-box in order to ensure that objects align to the grid automatically when they are moved or positioned.

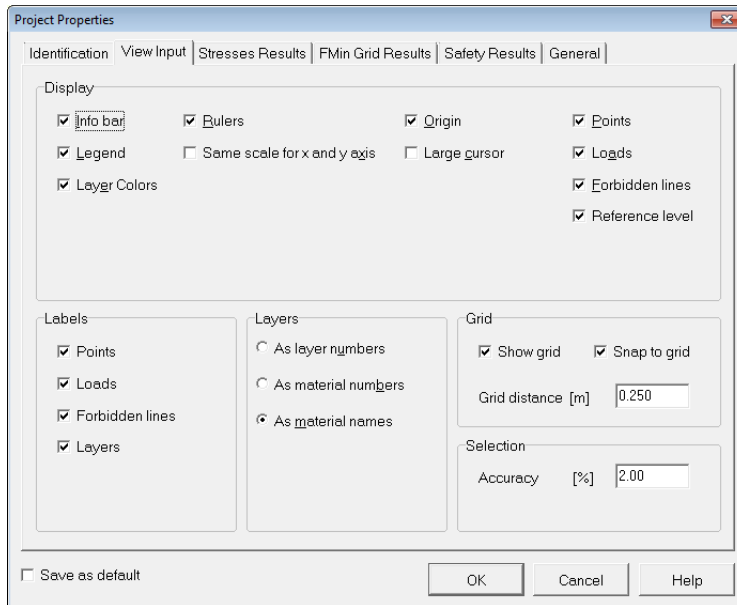


Figure 8.11: Project Properties window, View Input tab

33. Select the *Stresses Results* tab (Figure 8.12) to change the settings of the *Stresses* (section 8.8.3) and *Stresses in Geometry* (section 8.8.2) windows.
34. Select the *As material names* in the *Layers* sub-window to display the material name of the different layers in the *Stresses* window.

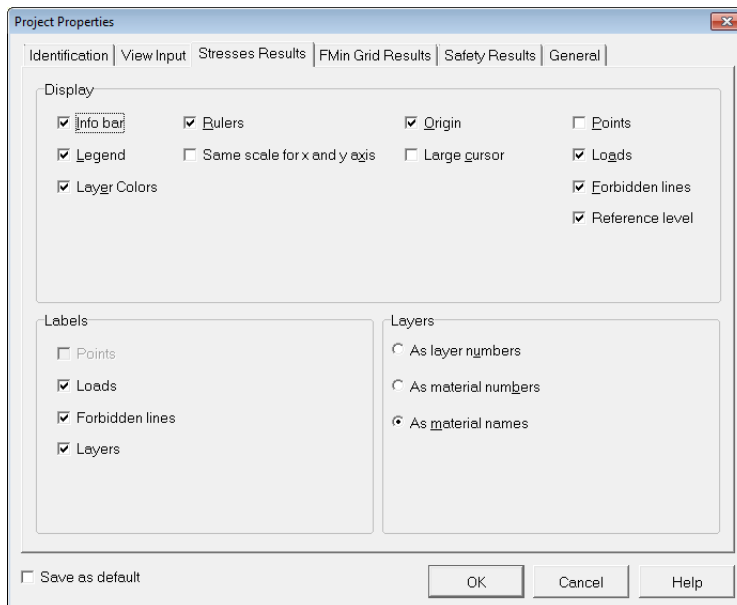


Figure 8.12: Project Properties window, Stresses Results tab

35. Select the *FMin Grid Results* tab (Figure 8.13) to change the settings of the *FMin Grid* window (section 8.8.4).
36. Mark the *Use values from results* check-box to display the iso-lines with a range automatically calculated by D-GEO STABILITY.
37. Mark the *Points labels* check-box to display the safety factor of each point of the FMin grid.

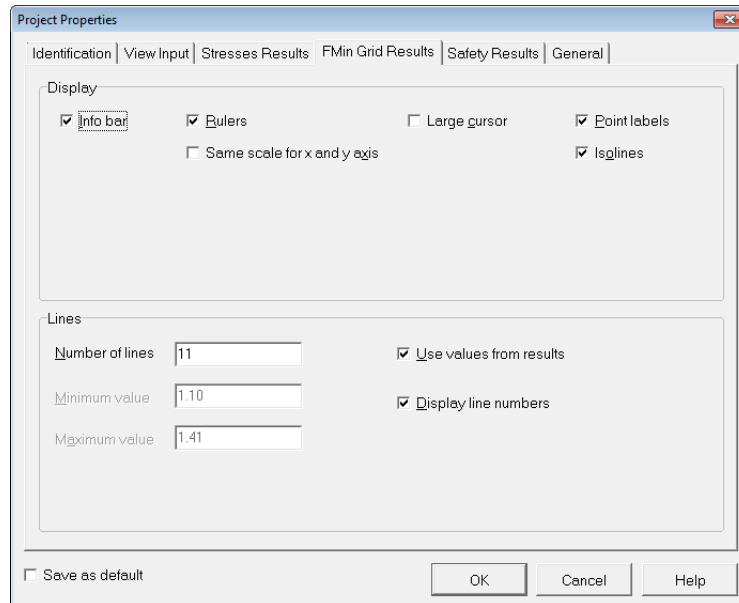


Figure 8.13: Project Properties window, FMin Grid Results tab

38. Select the *Safety Results* tab (Figure 8.14) to change the settings of the *Safety Overview* window (section 8.8.5).
39. Select the *As material names* in the *Layers* sub-window to display the material name of the different layers.
40. Enter values of <1.35> in the *Safe* >= box and <1.15> in the *Fail* < box to define respectively the safe and failure areas as given in the tutorial introduction (section 8.1).

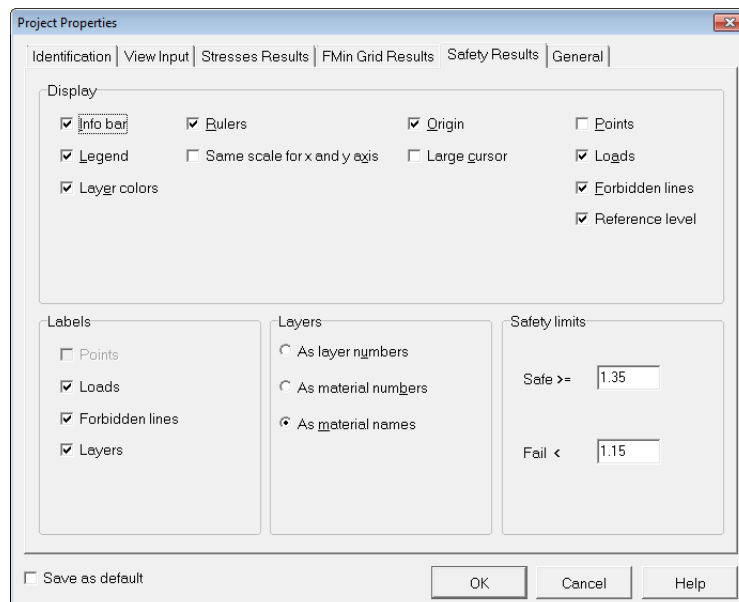


Figure 8.14: Project Properties window, Safety Results tab

41. Select the *General* tab (Figure 8.15) to check that the results will be displayed in kilo Newton and meters.

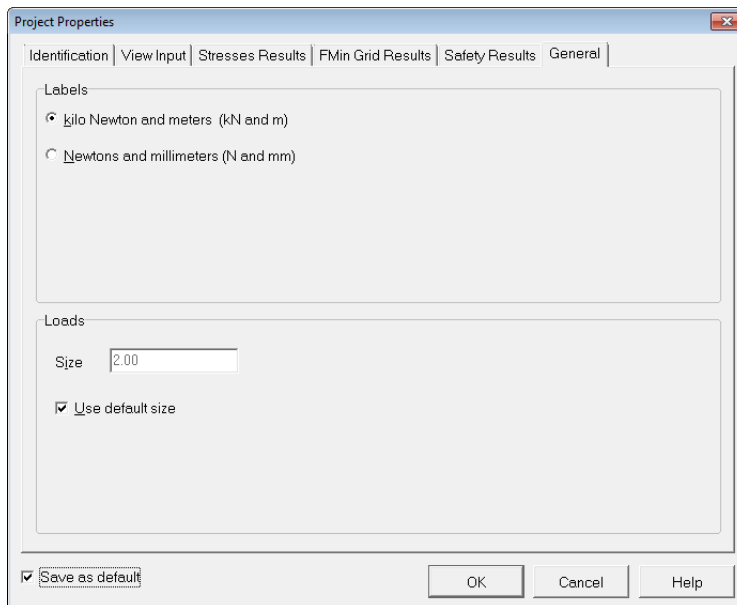


Figure 8.15: Project Properties window, General tab

42. Before closing the *Project Properties* window, mark the *Save as default* check-box to use the settings previously inputted every time D-GEO STABILITY is started, which mean for the other tutorials.
43. Click *OK* to confirm.

See [section 4.1.3 "Project Properties"](#) for a detailed description of this window.

8.4 Geometry

In the *Geometry* menu the geometry aspects of the project can be specified. Most of the relevant geometry aspects of this tutorial have already been addressed in the *Wizard* ([section 8.2](#)). With the *Geometry* menu it is possible to complete the geometry as given in [Figure 8.1](#). In this tutorial the shape of the phreatic line needs to be modified and the piezometric level lines (PL-lines) per layer need to be set. After this has been done, D-GEO STABILITY can perform a check if all the entered geometry is correct.

8.4.1 Points

At this point the phreatic level is still +4.0 m across the whole domain, as set in the *Wizard* ([section 8.2.1](#)). However, according to [Figure 8.1](#), the phreatic line has a curved shape with different water levels at both sides of the dike and a groundwater flow within the dike. Therefore, the phreatic line must be adjusted so that it represents the phreatic line of [Figure 8.1](#).

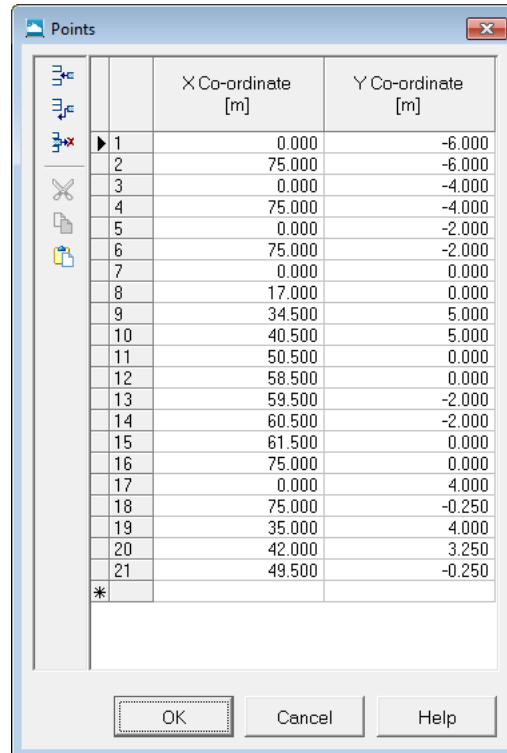
All lines in D-GEO STABILITY are connections between points. The phreatic line can be adjusted by creating new points (or modifying existing points) and connecting them to represent the phreatic line.

First the point on the right side of the boundary is lowered:

44. Choose *Points* from the *Geometry* menu. The *Points* window appears ([Figure 8.16](#)). It is possible to modify the coordinates of the current points in the entries to the right of the point number.
45. Click the Y coordinate of point 18 and change it from value 4.0 to <-0.25>.

Then, to get a new shape of the phreatic line three new points are added using the *Add row* button:

46. Click the *Add row* button three times to add three new points.
47. Modify the coordinates of the points 19, 20 and 21 as given in [Figure 8.16](#) below.



	X Co-ordinate [m]	Y Co-ordinate [m]
1	0.000	-6.000
2	75.000	-6.000
3	0.000	-4.000
4	75.000	-4.000
5	0.000	-2.000
6	75.000	-2.000
7	0.000	0.000
8	17.000	0.000
9	34.500	5.000
10	40.500	5.000
11	50.500	0.000
12	58.500	0.000
13	59.500	-2.000
14	60.500	-2.000
15	61.500	0.000
16	75.000	0.000
17	0.000	4.000
18	75.000	-0.250
19	35.000	4.000
20	42.000	3.250
21	49.500	-0.250
*		

Figure 8.16: Points window

48. Click *OK*.

See [section 4.3.8 "Points"](#) for a detailed description of this window.

8.4.2 PL-lines

The horizontal shape of PL-line 1 which represents the phreatic line is now modified by adding the three points defined before ([section 8.4.1](#)):

49. Click *PL-Lines* in the *Geometry* menu to open the *PL-Lines* window ([Figure 8.17](#)).

By clicking the *Insert Row* button, it is possible to enter new points in the sequence that connects the different points of PL-line 1.

50. Click on row number 2.
51. Click the *Insert Row* button three times. The PL-line will now consist of five points. Points 2, 3 and 4 have to be provided.
52. At the entry right of 2, enter <19>.
53. Click on the row that represents point 3.
54. At the entry right of point 3, enter <20>.
55. Click on the row that represents point 4.
56. At the entry right of point 4, enter <21>.

The *PL-lines* window should now look as in [Figure 8.17](#).

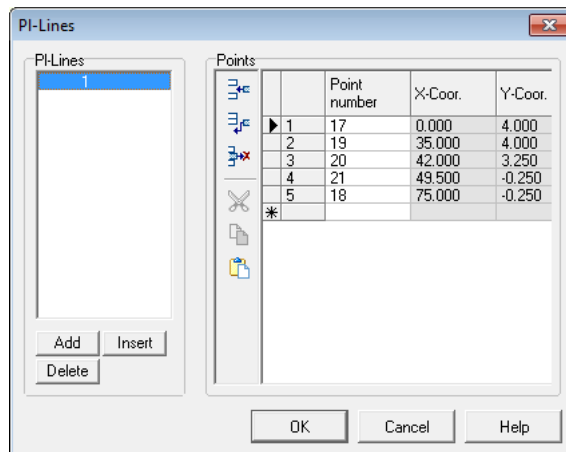


Figure 8.17: *PL-Lines* window

57. Click *OK* to confirm.



Note: The phreatic line drawn in this example is a very crude approximation on the actual shape of the phreatic line. It is possible to import a detailed and realistic shape of a phreatic line from calculations in MSeep or WATEX.

The *PL-line* and thus the phreatic line have been changed and can now be seen in the *View Input* window ([Figure 8.18](#)).

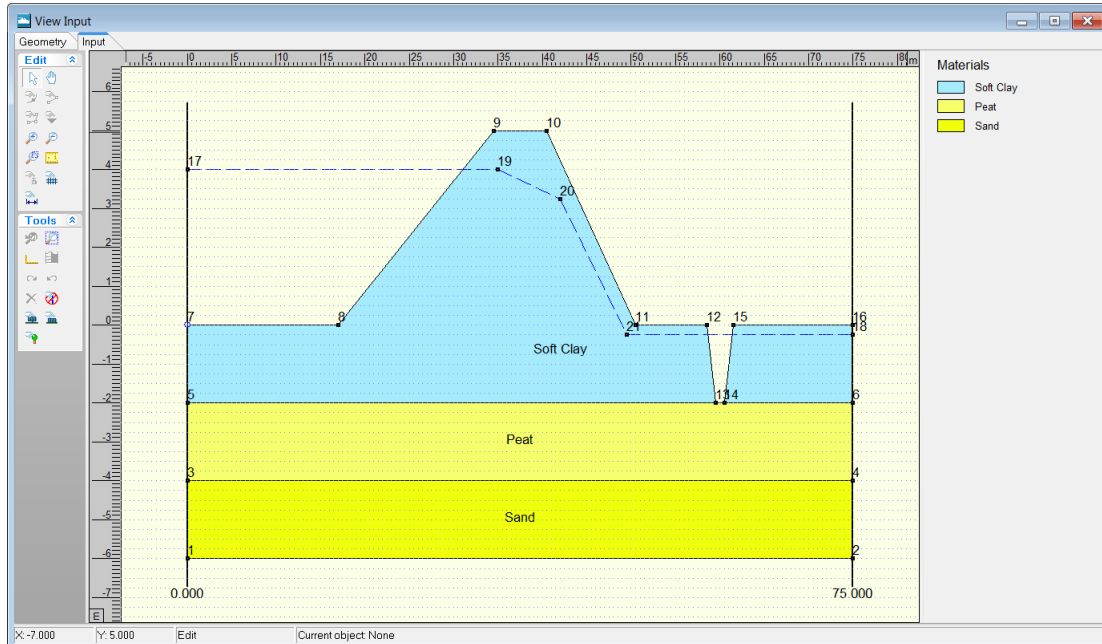


Figure 8.18: *View Input* window with new phreatic line

See [section 4.3.10 "PL-lines"](#) for a detailed description of this window.

8.4.3 PL-lines per layer

Each soil layer has to be assigned its own piezometric level. In the situation in this tutorial the water level in the reservoir is at its maximum design level. If this water level is constant for a longer period of time, it can be assumed that all the hydrostatic pressures in all the soil layers will be defined by the phreatic line. Such a situation is assumed in this tutorial and thus all the layers have their piezometric level in the phreatic line. In this case that is PL-line number 1. To assign the phreatic line (line 1) to be the PL-line of each of the layers, do the following:

58. In the *Geometry* menu, choose *PL-lines per layer* to open the *PL-lines per Layer* window.
59. Enter PL-line <1> as piezometric level for all the layers (Figure 8.19).
60. Click *OK*.

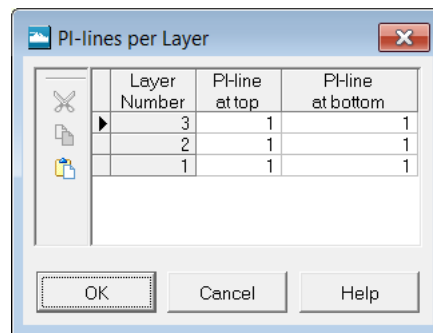


Figure 8.19: *PL-lines per Layer* window

See section [PL-lines per Layer \(section 4.3.13\)](#) for a detailed description of this window.

8.4.4 Check Geometry

It is possible to check whether the defined geometry has any errors:

61. Click *Check geometry* in the *Geometry* menu. At this point, an information window indicating that the entered geometry is correct should appear (Figure 8.20).

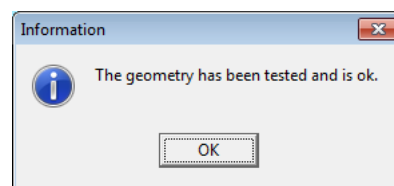


Figure 8.20: *Information* window

62. Click *OK*.

See [section 4.3.14 "Check Geometry"](#) for a detailed description of this window.

8.5 Soil

In the *Soil* menu it is possible to modify properties of the soil layers that were created earlier (section 8.2.4) to be in accordance with Table 8.1.

63. Choose *Materials* from the *Soil* menu to open the *Materials* window.
64. Select *Dense Sand* in the material list. Click *Rename* and change *Dense Sand* into <Berm Sand>.

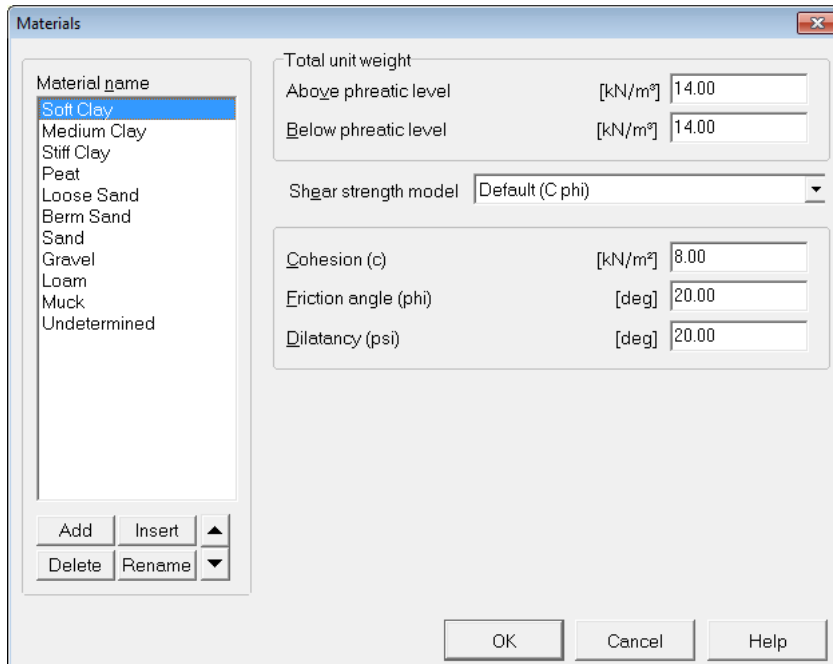


Figure 8.21: Materials window

65. Enter the soil properties values of the four layers used in this tutorial (*Soft Clay*, *Peat*, *Sand* and *Berm Sand*) as indicated in Table 8.1. For dilatancy, enter the same values as for friction angle.
66. Click *OK* when finished.




Note: It is possible to import soil properties from the MGeobase database, see section 4.3.4.

See section 4.2.4.1 "Materials – Input of fixed parameters" for a detailed description of this window.

8.6 Definitions

In this tutorial D-GEO STABILITY uses the Bishop method to determine the minimum safety factor for a soil structure by performing a slip plane calculation based on equilibrium of horizontal forces and moments. D-GEO STABILITY performs this Bishop calculation on several slip planes. From those calculations, D-GEO STABILITY determines the slip plane with the lowest safety factor. In D-GEO STABILITY a slip plane is geometrically defined by its midpoint and by a tangent line. In the *Definitions* menu specifications concerning such a calculation grid can be made by the user. In addition, possible tangent lines for each slip circle need to be defined. This can be done manually or via the *Slip Circle Definition* window in the *Definitions* menu (Figure 8.22). For the first method do the following:

67. In the *View Input* window, select the *Input* tab.

68. In the *Edit* toolbox on the left, click the *Add calculation grid*  button. The cursor will change to a hand. It is now possible to graphically “drop” the grid in the calculation domain.
69. By left clicking, place the grid to the right side of the dike, just above its crest.
70. The horizontal position can be manually adjusted by left clicking it and dragging it left or right. Under the point grid also a set of tangent lines appears. Its vertical position can be manually adjusted by left clicking it and dragging it up or down.
71. Left click on the grid to select the grid.
72. Modify precisely its properties by clicking the right-hand mouse and selecting *Properties*. The *Slip Circle Definition* window appears.
73. Fill in the values shown in [Figure 8.22](#).
74. Click *OK*

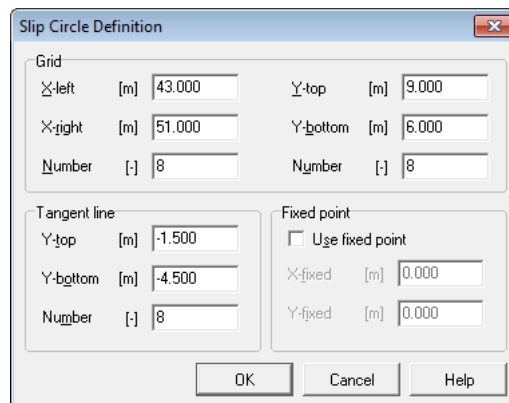




Figure 8.22: *Slip Circle Definition* window

Note: The position and coarseness of the calculation grid have an affect on the minimum safety factor (in the program also called FMin). Firstly, when the program finds a minimum value at one of the outer points of the grid, it will move the grid. This position of the grid will be shifted one grid point distance into the direction of the grid boundary with the minimum safety factor. The program will repeat this procedure until it finds a minimum safety factor that does not lie on one of the outer grid points. 

Note: A coarse grid produces less accurate information on the position of the slip circle with the lowest safety factor. A possibility is to define a coarse grid to find the position of the slip circle with the minimum safety factor. Then repeat the calculation with a finer grid, that cover the coordinates associated with the minimum safety factor in the foregone calculation. 

See [section 4.4.1.1 “Slip Circle Definition \(Bishop or Fellenius\)”](#) for a detailed description of this window.

8.7 Calculation

At this point all the necessary project input has been given to start a calculation. Before starting the calculation, there are some options which can be selected concerning the calculation and the kind of user preferred results report for the program to generate. This can be done in the *Start* window ([Figure 8.23](#)).

The *Move grid* option allows the program to move the grid, when it finds a minimum safety factor at one of the outer grid points. The grid will then shift one grid spacing. As these grid spacings are user defined, this can possibly result in a slightly differing safety factor. Not selecting this option means that the calculation will only produce a minimum safety factor within the given grid.

The *Graphic indicator* shows the different slip circles as the program calculates. Also the minimum safety factor found during the calculation thus far is displayed.

75. Choose *Start* in the *Calculation* menu.

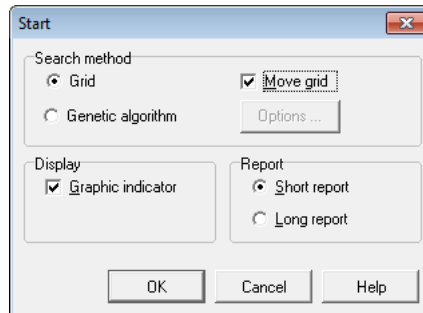


Figure 8.23: Start calculation window

76. Leave the *Move grid*, *Graphic indicator* and *Short report* marked by default.

77. Click *OK*.

At this point the calculation starts. It is possible to view the progress of the calculation, including the minimum safety factor, in a separate window (Figure 8.24) as the *Graphic indicator* option was selected in the *Start* window.

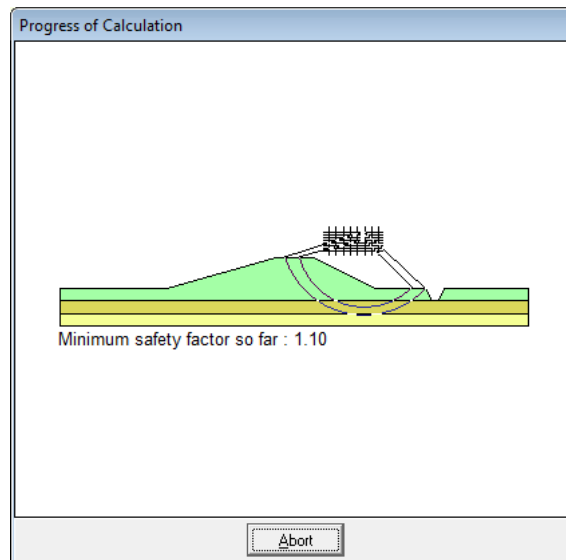


Figure 8.24: Progress of Calculation window

See [section 5.2 "Start Calculation"](#) for a detailed description of this window.

8.8 Results

In the *Results* menu there are several possibilities to view the results of the calculation.

8.8.1 Report

To view a report (text format) that includes the input geometry and information about the critical slip circle:

78. Choose *Report* from the *Results* menu.
 79. Go at the end of the short report to view information on the critical circle (Figure 8.25).

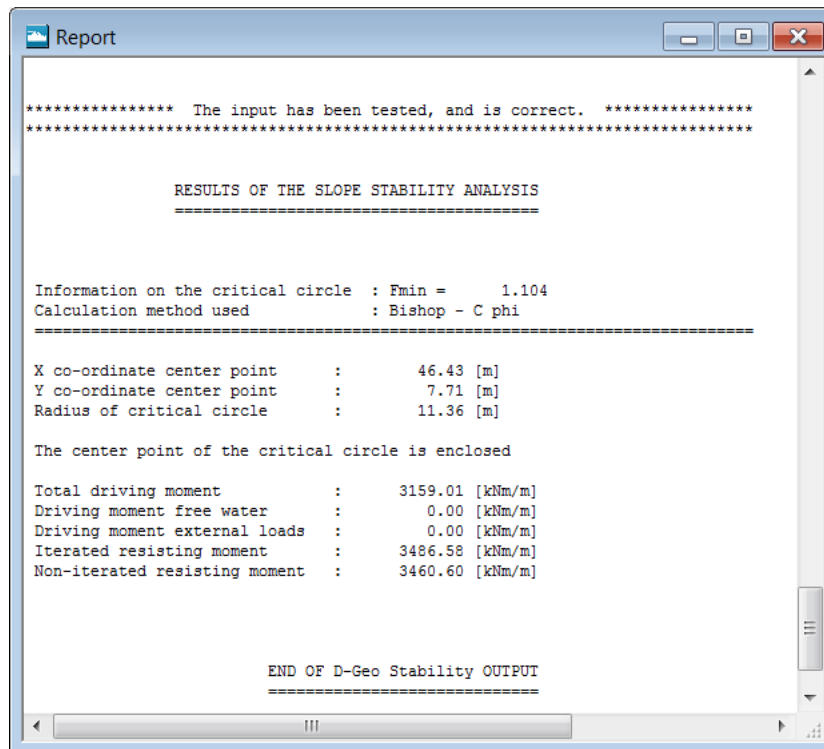


Figure 8.25: Report window

Note: It is possible to export the report shown in the *Report* window to a text file. When the *Report* window is active, choose *Export Active Window* in the *File* menu. In fact, it is possible to export any active window within D-GEO STABILITY. Windows that contain geometrical information can usually be exported to a 'Windows Meta File' (.wmf) or a 'Drawing exchange file' for AutoCAD 14 (.dxf).



See section 6.1 "Report" for a detailed description of this window.

8.8.2 Stresses in Geometry

To view the stresses in any vertical across the calculation domain:

80. Click Results and then choose Stresses in Geometry.

This will produce the graphical output (Figure 8.26). The blue (left) area represents water pressure. The green (right) area represents the total soil pressure. As expected the pore pressure is linear throughout all the layers. The effective vertical stress increases linearly within each layer.

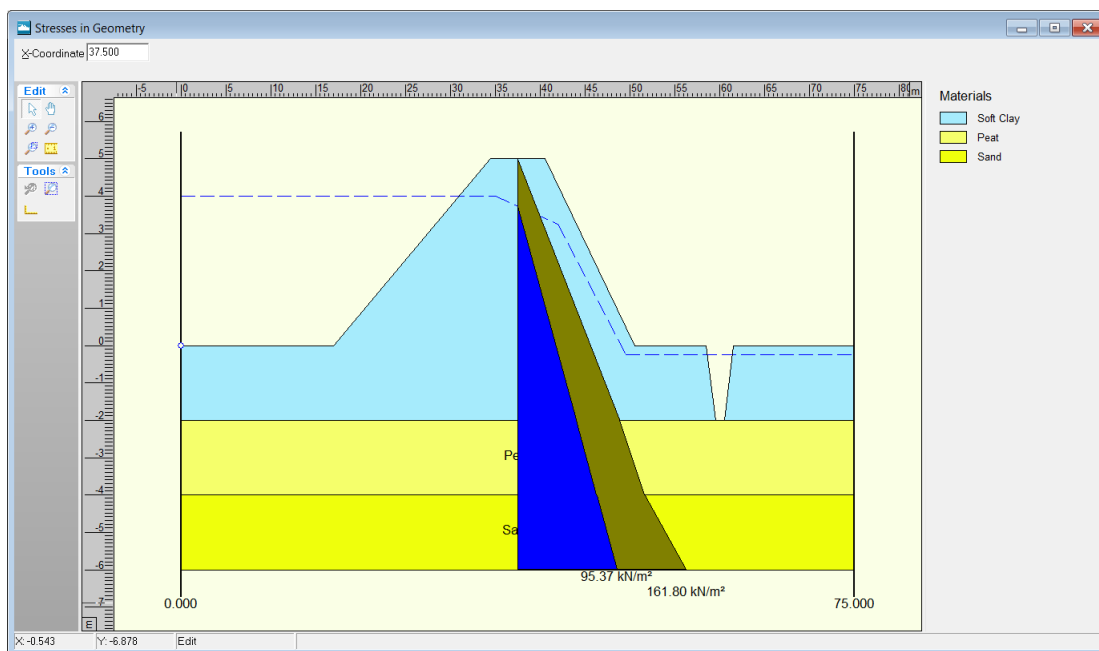


Figure 8.26: Stresses in Geometry window

81. Clicking the cursor anywhere in the horizontal domain will produce a representation of the stresses in the vertical at that point.

It is also possible to manually provide the X coordinate (in the domain) of which to see the stresses in the vertical at that point. This X coordinate can be given in the upper left corner of the window.

See [section 6.2 "Stresses in Geometry"](#) for a detailed description of this window.

8.8.3 Stresses

To view the slip circle that coincides with the lowest safety factor found by the calculation:

82. Choose *Stresses* from the *Results* menu to open the *Critical Circle* window ([Figure 8.27](#)). This window shows the slip circle drawn in the geometry and includes its measurements. Here, it can be seen that D-GEO STABILITY did not moved the grid to find the minimum safety factor; the center point of the slip circle lies within the chosen grid. The slip circle measurements meet expectations. With a minimum safety factor of 1.10, the dike is unsafe.

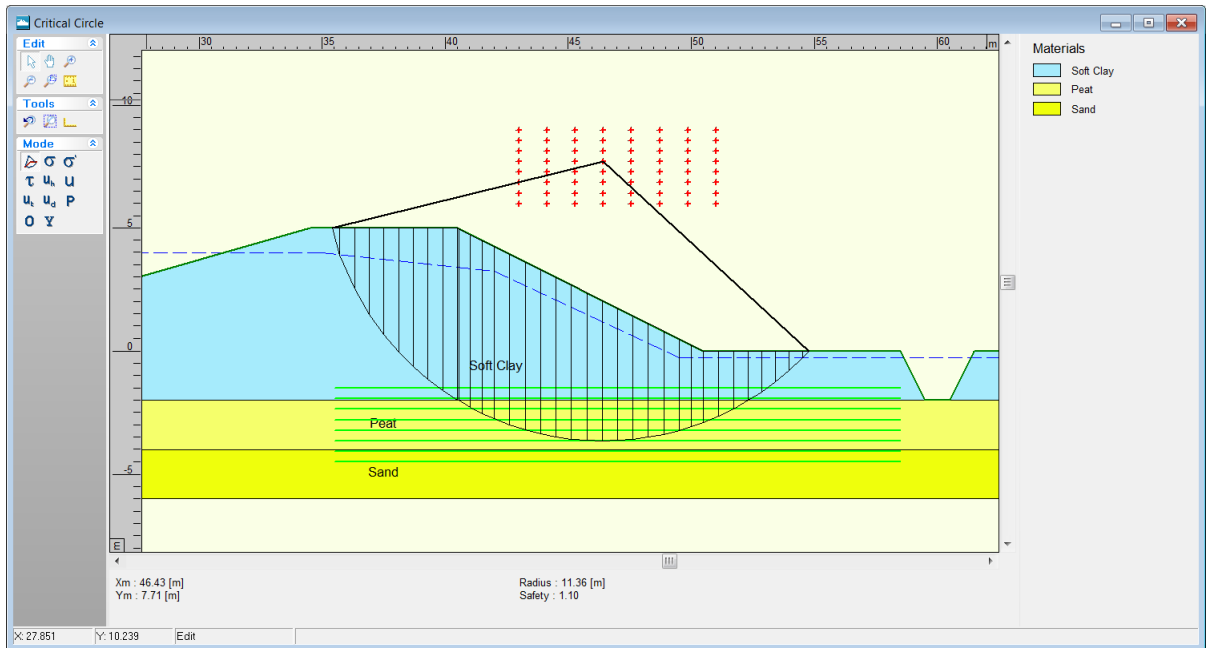


Figure 8.27: Critical Circle window (Slip circle with lowest safety factor)

In this window it is also possible to see the different stress types displayed in the geometry. In the *Mode* toolbox in the left of the screen, the type of stress to be displayed can be selected, see Figure 8.28.

Note: When the cursor is placed over one of the symbols in the stress mode toolbox, a textbox will appear to remind the user on which sort of stress the symbol indicates (section 6.2) .

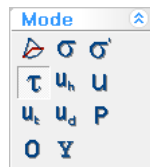


Figure 8.28: Stress mode toolbox

83. Click the *Shear stress* τ button in the *Mode* toolbox. The results window will show the shear stresses along the slip circle (Figure 8.29).

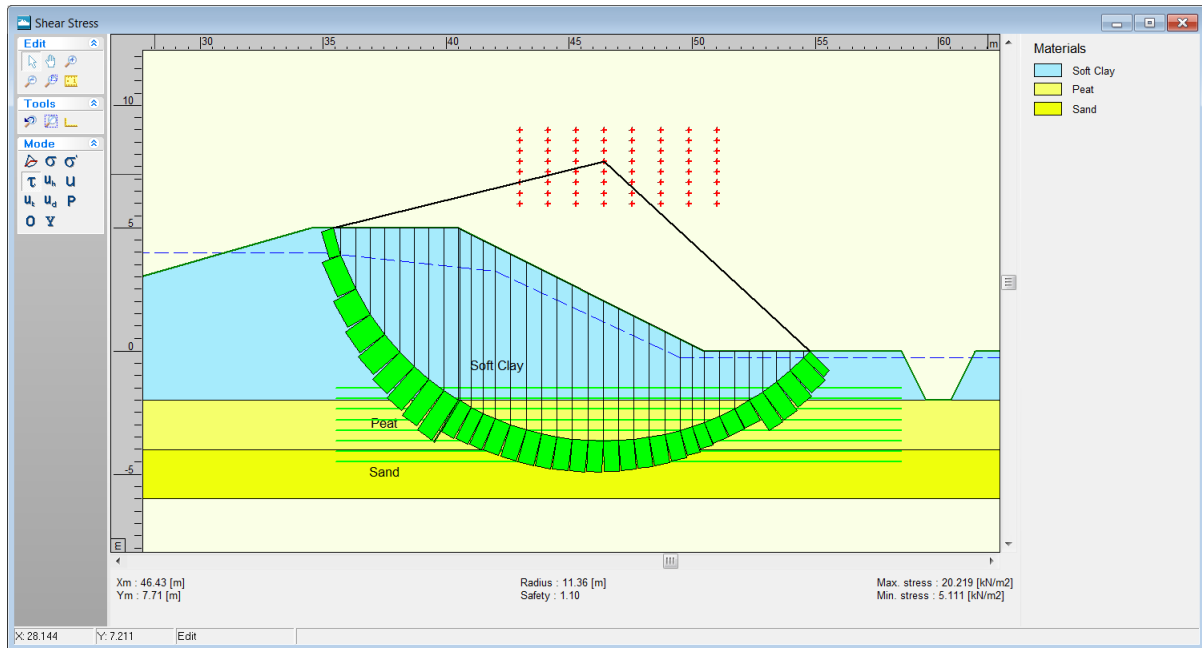


Figure 8.29: Shear stresses window (along the slip circle)

See [section 6.3 “Stresses”](#) for a detailed description of this window.

8.8.4 FMin Grid

To see an overview of the safety factors within the grid:

84. Choose *FMin Grid* in the *Results* menu.

In the *FMin Grid* window displayed ([Figure 8.30](#)), the isolines connect point with equal values for the safety factor. The variations of the safety factors within the grid are within an acceptable margin of each other. When the differences are larger, it is advisable to perform a new calculation with a finer grid.

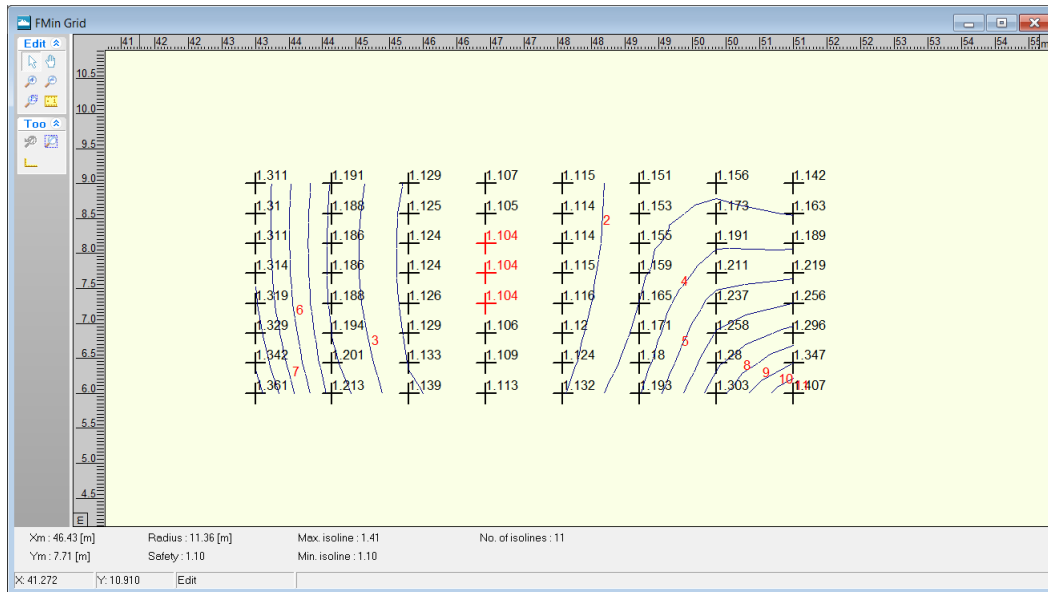


Figure 8.30: FMin Grid window

Note: Values of -1 indicate the impossibility of calculation.



See [section 6.4 "FMin Grid"](#) for a detailed description of this window.

8.8.5 Safety overview

To view the areas with particular ranges of safety factor:

85. Click *Safety Overview* option in the *Results* menu.

In the *Safety Overview* window displayed ([Figure 8.31](#)), the green color indicates the area with a safety factor greater than 1.35, the red color indicates an area with a safety factor below 1.15, and the orange color indicates an area with a safety factor in the range between 1.15 and 1.35. In this way, it is possible to get an idea of areas that are more sensitive and less sensitive to instability.

A large part of the study area of the dike has a safety factor lower than 1.15, which through the definitions in the preferences window, is regarded as unsafe.

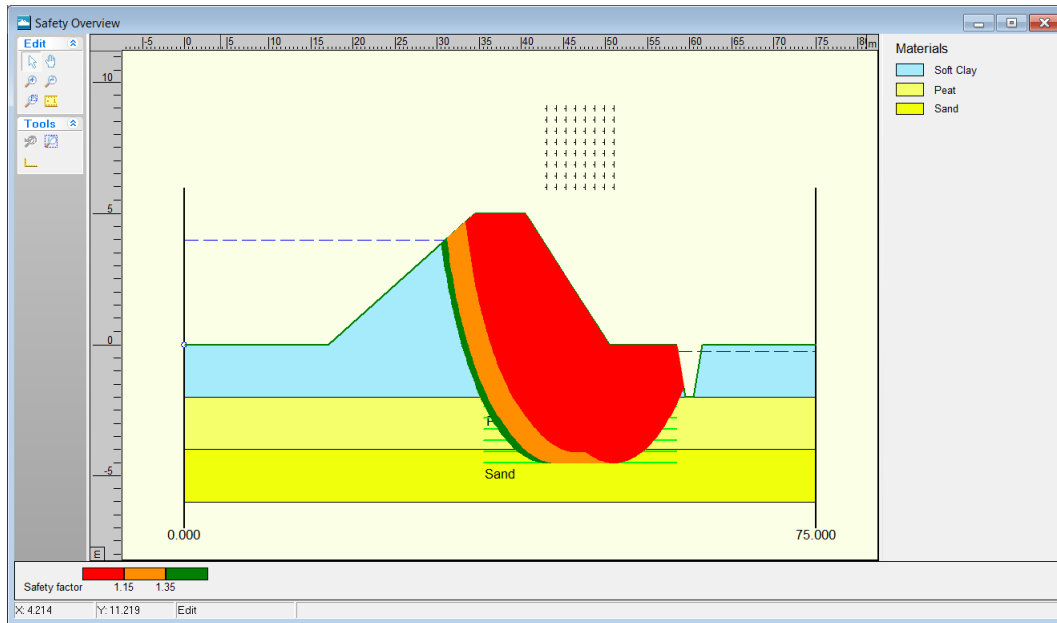


Figure 8.31: Safety Overview window

See [section 6.8 "Safety Overview"](#) for a detailed description of this window.

8.9 Berm construction

The result of the calculation is a minimum safety factor lower than 1.15; this usually means that the dike is considered unsafe. In order to improve the dike's stability, it is proposed to construct a berm structure at the right side of the dike. The general measurements of the proposed berm are depicted in [Figure 8.32](#).

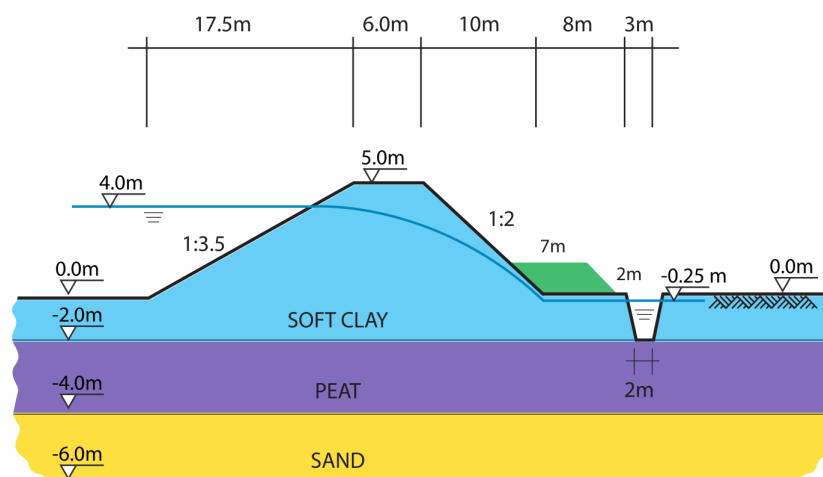


Figure 8.32: Construction of a berm (Tutorial 1b)

Before adding a berm to the current project, a new file is created:

86. Save the current file as <Tutorial-1b> using the *Save As* window of the *File* menu.
87. Click *Save*.

To check whether the point of the new polyline has the correct coordinates, do the following:

92. Click on point number 13. A red square will be placed over the selected point.
93. Click the right-hand mouse button and select *Properties*. In the window displayed (Figure 8.35), the coordinates can be checked and modified if needed.
94. Click *OK*.
95. Repeat this verification for points 14 and 15 using Table 8.2.

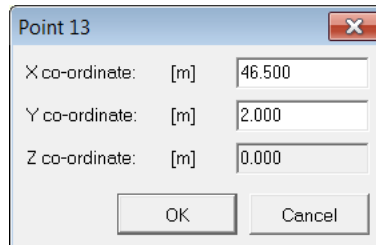


Figure 8.35: Point 13 properties window

8.9.2 Soil material assigned to the berm

The soil material <Berm Sand> previously defined (section 8.5) is assigned to this berm:

96. In the *Geometry* tab of the *View input* window, click the name *Undetermined* in the berm geometry. When selected, the name becomes red.
97. Then right click and choose *Properties*. The *Layer 5* properties window will appear.
98. From the drop-down menu choose the material *Berm Sand* as shown in Figure 8.36.
99. Click *OK*.

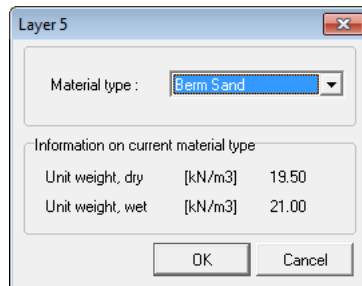


Figure 8.36: Layer 5 properties window

8.9.3 Calculation and Results

In order to start a calculation with this new geometry:

100. Click *Start* from the *Calculation* menu to open the *Start* calculation window.
101. Click *OK*.
102. Choose *Stresses* from the *Results* menu to open the *Critical Circle* window. This window shows that the minimum safety factor is now 1.35 (instead of 1.10 without the berm).

The increase of the minimum safety factor, as expected when adding a berm, can also be seen in the *Safety Overview* window:

103. Select *Safety Overview* from the *Results* menu.

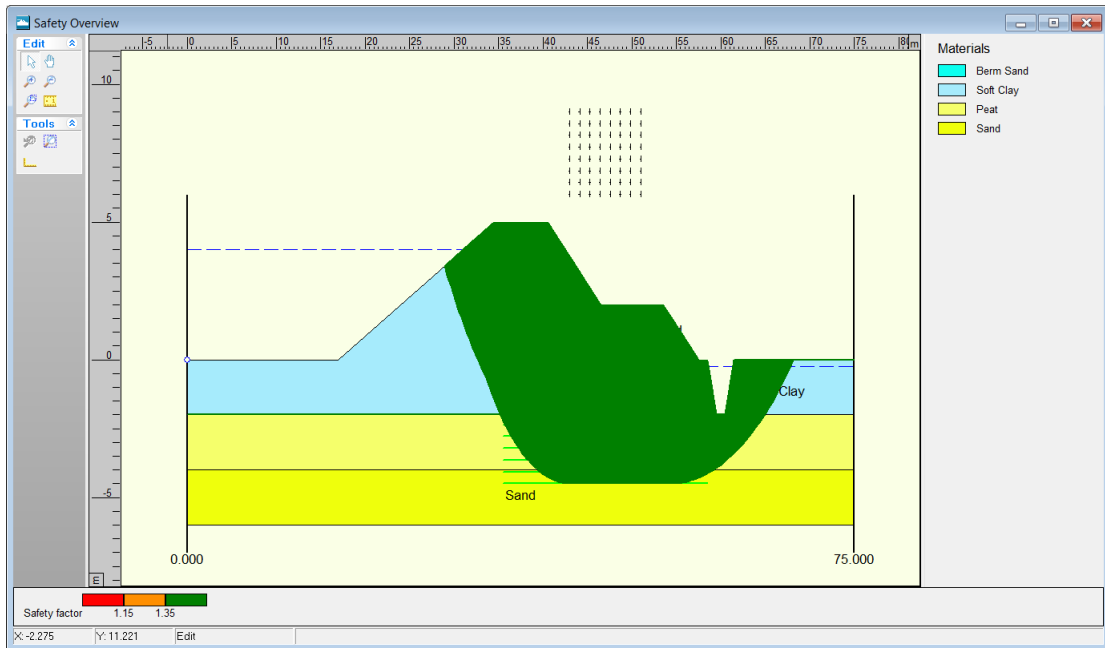


Figure 8.37: Safety Overview window

The window displayed (Figure 8.37) shows that the full dike has a safety factor higher than 1.35. Therefore, the construction of the berm has made the dike structure safer.

8.10 Conclusion

The *Geometry Wizard* is one of the ways to construct a simple project geometry. There are tools in the program to completely customize the geometry to specific needs. Once these details have been input, they can be used to calculate a range of results. These include the minimum safety factor, measurements of the critical slip circle and stresses along the slip circle and in any vertical in the geometry. One way to view these results is to display them graphically on the screen.

A design conclusion is that, in this case, the construction of a berm has helped to increase the minimum safety factor of the dike structure.

9 Tutorial 2: Unsaturated soil

This tutorial continues the case in Tutorial 1 (chapter 8). Here, a measure is taken to lower the water level in the reservoir (left of the dike). In the dike itself excess pore pressures shall arise (clay). Pore pressures will remain high for a period of time after lowering the water level. To see what this means for slope stability on both sides of the dike, the strength of the dike layer shall be described by the unsaturated cohesion, s_u . The underlying layers will adjust pore pressures more rapidly as they consist of more permeable soils.

The objective of this exercise is:

- ◇ To learn how to assign different shear strength properties to a particular soil (layer).

For this example, the following D-GEO STABILITY module is needed:

- ◇ D-GEO STABILITY Standard module (Bishop and Fellenius).

This tutorial is presented in the file Tutorial-2.sti.

9.1 Introduction to the case

The same dike geometry as Tutorial 1b is used. In this example the water level on the left side of the dike is lowered, see Figure 9.1. This might occur when, for instance, maintenance is needed on the dike. The water level is lowered at a considerable place. A calculation of the safety factor of the dike is performed when the water level at the left of the dike is at its required level. As can be seen in Figure 9.1, the groundwater level in the dike is still quite high. Therefore it is now possible to describe the shear strength model for the top layer by its undrained shear strength value s_u which is equal to 6.0 kN/m^2 at the top and 8.0 kN/m^2 at the bottom of the clay layer.

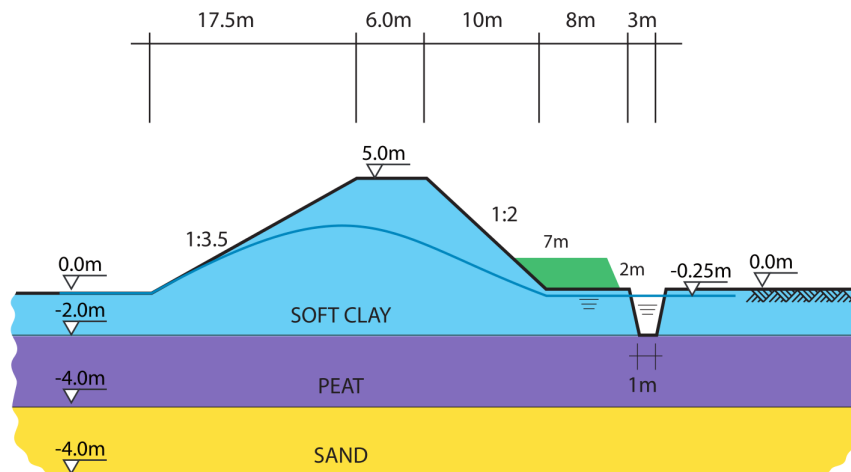


Figure 9.1: Dike with lowered water level (Tutorial 2)

9.2 Project Properties


In this tutorial, the same file which has been created in the Tutorial 1 is used.

1. Click *Open* in the *File* menu.
2. Select Tutorial-1b.
3. Click *Open*.

4. Click *Save As* in the *File* menu.
5. Enter <Tutorial-2> as a file name.
6. Click *Save*.
7. On the menu bar, click *Project* and then choose *Properties* to open the *Project Properties* window.
8. Fill in <Tutorial 2 for D-GEO STABILITY > and <Unsaturated soil> for *Title 1* and *Title 2* respectively in the *Identification* tab.
9. Click *OK*.

9.3 Changing the phreatic line

To lower the water level, the phreatic line needs to be altered. This can be done in the *Geometry* tab of the *View Input* window.

10. Click the  *Add point(s) to boundary / PL-line* button to create extra points on the current phreatic line.
11. Place three points on the left part of the phreatic line by clicking three times between points 20 and 21 (from left to right). Points 25, 26 and 27 should appear consecutively as shown in [Figure 9.2](#).

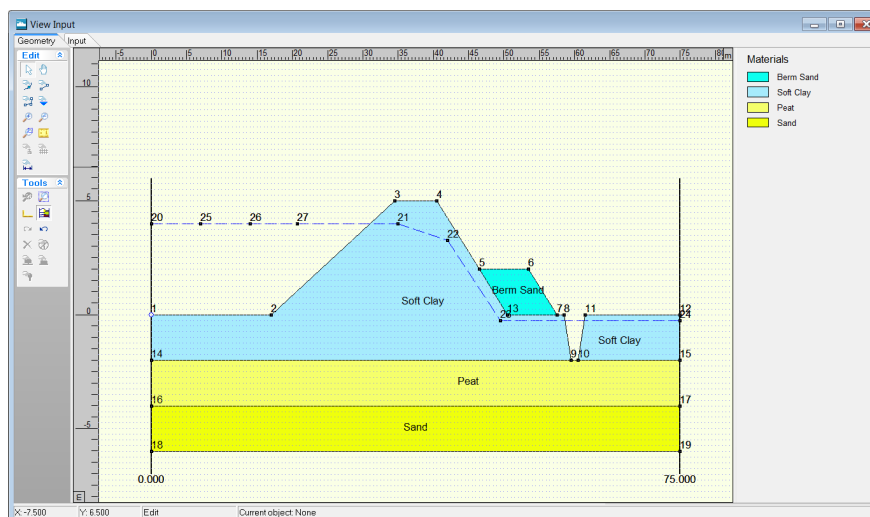



Figure 9.2: View Input window, Geometry tab – Adding of three points on the phreatic line

12. Click the *Edit*  button to exit the *Add point* mode.

The coordinates of the first six points of the phreatic line have to be adjusted so that it represents the shape of [Figure 9.1](#). The new points' positions of [Table 9.1](#) give an approximation of the desired shape. To alter the phreatic line, follow these steps:

13. Select the first left point (point 20). After selection, it should be covered by a red square.
14. To change its position, click the right-hand mouse button and select *Properties*.
15. In the window displayed ([Figure 9.3](#)), modify the coordinates of point 20 according to [Table 9.1](#).

Table 9.1: X and Y coordinates of the consecutive points of the phreatic line

Points nr.	X coordinate [m]	Y coordinate [m]
20 (left)	0.0	0.0
25	17.0	0.0
26	23.0	1.5
27	29.5	2.0
21	39.5	1.75
22	47.0	0.75
23	49.5	-0.25
24 (right)	75.0	-0.25

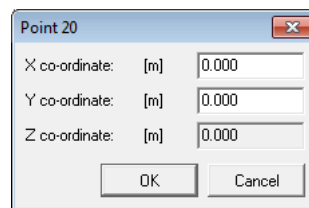


Figure 9.3: Point 20 properties window

- Repeat this for points 22, 21, 27, 26 and 25 consecutively. It is not possible to move a point horizontally beyond the adjacent points, otherwise an error message appears. That's why the coordinates of the points must be changed from the right (point 22) to the left (point 25).

The new shape of the phreatic line is shown in [Figure 9.4](#).

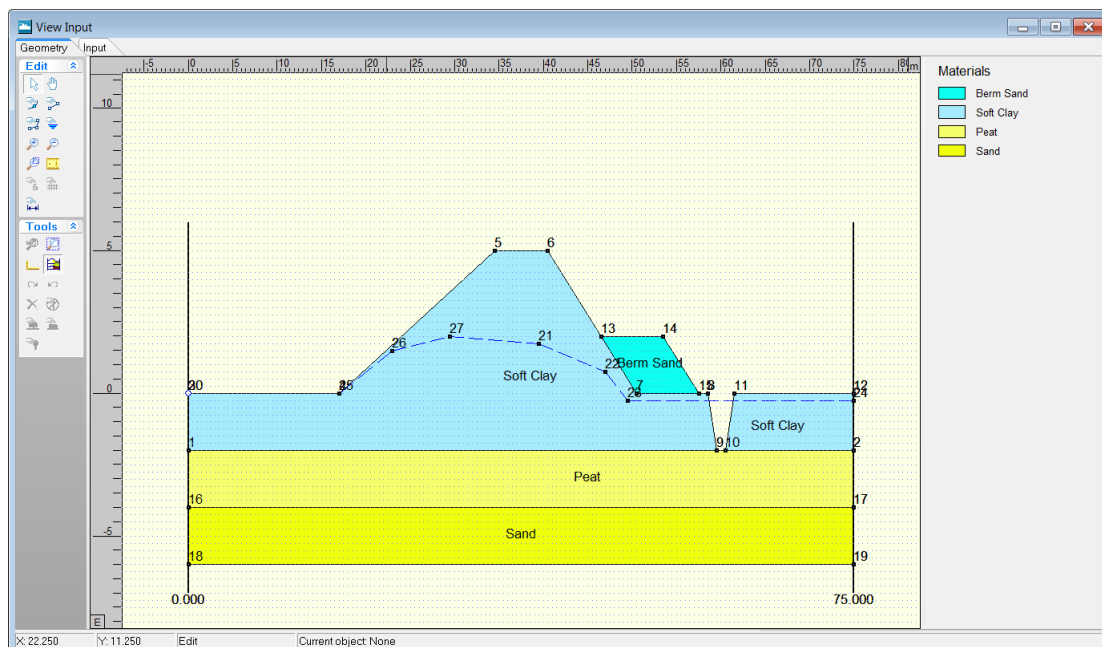


Figure 9.4: View Input window, Geometry tab – New phreatic line

Note: The coordinates can also be changed by dragging the points. It is advised to individually check the points coordinates.



9.4 Soil properties

As explained in introduction, the shear strength model for the top layer (Soft clay) shall be described by the undrained shear strength s_u .

17. Click *Materials* in the *Soil* menu.
18. Select *Soft Clay*.
19. From the drop down menu at *Shear strength model*, choose *Su measured* as the undrained shear strength at the top and the bottom is known ([section 9.1](#)).
20. Enter the suggested values for s_u . At the top of the clay layer Su_{top} is $\langle 6.0 \text{ kN/m}^2 \rangle$. At the bottom of the clay layer Su_{bottom} is $\langle 8.0 \text{ kN/m}^2 \rangle$.
21. Click *OK*.

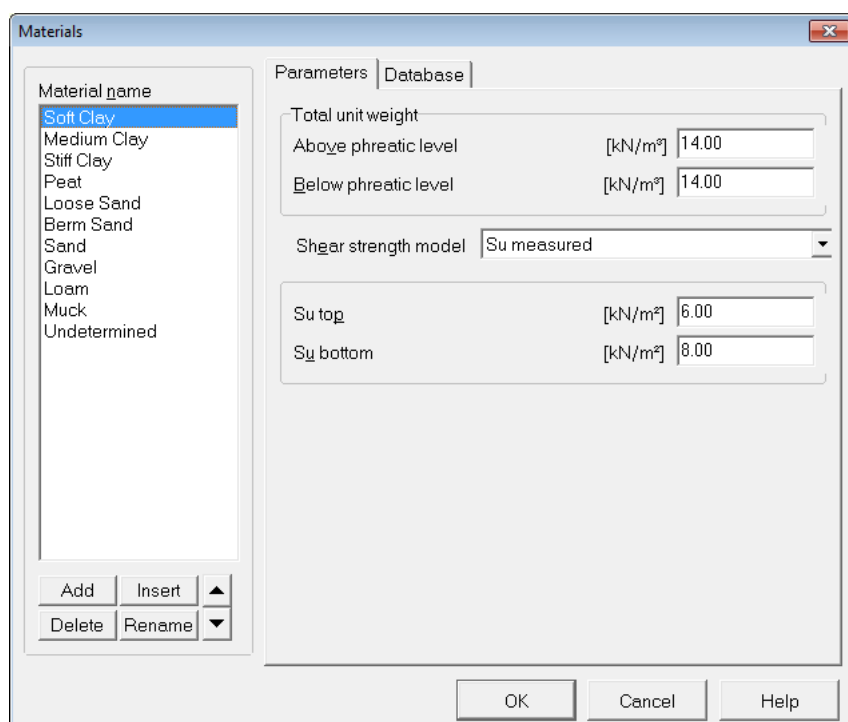
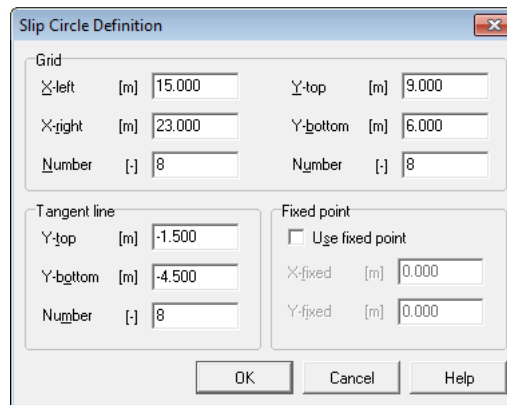


Figure 9.5: Materials window

9.5 Definitions

The safety factor of the dike has to be determined considering the left side of the dike. To this end the calculation grid is placed on the left side of the dike.

22. Make sure the *Input* tab in the *View Input* window is active. Select the calculation grid. It will turn red.
23. Right click and then select *Properties*.
24. Enter the coordinates as shown in [Figure 9.6](#).
25. Click *OK*.



The 'Slip Circle Definition' window contains the following fields:

- Grid:**
 - X-left [m]: 15.000
 - X-right [m]: 23.000
 - Y-top [m]: 9.000
 - Y-bottom [m]: 6.000
 - Number [-]: 8
- Tangent line:**
 - Y-top [m]: -1.500
 - Y-bottom [m]: -4.500
 - Number [-]: 8
- Fixed point:**
 - Use fixed point
 - X-fixed [m]: 0.000
 - Y-fixed [m]: 0.000

Buttons: OK, Cancel, Help

Figure 9.6: Slip Circle Definition window

9.6 Calculation and Results

26. To perform the calculation, select the *Start* option from the *Calculation* menu and click *OK*.
27. Select the *Stresses* option from the *Results* menu to open the *Critical Circle* window (Figure 9.7).

In this window, the slip circle with the lowest safety factor is shown. The safety factor is relatively low: 0.84.

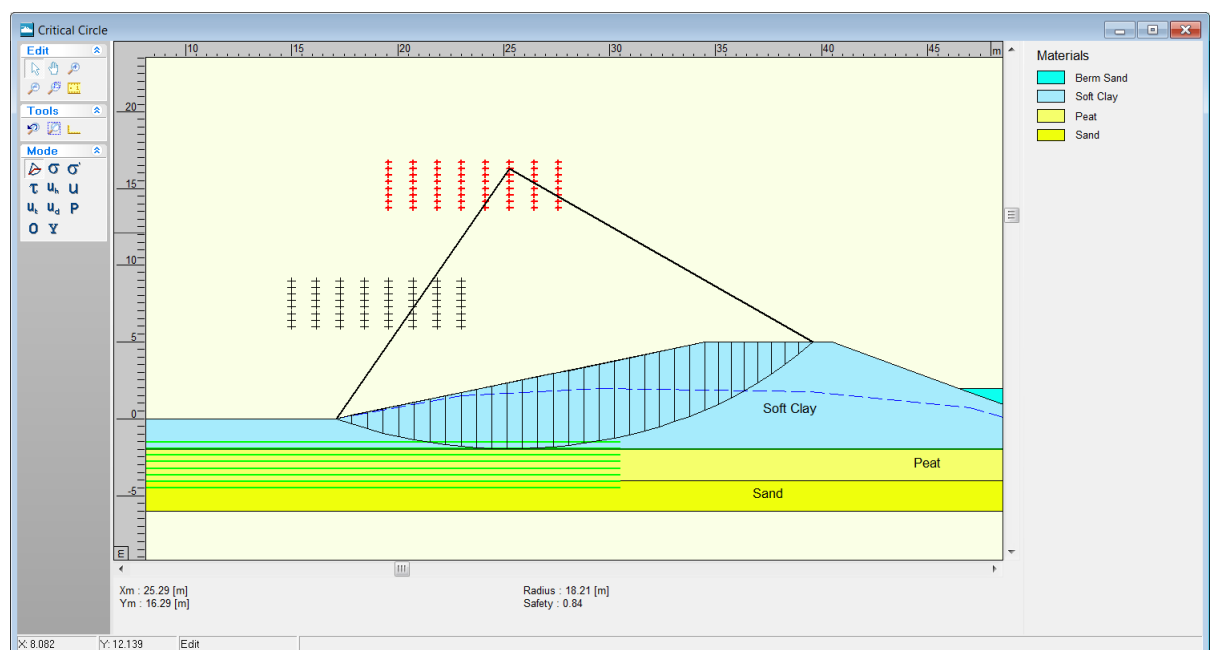


Figure 9.7: Critical Circle window

It is common for a calculation, which incorporates the undrained shear strength properties of a soil type, to result in a lower safety factor than for soil with a c - ϕ shear strength model. To compare the results for calculations using an undrained shear strength and c - ϕ relation, change the shear strength model in the *Materials* option in the *Soil* menu. Run the calculation again and compare the results. When a c - ϕ shear strength model is used for Soft Clay the safety factor will be 1.38.

9.7 Conclusion

It is possible to describe the shear strength properties of a soil with different models. One of those models is the undrained shear strength. In this tutorial a case in which it is relevant to use this model has been presented.

10 Tutorial 3: Geotextile

This example continues the case in Tutorial 1 ([chapter 8](#)). The same soil structure is in place and the same layer build up is present. Now the effect of the presence of a geotextile placed in the geometry is considered.

The objective of this exercise is:

- ◇ To learn how to place a geotextile into the geometry.

For this example, the following D-GEO STABILITY module is needed:

- ◇ D-GEO STABILITY Standard module (Bishop and Fellenius).

This tutorial is presented in the file Tutorial-2.sti.

10.1 Introduction to the case

In the geometry presented in Tutorial 1, the influence the placement of a geotextile has on the safety factor is assessed (see [Figure 10.1](#)). Using a geotextile placed between two soil layers can help improve the stability of a slope. When a geotextile intersects the critical slip circle, it helps to enlarge the resisting moment and increase the safety factor. The contribution to the resisting moment increases when the tensile strength of the geotextile is of a greater value. The characteristics of the geotextile are given in [Table 10.1](#). The reduction area is set at a low value in order to make sure that the full tensile strength of the geotextile is used.

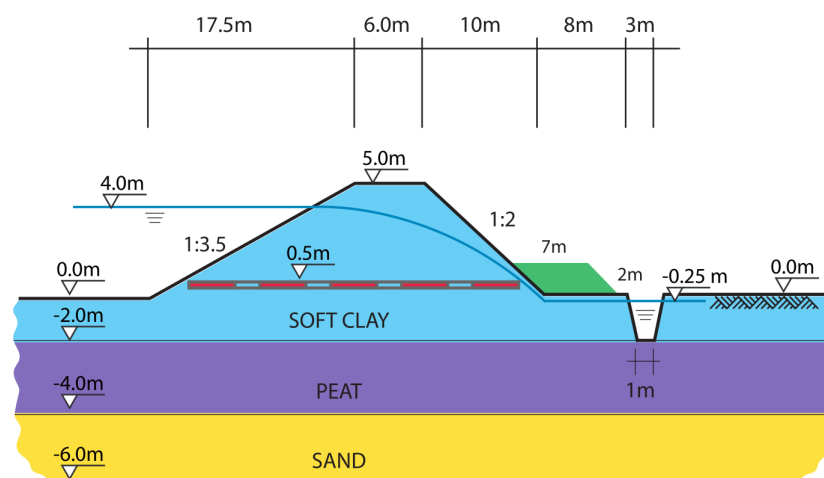


Figure 10.1: Dike reinforced with geotextile (Tutorial 3)

Table 10.1: Characteristics of the geotextile

Effective tensile strength	[kN/m]	200
X coordinates at start	[m]	20
Y coordinates at start	[m]	0.5
Length	[m]	28
Reduction area	[m]	5

10.2 Project Properties

In this tutorial, the same file which has been created in the Tutorial 1 is used.

1. Open the first tutorial by clicking *Open* in the *File* menu and selecting the tutorial named *Tutorial-1a*.
2. Click *Open*.
3. Save the project as a new file by clicking *Save as* in the *File* menu and by entering <Tutorial-3> as the file name.
4. Click *Save*.
5. On the menu bar, click *Project* and then choose *Properties* to open the *Project Properties* window.
6. Fill in <Tutorial 3 for D-GEO STABILITY > and <Dike reinforced with geotextile> for *Title 1* and *Title 2* respectively in the *Identification* tab.
7. Click *OK*.

10.3 Geotextile

To add a geotextile to the geometry do the following:

8. Mark the *Geotextiles* check-box in the *Model* window of the *Project* menu.

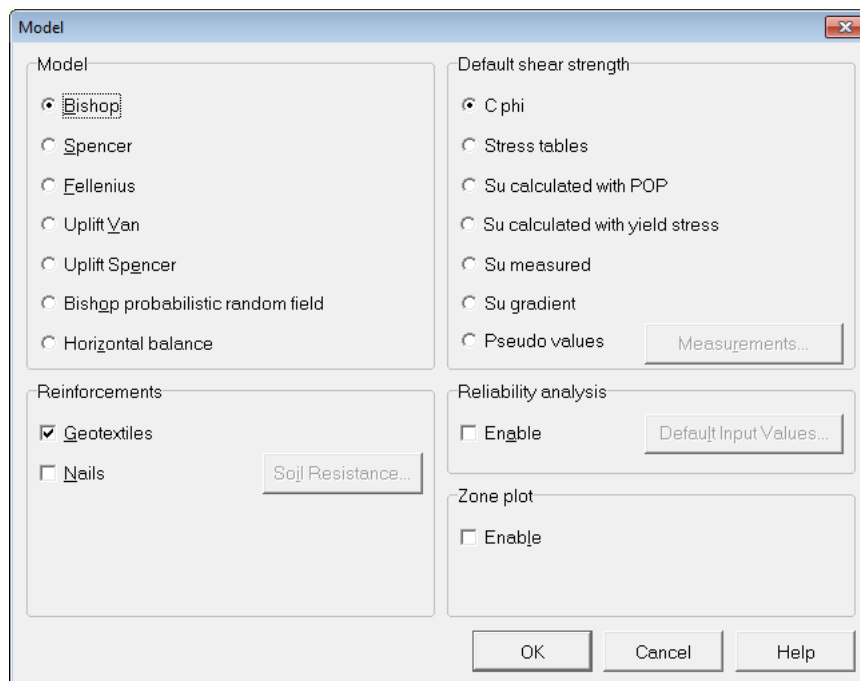


Figure 10.2: Model window

9. Select *Geotextiles* in the *Reinforcements* menu.
10. Click on the *Add* button. The geotextile will automatically be given number <1>.
11. Enter the characteristic values given in [Table 10.1](#) which describe the geotextile ([Figure 10.3](#)).
12. Click *OK*.

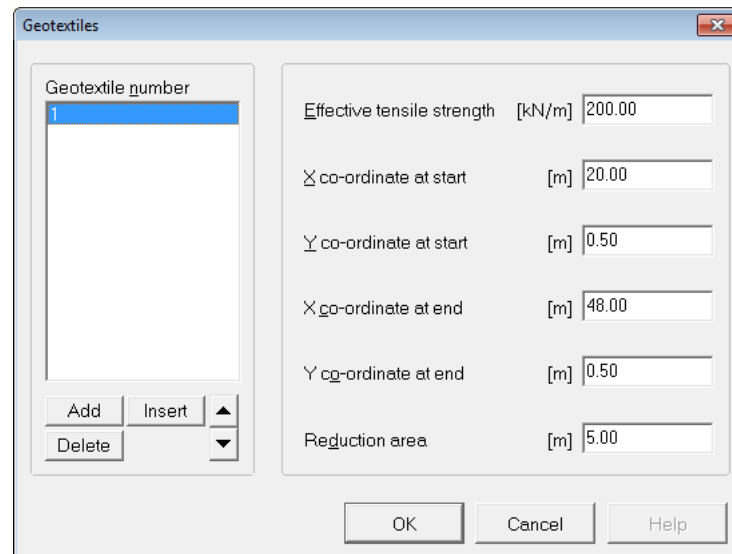


Figure 10.3: Geotextiles window

See [section 4.5.1 "Geotextiles"](#) for a detailed description of this window.

In the *View Input* window, the inputted geotextile is represented in purple (see [Figure 10.4](#)).

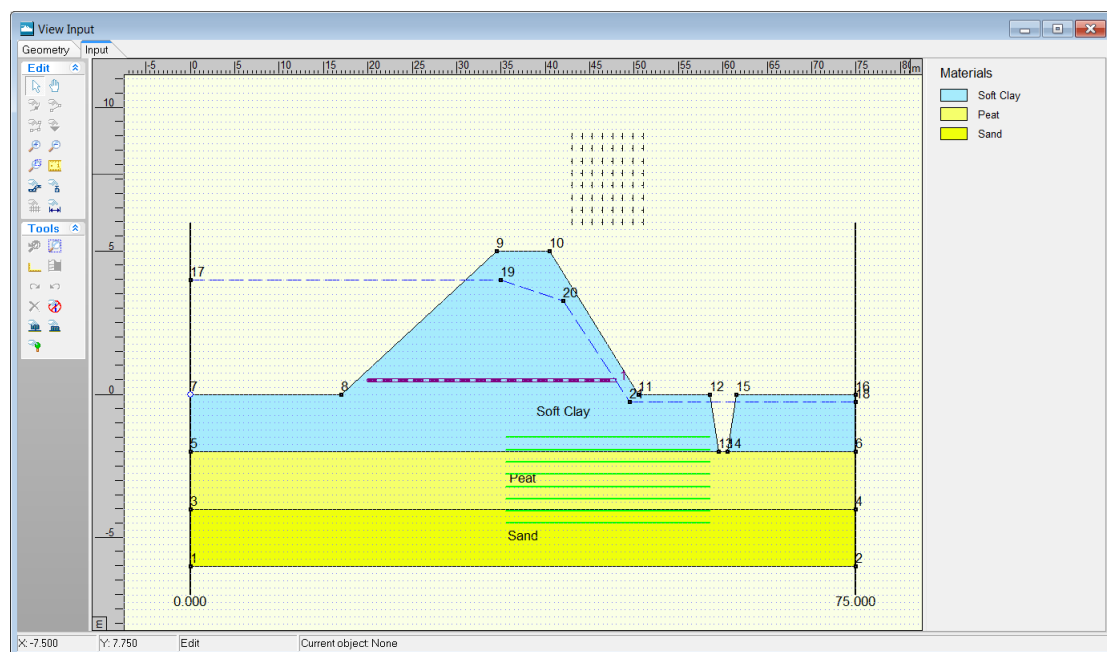


Figure 10.4: View Input window

10.4 Calculation and Results

13. Click *Start* in the *Calculation* menu to perform the calculation.
14. Click *Stresses* in the *Results* menu to open the *Critical Circle* window ([Figure 10.5](#)).
15. Check that the safety factor is 1.56.

Adding the geotextile results in an increase of the safety factor from 1.10 (Tutorial 1a) to 1.56. The dike can be considered safe with the geotextile.

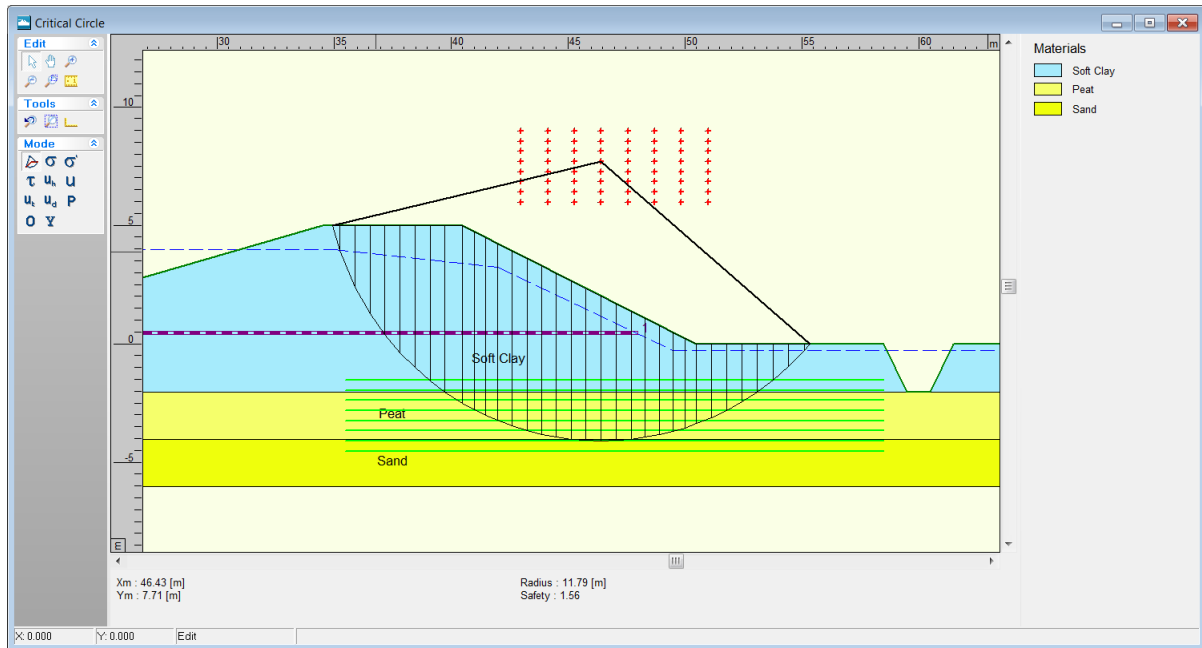


Figure 10.5: Critical Circle window

10.5 Conclusion

D-GEO STABILITY is able to make calculations incorporating a geotextile in the geometry. For this, the strength properties of the geotextile should be known. The safety factor will increase when a geotextile with greater tensile strength is placed in the geometry.

11 Tutorial 4: The Spencer Method

In this tutorial, the safety factor of a dike with different water levels at either side is established. The calculation is carried out with the Spencer method. This method uses a user defined slip plane, and thus requires the user to manually describe this slip plane. The slip plane is of an arbitrary shape, consisting of a line defined by a series of user defined points.

The objectives of this exercise are:

- ◇ To learn how to import the soil type properties from an MGeobase database;
- ◇ To learn how to assign different piezometric levels to layers;
- ◇ To learn how to apply loads;
- ◇ To learn how to carry out a calculation using the Spencer method;
- ◇ To learn how to perform a calculation using a generic algorithm.

For this example, the following D-GEO STABILITY modules are needed:

- ◇ D-GEO STABILITY Standard module (Bishop and Fellenius)
- ◇ Spencer module.

This tutorial is presented in the files Tutorial-4a.sti and Tutorial-4b.sti.

11.1 Introduction to the case

In the soil structure geometry of this tutorial (Figure 11.1), two different piezometric levels are assigned to the different layers. Moreover, some of the layers have not completely consolidated; to model this, it is possible to input a degree of consolidation for each layer. In addition loads are applied on the dike.

To see what effect this will have on the stability of the dike, a calculation using the Spencer method will be carried out. One might use this method, when there is reason to believe that the slip plane might have a preferred shape.

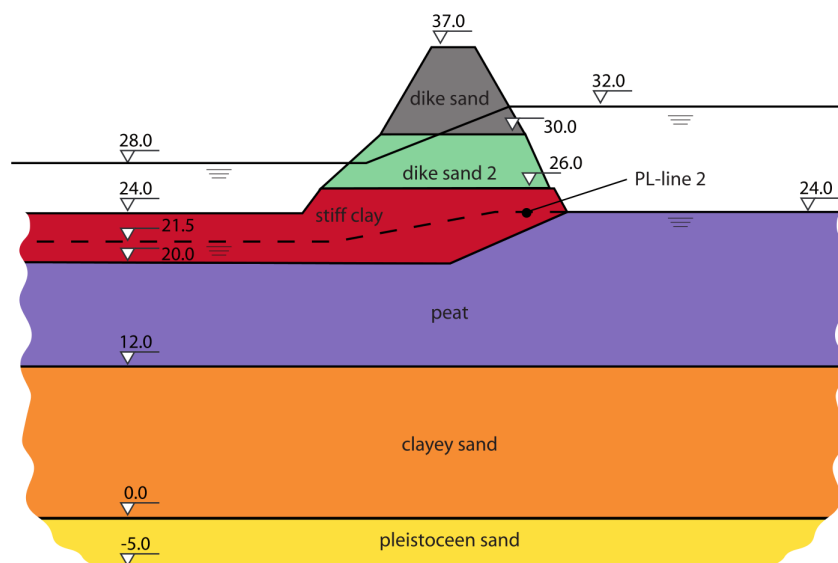


Figure 11.1: Dike with different water levels at either side (Tutorial 4)

The relevant values of the soil types used in this tutorial are given in Table 11.1.



Table 11.1: Soil properties (Tutorial 4)

	Cohesion [kN/m ²]	Friction angle [°]	Unsaturated unit weight [kN/m ³]	Saturated unit weight [kN/m ³]
Dike sand	0	25	18	20
Dike sand 2	0	25	19	21
Stiff clay	30	22	20	21
Peat	5	10	11	16
Clayey sand	10	23.5	18	21
Pleistocene sand	0	27	18	20



Note: The dilatancy ψ is set equal to the friction angle φ .

For this project, two different calculation are performed:

- ◇ Tutorial-4a uses one defined slip plane;
- ◇ Tutorial-4b uses two defined slip planes to search for the slip plane with the least resistance, without presupposing the shape of the slip plane (i.e. genetic algorithm).

11.2 Project

How to define the layers geometry and soil properties has been explained already in the previous tutorials. Use the different figures and data's given in [section 11.1](#) to create the geometry and then proceed with [section 11.3](#) for the description of the additional steps.

However, an alternative to the manual input is to import the geometry from a so-called GEO file ([section 11.2.1](#)) and to import the soil properties from an MGeobase database ([section 11.2.3](#)).

11.2.1 Importing an existing geometry

To import the geometry from a GEO file, follow the steps below.

1. In the *File* menu, select *New* to open the *New File* window ([Figure 11.2](#)).
2. Select the *Import geometry* option and click *OK*.

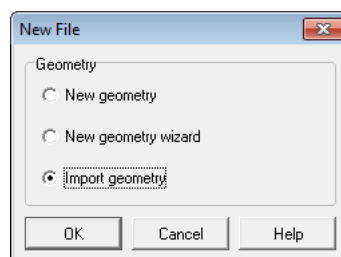


Figure 11.2: New File window

3. In the *Import Geometry From* window displayed, select the GEO file named <Tutorial-4.geo> located in the Examples folder where the program was installed.
4. Click *OK*.

The predefined geometry is displayed in the *Geometry* tab of the *View Input* window ([Figure 11.3](#)). This imported geometry contains only the points, the layers boundary and the

PL-lines, not the material types and properties. They will be imported from an MGeobase database (section 11.2.3).

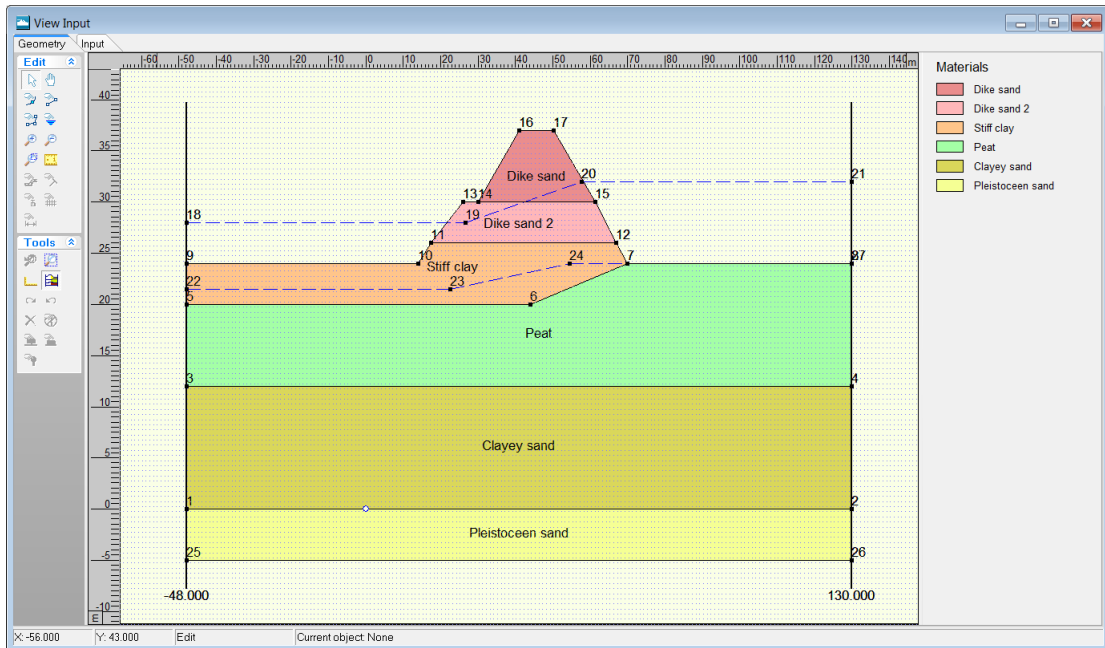


Figure 11.3: View Input window, Geometry tab after importing geometry

5. Click *Save as* in the *File* menu, enter <Tutorial-4> as file name and click *Save*.

11.2.2 Model

The calculation is carried out with the Spencer method as a user defined slip plane will be used.

6. Open the *Model* window from the *Project* menu.

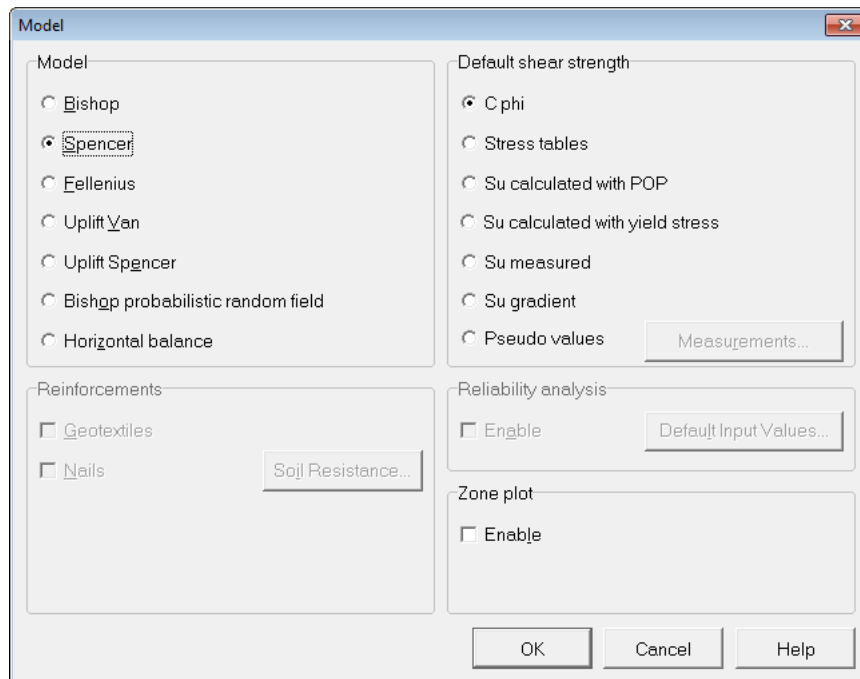


Figure 11.4: Model window

7. Select the *Spencer* model.
8. Click *OK* to confirm.

11.2.3 Importing material properties from an MGeobase database

The layers geometry is already modeled however the material properties still need to be defined.

The parameters from [Table 11.1](#) were saved in an MGeobase database. To import them, the location of this MGeobase database must be first specified:

9. In the *Program Options* window from the *Tools* menu, select the *Locations* tab.
10. Mark the *Use MGeobase database* check-box and click the *Browse* button to specify the location of the MGeobase database with material data.
11. In the *Open* project database window displayed, select the MDB file named <Tutorial-4.mdb> located in the Examples folder where the program was installed.
12. Click *Open* and then *OK*.

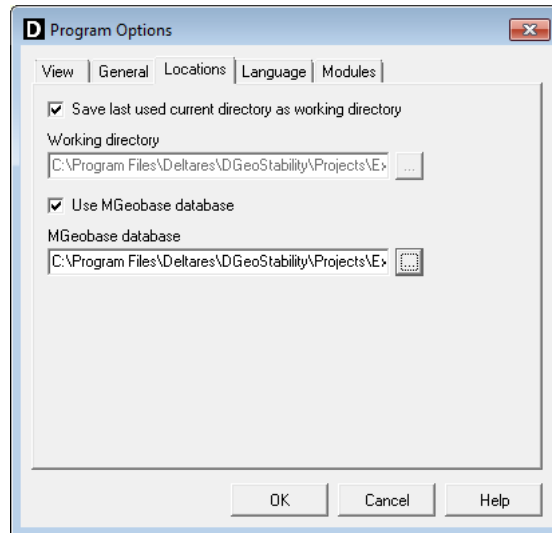


Figure 11.5: Program Options window, Locations tab

11.2.4 Materials

The soil properties of each material given in Table 11.1 can now be imported from this MGeobase file:

13. Open the *Materials* window from the *Soil* menu and select the *Database* tab.
14. Select *Clayey sand* in the *Materials* list at the right of the *Database* tab and click the button to import this soil type (with associated properties) in the material list of the *Materials* window (Figure 11.6).

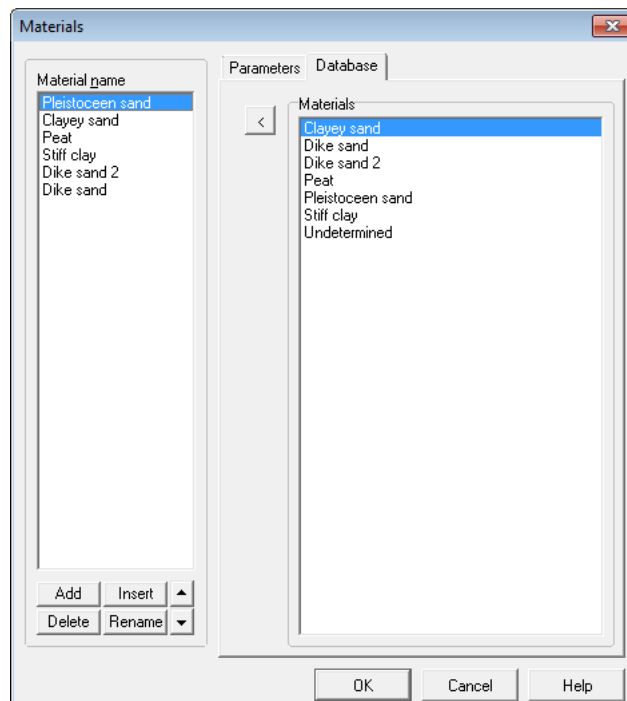


Figure 11.6: Materials window, Database tab

15. As the soil type already exists, an *Information* window opens asking if the existing local properties should be overwritten (Figure 11.7). Confirm by clicking Yes.

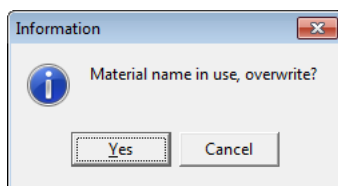


Figure 11.7: Information window

16. Repeat it for the five other materials.
17. In the *Parameters* tab (Figure 11.8), check that the imported properties are the same as in Table 11.1. Manually add for dilatancy the same values as for friction angle, since dilatancy was not included in the database.

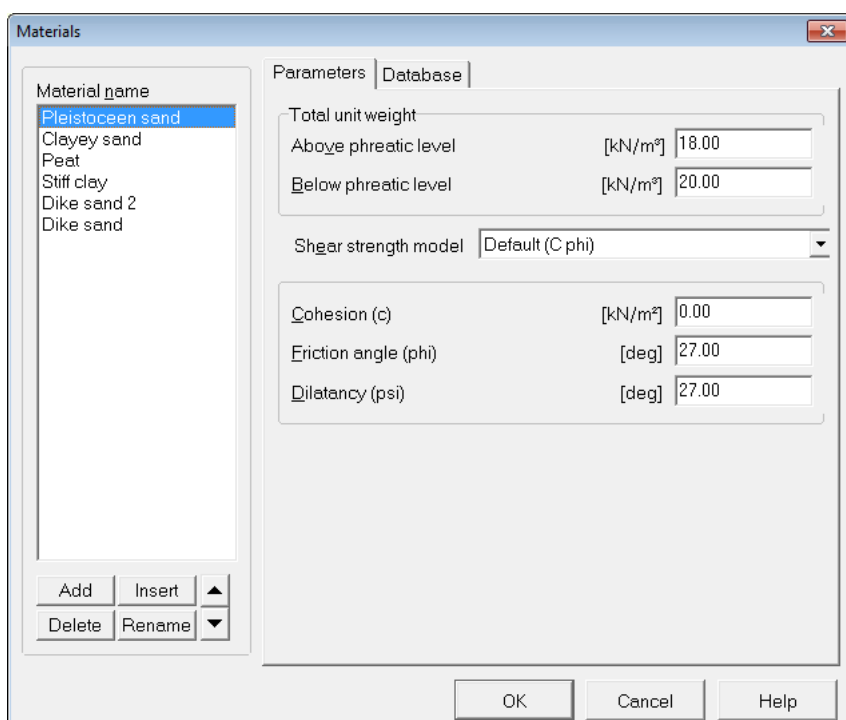


Figure 11.8: Materials window, Parameters tab

18. Click *OK*.

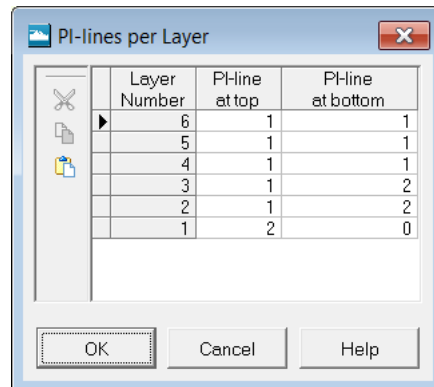
11.2.5 PL-lines per layer

In the current file two piezometric level lines are drawn. PL-line 1 is the phreatic level. Some of the layers have a different PL-line. The bottoms of layers 2 and 3 have PL-line 2 as their piezometric level.

19. Click *PL-lines per Layer* in the *Geometry* menu.
20. Enter the PL-line numbers as given in Figure 11.9.
21. Click *OK*.

Table 11.2: Degree of consolidation per layer

Layer number	Effect of layer 6	Effect of layer 5
6	100	-
5	100	100
4	50	100
3	40	80
2	30	60
1	100	100

**Figure 11.9:** PL-lines per Layer window

11.2.6 Degree of Consolidation

The weight of the top layers of the dike will cause excess pore pressure in some layers. Part of the excess pore pressure is still present in the less permeable layers. The dissipation of pore pressure is expressed in the degree of consolidation. E.g. when 60% of the excess pore pressure has dissipated, the degree of consolidation is 60%. Let assume that layer 4 (stiff clay) is affected by layer 6. 50% of the excess pore pressures in layer 4 have dissipated. Similarly, some of the lower layers are affected by layer 5. In [Table 11.2](#) the degree of consolidation due to the influencing layers is given.

To input this, perform the following steps:

22. From the *Water* menu, choose the *Degree of Consolidation* option.
23. In the window displayed, select for *Effect of layer* number 6, change the degree of consolidation in layer 4 to 50%, in layer 3 to 40% and in layer 2 to 30% according to [Table 11.2](#). The *Degree of Consolidation* window should be as [Figure 11.10](#).

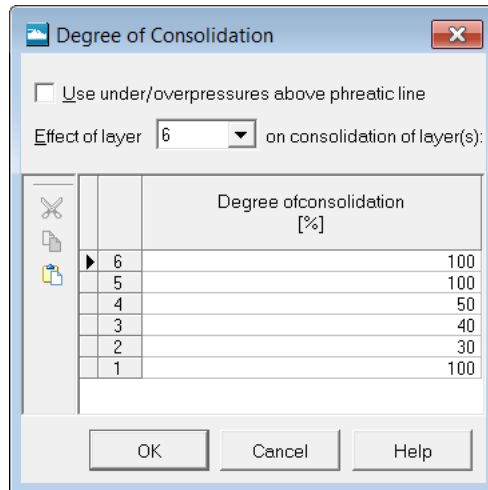



Figure 11.10: Degree of Consolidation window

24. Select *Effect of layer* number 5, and change the degree of consolidation in layer 3 to 80%, and in layer 2 to 60% according to Table 11.2.
25. Click *OK* to confirm and close the window.

11.2.7 Loads

A temporary uniform load at the foot of the dike shall be applied to the dike structure. In order to input these loads, perform the following steps:

26. Make sure the *Input* tab in the *View input* window is selected. Click the *Add uniform loads*  button.
27. In the *Load name* sub-window click *Add*. D-GEO STABILITY gives a default name *Uniform Load (1)* to the load.
28. Rename it with <Temporary load>.
29. Fill in <25 kN/m²> for the magnitude of the load.
30. Fill in <9.0 m> for the X coordinate at start, and <14.0 m> for the X coordinate at end.
31. In the load type section, select *Temporary*.
32. Click *OK* to confirm.

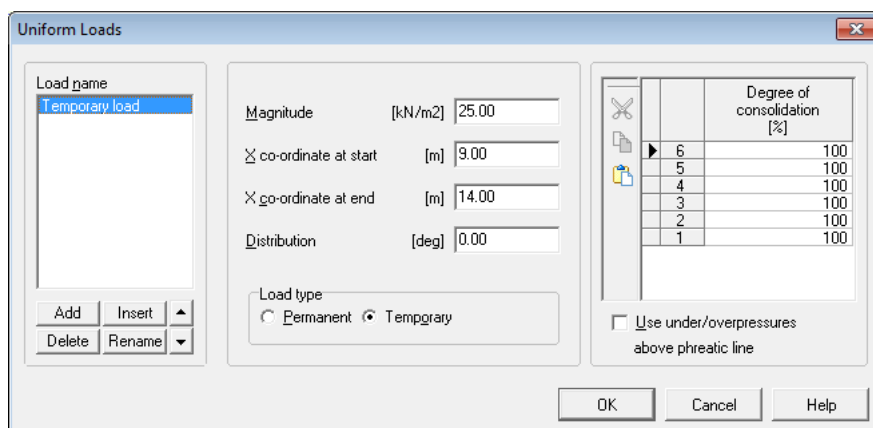


Figure 11.11: Uniform Loads window




Note: In the right section of the *Uniform Loads* window (Figure 11.11), it is possible to assign a degree of consolidation to the soil layers as a result of the uniform load. The default is set

to 100%. The distribution is set to 0 degrees.

11.3 Calculation using one defined slip plane (Tutorial-4a)

11.3.1 Slipse Plane

To perform a calculation with the Spencer model, a slip plane has to be created.

33. Select the *Input* tab in the *View Input* window.
34. Create a slip plane by clicking the *Add slip plane*  button.

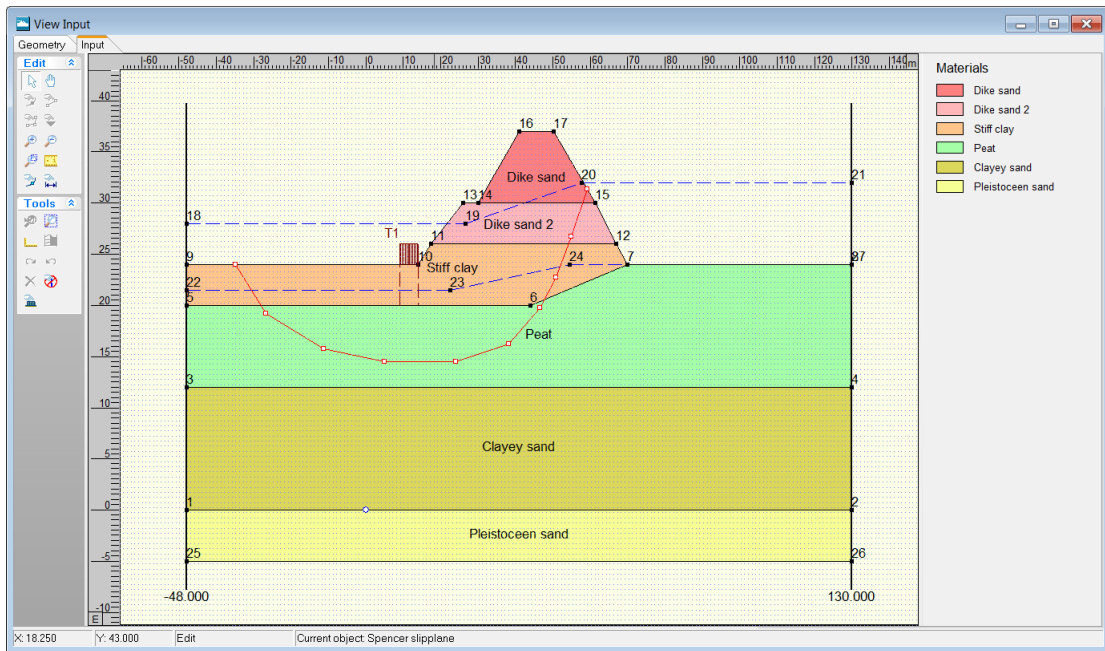


Figure 11.12: View Input window, Input tab (Tutorial-4a)

35. Draw the slip plane by placing ten points from left to right in the dike body. [Figure 11.12](#) suggests a shape for the slip plane.
36. Click *Slip Plane* in the *Definitions* menu to view the properties of the slip plane just created manually.
37. Modify the X and Y coordinates of the slip plane to be in accordance with the values of [Figure 11.13](#).
38. Click *OK*.

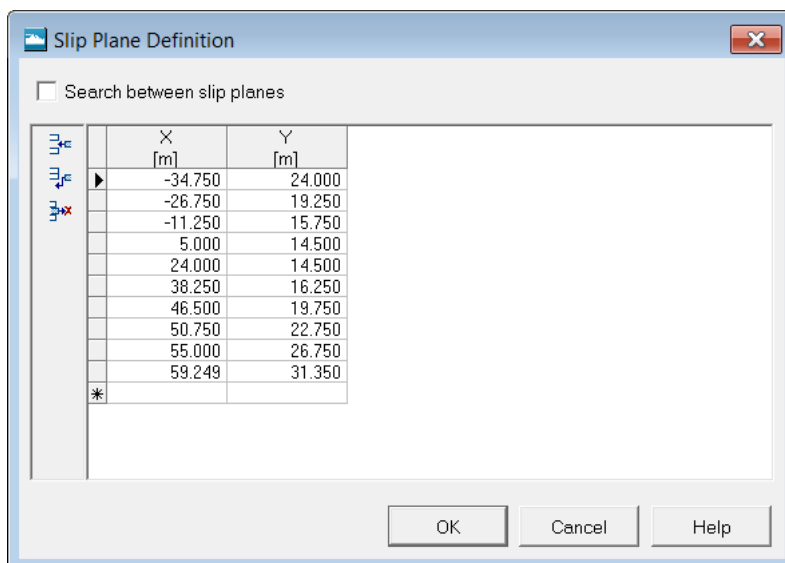


Figure 11.13: Slip Plane Definition window (Tutorial-4a)

As only one slip plane is inputted, D-GEO STABILITY will calculate only one safety factor (for this slip plane). D-GEO STABILITY allows the calculation of either one or a multitude of slip planes with the Spencer method. These slip planes shall be defined later on in this tutorial (section 11.4.1). The Spencer method ensures moment, vertical and horizontal equilibrium.

11.3.2 Calculation and Results

To calculate the safety factor for the slip plane that has been inputted, do the following:

39. Click *Start* in the *Calculation* menu.
40. Click *OK* to perform the calculation.
41. Click *Stresses* in the *Results* menu to open the *Slip Plane* window. The *Slip Plane* window displayed (Figure 11.14) gives a safety factor of 1.46.

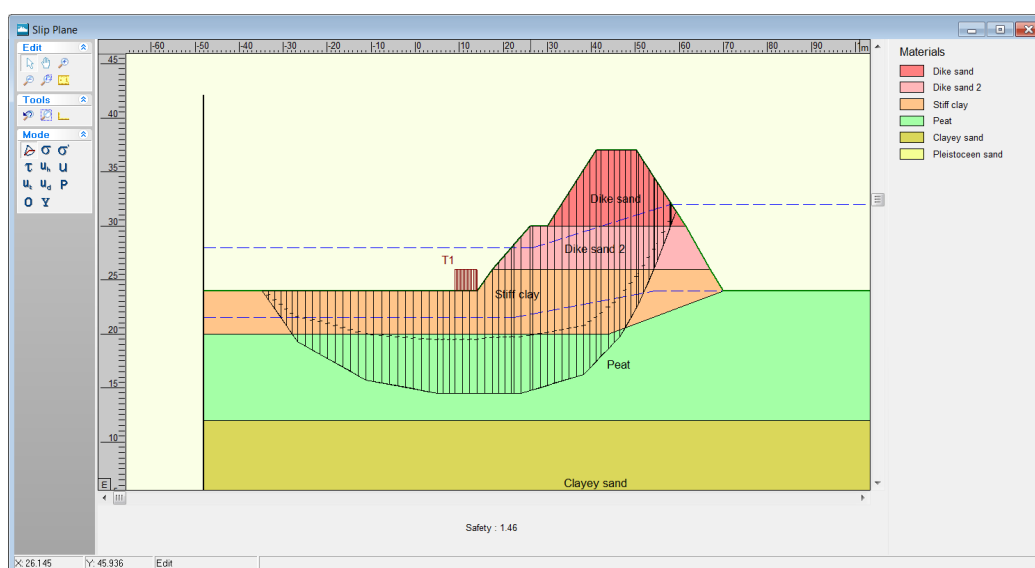


Figure 11.14: Slip Plane window (Tutorial-4a)

42. Double click on a slice to see the results for this individual slice. In [Figure 11.15](#) the results for slice 57 are shown. They include the visualization of the force balance and several values that describe the slice's geometry, forces or stresses.

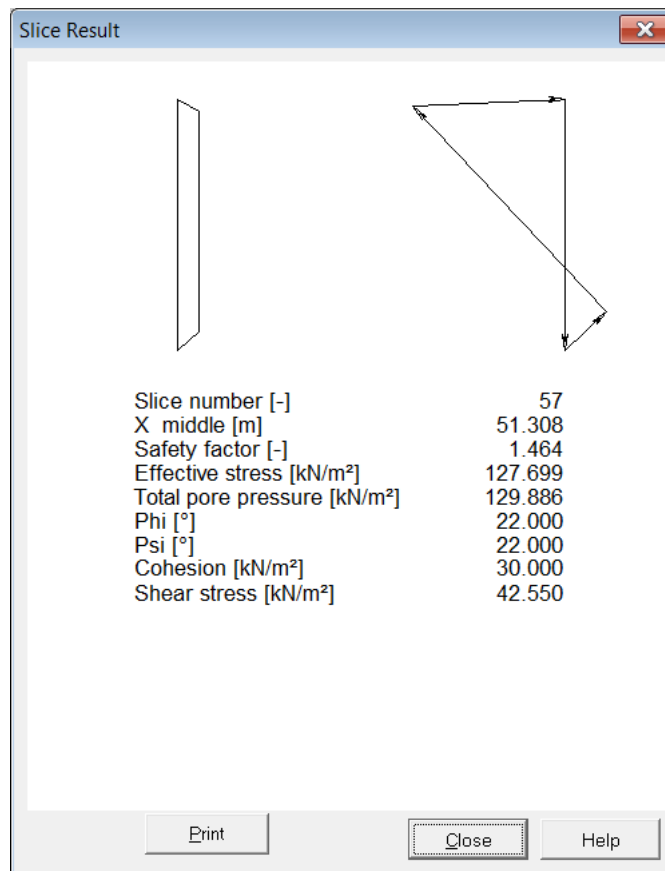


Figure 11.15: Slice Result window for slice 57 (Tutorial-4a)

43. Click *Stresses in Geometry* in the *Results* menu to open the *Stresses in Geometry* window ([Figure 11.16](#)).

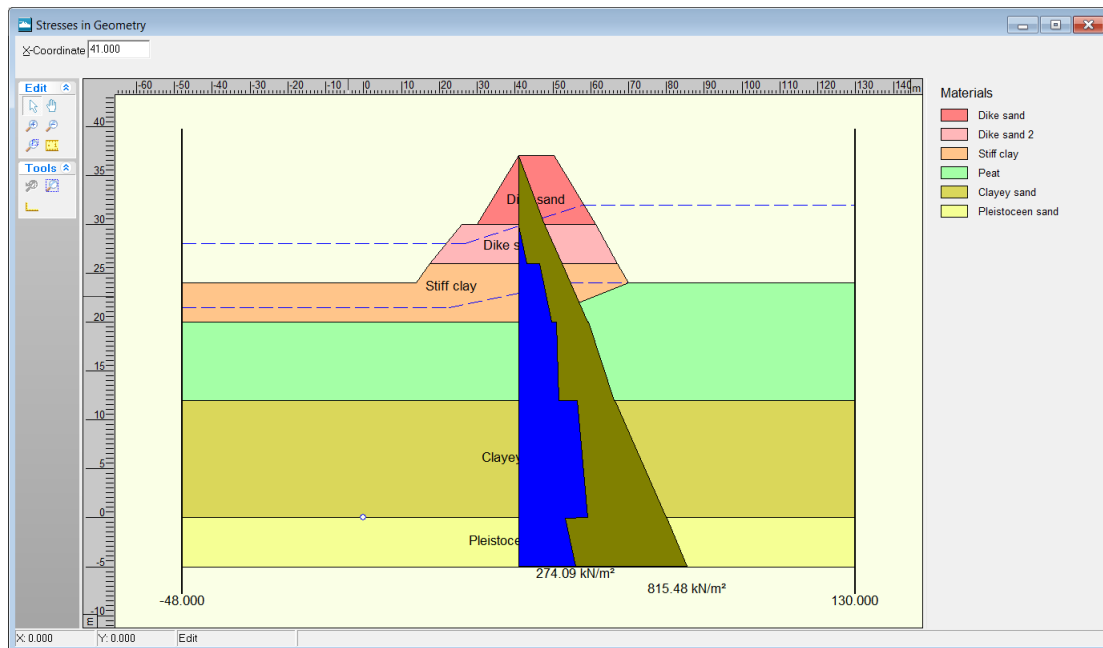


Figure 11.16: Stresses in Geometry window (Tutorial-4a)


It can be seen that the pore pressures in the vertical have strongly alternating values from layer to layer. This is due to the different degrees of consolidation that have been assigned to the layers.

11.4 Search between slip planes (Tutorial-4b)

D-GEO STABILITY offers the unique possibility to search for the slip plane with the least resistance, without presupposing the shape of the slip plane.

11.4.1 Define slip planes

D-GEO STABILITY has now calculated the safety factor for the dike, using one defined slip plane. However it is possible for D-GEO STABILITY to determine the safety factors of the dike using a multitude of slip planes. To create those slip planes, the existing slip plane (section 11.3.1) has to be enlarged and a second slip plane has to be first created. D-GEO STABILITY will create a number of slip planes based on these two slip planes.

44. Click *Save as* in the *File* menu and save this tutorial as <Tutorial-4b>.
45. Click *Save*.
46. Create a second slip plane by clicking the *Add slip plane*  button. Be sure that the *Input* tab of the *View Input* window is selected.
47. Draw the second slip plane by placing points from left to right in the dike body. It is important that the number of points is equal to that of the initial slip plane (which is 10). [Figure 11.17](#) suggests a shape for the second slip plane (red line).

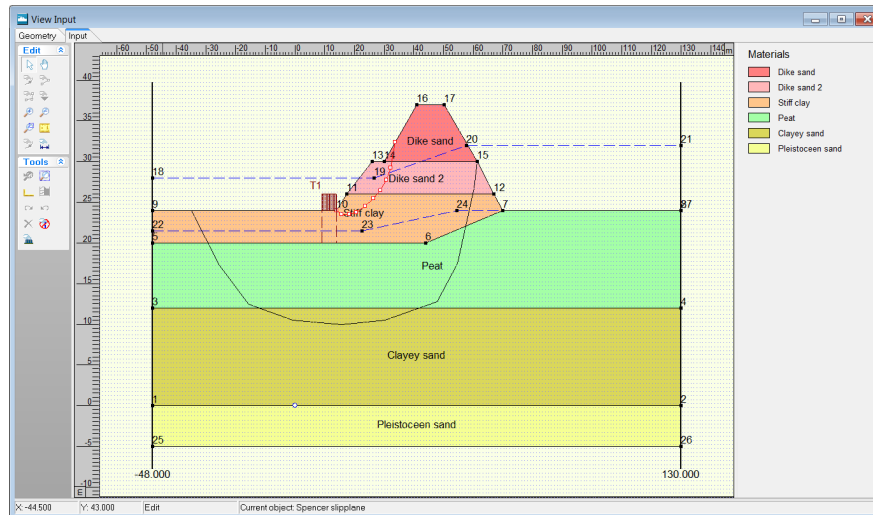


Figure 11.17: View Input window, Input tab – Suggested second slip plane (Tutorial-4b)

48. Click *Slip Plane* in the *Definitions* menu to view the properties of the slip planes to be created using the two that are now provided (Figure 11.18).
49. Modify the coordinates (first and second columns) of the first slip plane to be in accordance with the values of Figure 11.18.
50. Modify the coordinates (third and fourth columns) of the second slip plane just inputted manually to be in accordance with the values of Figure 11.18.
51. Click *OK*.

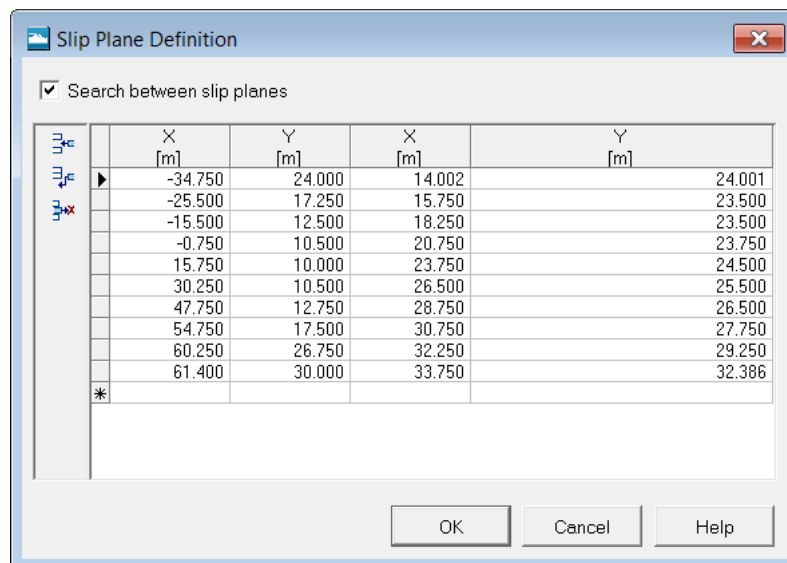


Figure 11.18: Slip Plane Definition window (Tutorial-4b)

See section 4.4.1.3 “Slip Plane Definition (Spencer)” for a detailed description of this window.

Note: Too many points on a slip plane can decrease the smoothness of a slip plane, and therefore increase the resulting safety factor (Van der Meij, 2014). In general 10-12 points along the plane are sufficient to find an unconstrained slip plane.



11.4.2 Calculation and Results

52. Click *Start* in the *Calculation* menu. Genetic algorithm is automatically selected because the option *Search between slip planes* in the Slip Plane Definition window was selected.

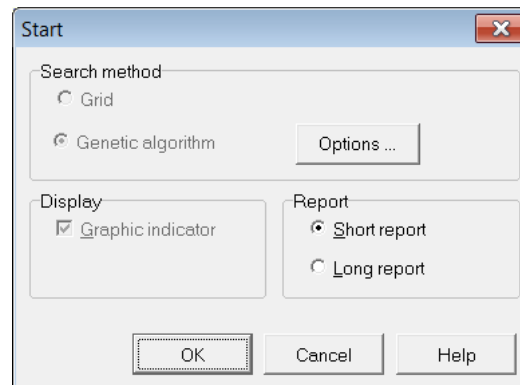


Figure 11.19: Start window (Tutorial-4b)

53. Click the *Options* button to open the *Options Genetic Algorithm* window and view the default options (Figure 11.20). Those advanced options are chosen automatically, based on the chosen limit equilibrium method and the size of the search space. If these defaults do not lead to the desired optimum, the advanced options must be set differently. Some knowledge of genetic algorithms is required in order to do this.

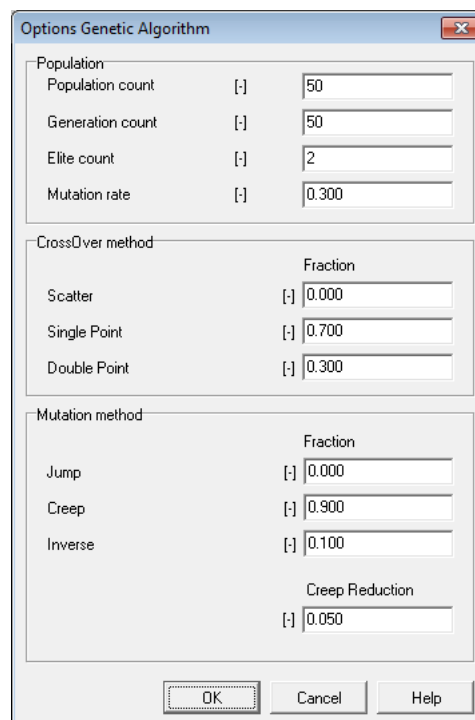


Figure 11.20: Options Genetic Algorithm window (Tutorial-4b)

54. Leave the values to their defaults and click *OK* to close the window.



Note: Having a unnecessarily large search space decreases the precision of the answer. This can be compensated by increasing the size of the population and the number of generations but it increases the computational time.

Note: The optimization parameters are calculated based on the limit equilibrium method and the size of the search space. These defaults do not always guarantee a global minimum with sufficient accuracy. With a little knowledge of genetic algorithms, the user can change the calculation options, but a comparison with another analysis (e.g. Bishop with grid) is always advised.



55. Click *OK* to perform the calculation.
56. Click *Stresses* in the *Results* menu to open the *Slip Plane* window.

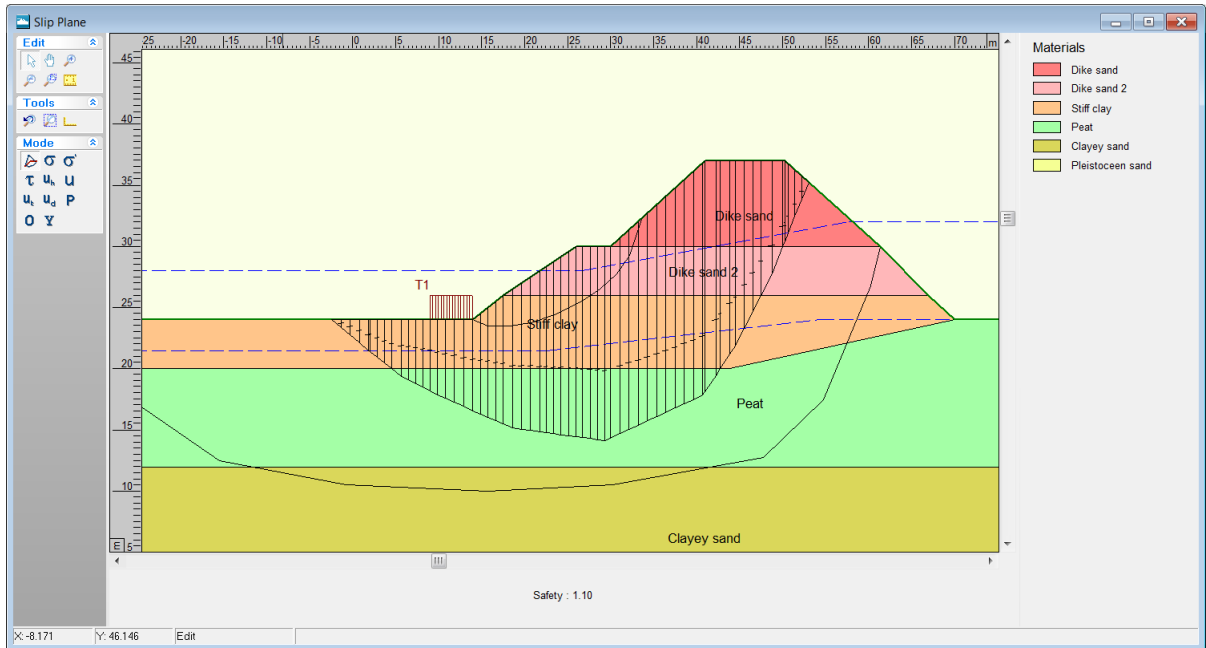


Figure 11.21: Slip Plane window with lowest safety factor found by Spencer model using a genetic algorithm (Tutorial-4b)

This slip plane is unconstrained and the limit equilibrium method guarantees the equilibrium of all forces. The calculated safety factor is 1.10.

11.5 Conclusion

D-GEO STABILITY uses the Spencer method to calculate minimum safety factors with unconstrained or user defined slip planes. It is also possible to add uniform loads and attribute degrees of consolidation to soil layers due to the influence of either loads or other soil layers.

12 Tutorial 5: The Uplift-Van model

In this tutorial, a soil structure beneath which some of the layers have low weight and low cohesion is considered. This situation might cause a non circular slide plane to come into effect. In addition, some of the layers have a different piezometric level than the phreatic line. This might cause a portion of the layers to be lifted. Therefore, for this case it is strongly advised to use the Uplift-Van method.

The objective of this exercise is:

- ◇ To learn how to make calculations using the Uplift-Van method.

For this example, the following D-GEO STABILITY modules are needed:

- ◇ D-GEO STABILITY Standard module (Bishop and Fellenius).
- ◇ Uplift Van model.

This tutorial is presented in the file Tutorial-5.sti.

12.1 Introduction to the case

In the soil geometry (Figure 12.1) the thin peat layer beneath the clay layer might have an effect on a slip failure mechanism. It is possible that the soil might slip along a certain length of this peat layer. When this happens, describing the slip surface by a single circle would be incorrect. Using the Uplift Van method the slip surface can be described by two circular slip surfaces connected by a straight slip surface. This straight slip surface usually lies along the bottom of a weak soil layer. The slip surface is thus described by more parameters.

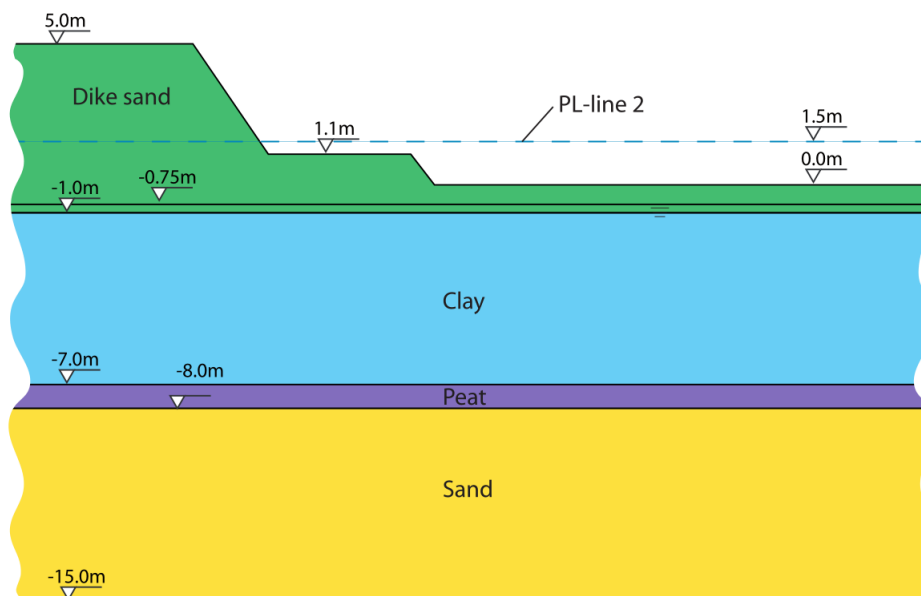


Figure 12.1: Geometry overview (Tutorial 5)

The relevant values of the soil types used in this tutorial are given in Table 12.1.

Table 12.1: Soil properties (Tutorial 5)

	Cohesion [kN/m ²]	Friction angle [°]	Unsaturated unit weight [kN/m ³]	Saturated unit weight [kN/m ³]
Dike sand	5	20	17	17
Clay	3	20	14	14
Peat	2	20	11	11
Sand	0.1	30	17	20



Note: The dilatancy ψ is set equal to the friction angle φ .

12.2 Geometry Wizard

Firstly, the geometry of [Figure 12.1](#) needs to be inputted in D-GEO STABILITY. This is done using the *Geometry Wizard* as for Tutorial 1 ([section 8.2](#)). When the *Wizard* is completed, modifications to change and complete the geometry will be made using the *Geometry* menu.

To create a new geometry using the *Wizard*, follow the steps described below:

1. Click *File* and choose *New* on the D-GEO STABILITY menu bar.
2. Select *New geometry wizard* and click *OK*.
3. Enter the basic geometrical properties, the basic geometric situation with the geometric values and the soil type for each layer as given in [Figure 12.2](#).

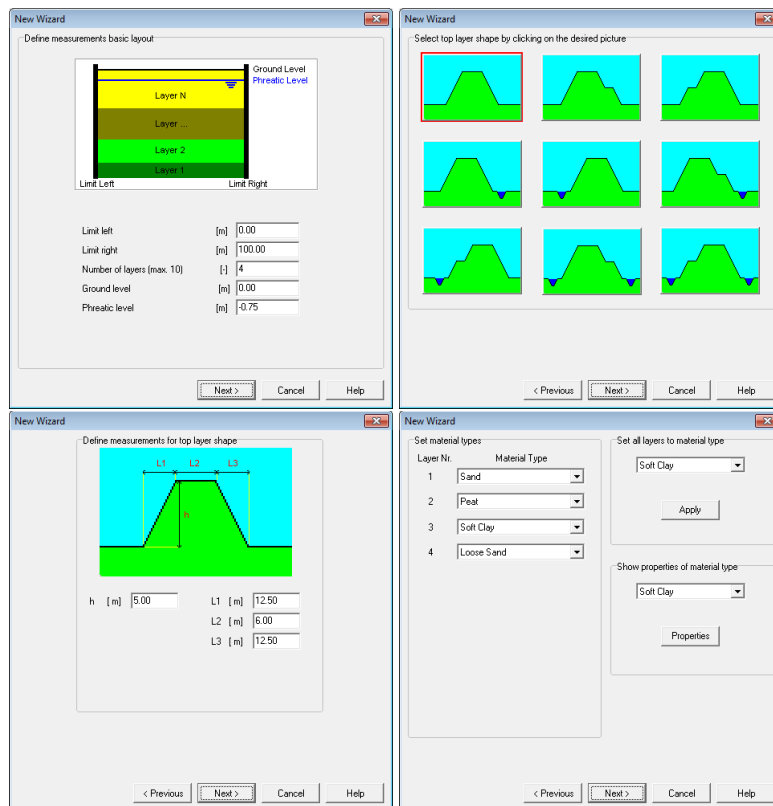


Figure 12.2: New Wizard windows

4. Click *Finish* in the last *New Wizard* window which gives an overview of the inputted geometry. A *View Input* window appears ([Figure 12.3](#)) with the D-GEO STABILITY geometry that

has been created so far. At this point the geometry needs to be saved.

5. Click *Save as* in the *File* menu.
6. Enter <Tutorial-5> as file name.
7. Click *Save*.

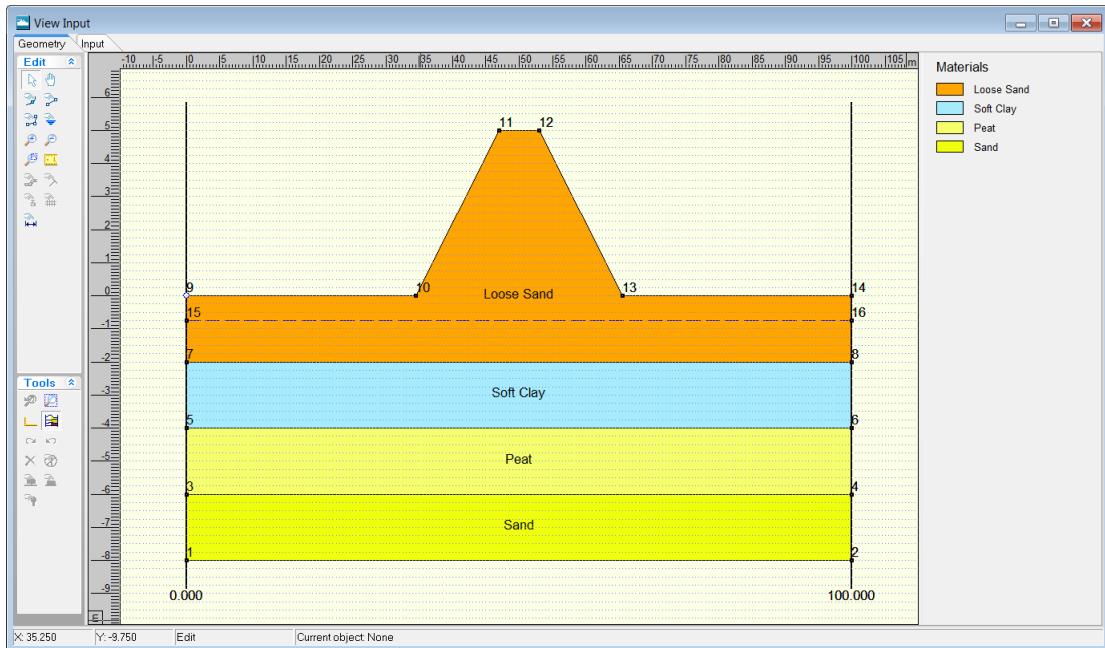


Figure 12.3: View Input window, Geometry tab

12.3 Model

As the Bishop method, the Uplift Van method can also be used to calculate the safety factor of many different slip surfaces and ensures vertical force equilibrium and moment equilibrium.

8. Click *Model* in the *Project* menu.
9. Select the *Uplift Van* model.
10. Unmark the *Geotextiles* and *Nails* check-boxes as no geotextile or nail is used in this tutorial.
11. Click *OK*.

12.4 Soil materials

In the *Soil* menu it is possible to modify the properties of the soil layers to be in accordance with [Table 12.1](#).

12. Choose *Materials* from the *Soil* menu to open the *Materials* window.

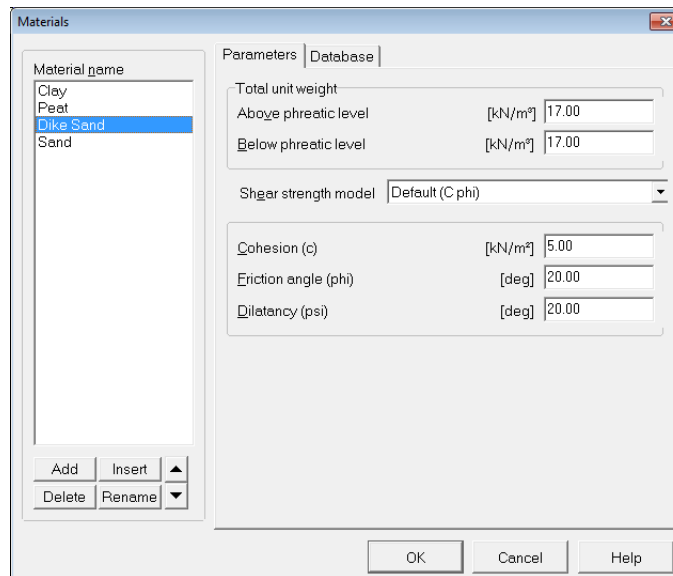


Figure 12.4: Materials window


13. Select *Loose Sand* in the material list. Click *Rename* and change *Loose Sand* into <Dike sand>.
14. Select *Soft Clay* in the material list and rename it into <Clay>.
15. Delete the unused materials by selecting them and clicking the *Delete* button.
16. Enter the soil properties values of the four layers used in this tutorial (*Clay*, *Peat*, *Sand* and *Dike Sand*) as indicated in [Table 12.1](#).
17. Click *OK* when finished.

12.5 Geometry

With the *Geometry* menu it is possible to modify the current geometry as given in [Figure 12.1](#).

12.5.1 Points

The geometric values of the different layers need to be adjusted and two points need to be added to create a second PL-line (called PL-line 2 in [Figure 12.1](#)) at level 1.5 m.

18. Click *Points* in the *Geometry* menu to open the *Points* window.
19. Click two times the *Add row*  button to add points number <17> and <18> which will be used to create PL-line 2 (see [section 12.5.2](#)).
20. Modify the coordinates of points number <1> till <18> as given in [Figure 12.5](#).
21. Click *OK*.

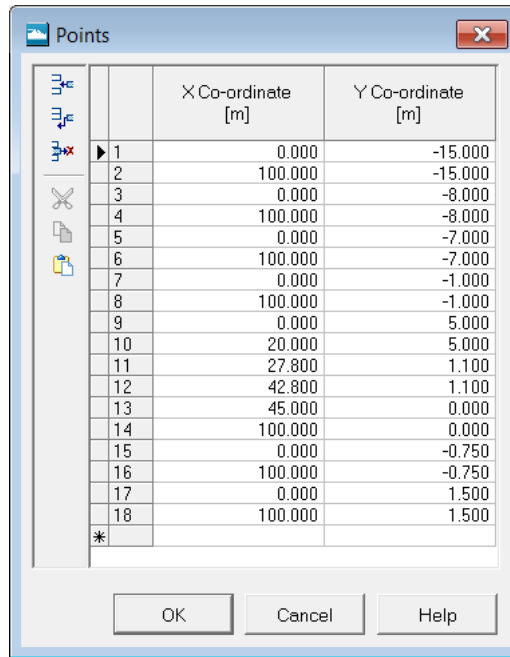



Figure 12.5: Points window

22. Click the *Zoom limits*  button to display the complete new geometry.

12.5.2 PL-lines

To create PL-line 2, follow these steps:

- 23. Click *PL-lines* in the *Geometry* menu to open the *PL-Lines* window.
- 24. Click the *Add* button to add PL-line number <2>.
- 25. Enter points number <17> and <18> in the *Point number* column at the right of the *PL-Lines* window (Figure 12.6).
- 26. Click *OK*.

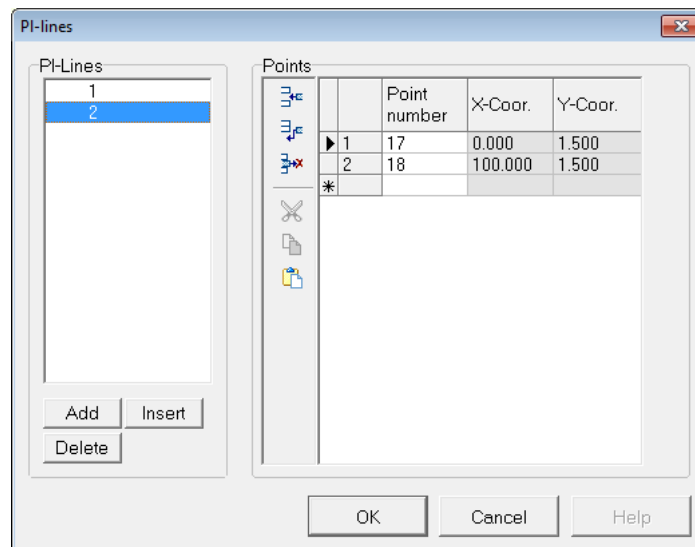


Figure 12.6: PL-Lines window

12.5.3 PL-lines per Layers

To assign a PL-line to each layer, do the following:

27. In the *Geometry* menu, choose *PL-lines per layer* to open the *PL-lines per Layer* window.
28. Enter the PL-line numbers given in [Figure 12.7](#) for each layer.
29. Click *OK*.

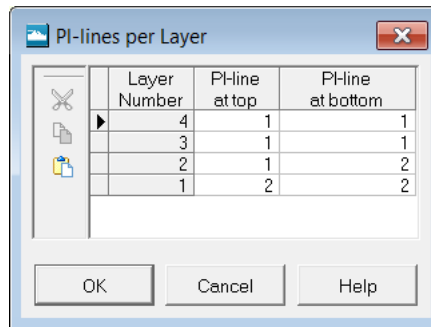


Figure 12.7: PL-Lines per Layer window

Due to the different piezometric levels in the soil layers, the soil is prone to lifting forces. This can be verified with a simple evaluation or hand calculation.

12.6 Definitions

To make a calculation with the Uplift Van model, the specifications of the slip surface need to be defined. To this end two grids are needed to define the slip circles on either side of the slip surface. The slip surface on the left will cut the soil structure. The right slip surface will cut the surface somewhere right of the soil structure. Also, tangent lines that connect the two slip circles need to be placed in the geometry. Those lines will lie at the bottom of the weak peat layer. Those connecting lines complete the total slip surface.

30. Click *Slip Plane* in the *Definitions* menu.
31. In the *Slip Plane Definition* window, enter the specifications shown in [Figure 12.8](#).

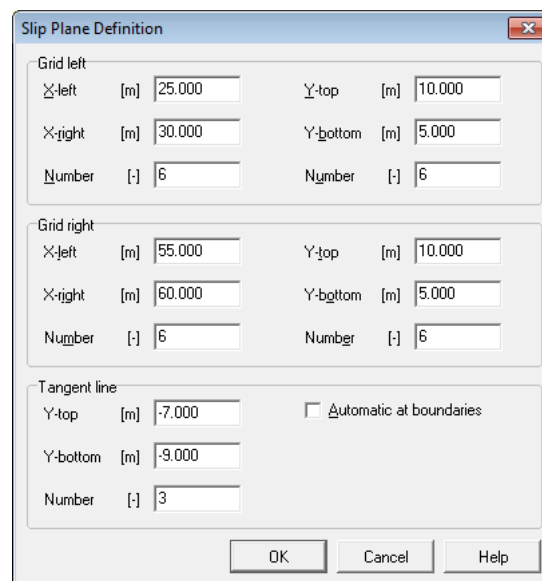



Figure 12.8: Slip Plane Definition window

32. Click *OK*. The entered specifications will result in the calculation set up as seen in [Figure 12.9](#).
33. Select the *Input* tab in *View Input* and click the *Zoom limits*  button to display the complete geometry.

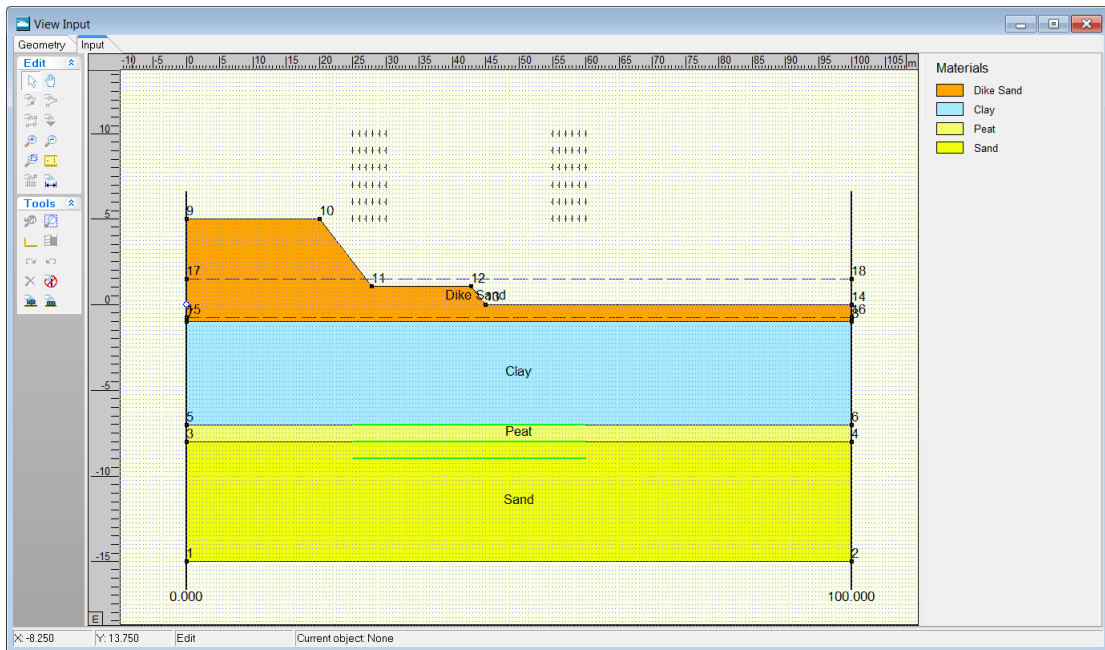


Figure 12.9: View Input window, Input tab

12.7 Calculation and Results

34. Click *Start* in the *Calculation* menu.
35. Click *OK* to perform the calculation.

12.7.1 Stresses

To view the shape of the slip surface:

36. Click *Stresses* in the *Results* menu to open the *Slip Plane* window.

In the window displayed ([Figure 12.10](#)) the measurements of the slip surface can be seen. It consists of two partial circular slip surfaces connected by a line. As with the Bishop method each slip circle has a grid that has moved from its original position. The safety factor is equal to 1.94.

The measurements of the left slip circle are given as this is the more deciding factor in the determination of the safety factor. The measurements of the right slip circle are found in the report.

Note: It is possible to compare results obtained by the Uplift Van method to those of other methods. E.g. the Bishop method in this case gives a result with a slip circle with a large radius and a higher safety factor.



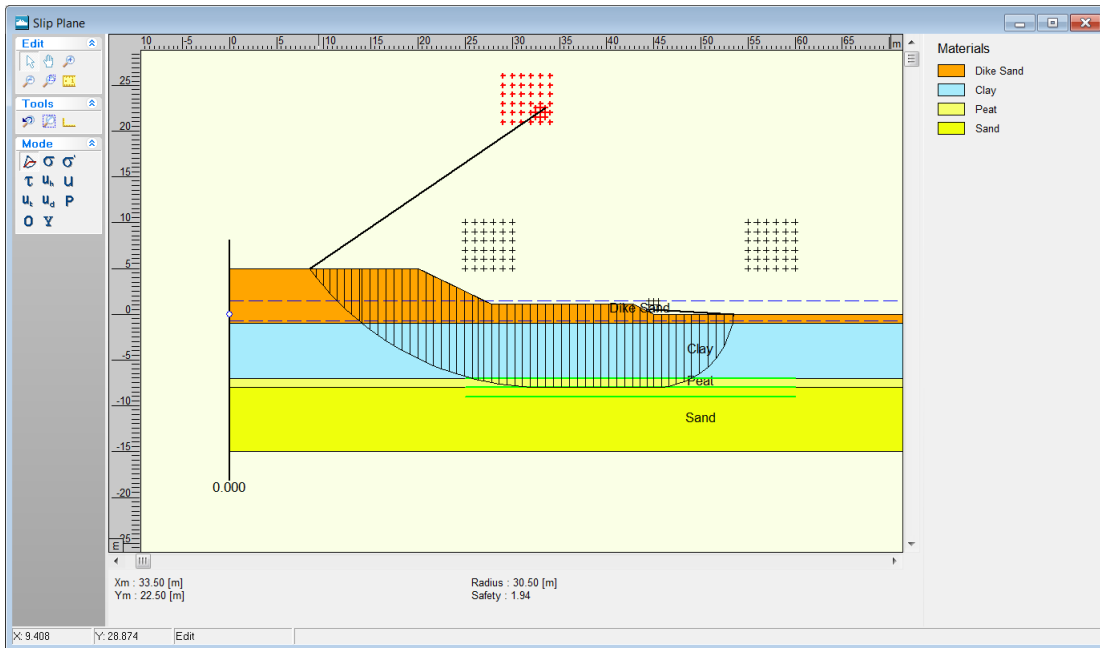


Figure 12.10: Slip Plane window

12.7.2 FMin Grid

The *FMin Grid* window also shows the grid of the left slip circle:

37. Click *FMin Grid* in the *Results* menu to open the *FMin Grid* window (Figure 12.11). The minimum safety factor of 1.939 is indicated in red.

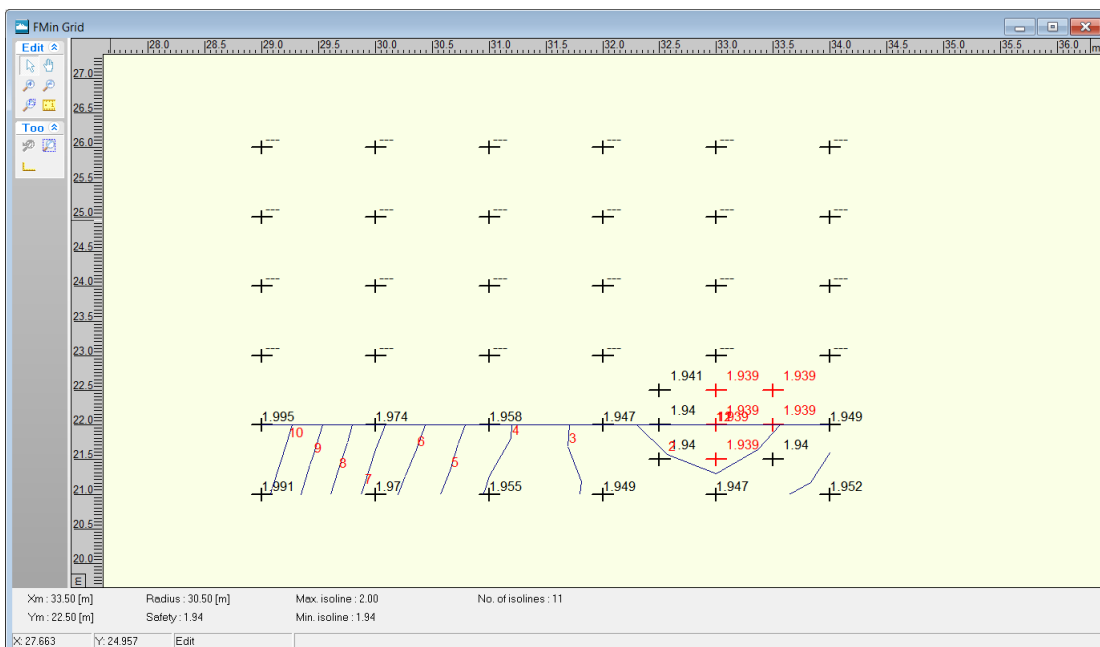


Figure 12.11: FMin Grid window

12.8 Conclusion

In this tutorial the soil conditions and piezometric levels are such that it is probable to expect a non-circular slip plane. That's why the Uplift Van model is used as it evaluates the safety factor of a soil structure finding a non-circular slip plane.

13.2 Model

6. Click the *Model* option in the *Project* menu.
7. Make sure the *Bishop* method is selected.
8. Mark the *Enable Reliability analysis* check-box as a probabilistic calculation will be performed.

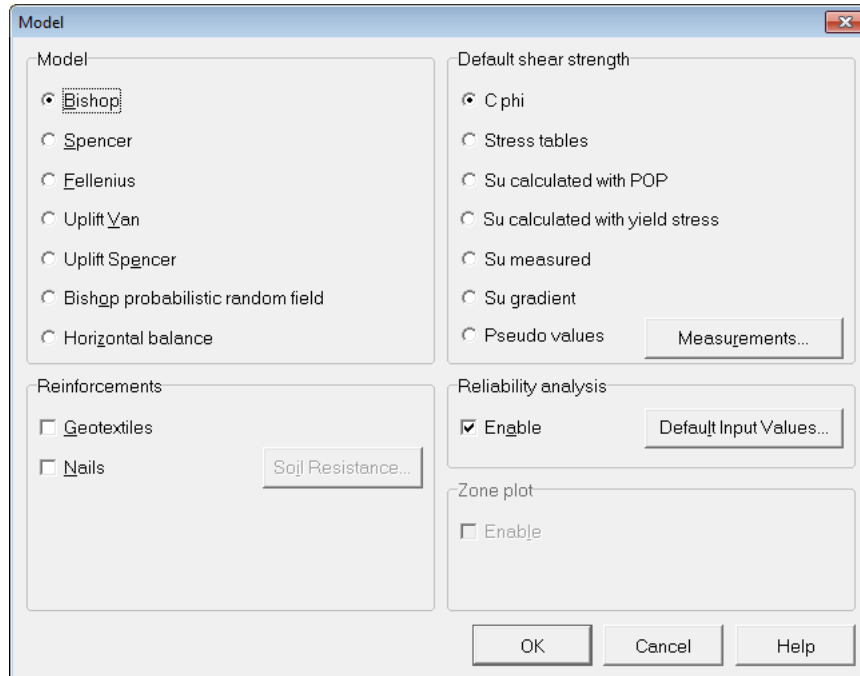


Figure 13.2: Model window

9. Click on the *Default Input Values* button to open the *Default Input Values* window and choose *mean* as input values (Figure 13.3).

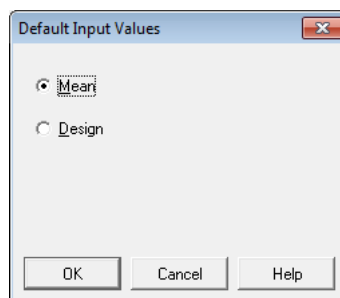


Figure 13.3: Default Input Values window

10. Click *OK* to close the *Default Input Values* window.
11. Click *OK* to close the *Model* window.

13.3 Probabilistic Defaults

To perform a probabilistic calculation, D-GEO STABILITY makes use of predefined probabilistic parameters. These are applied to soil strength parameters, pore pressure properties and a model factor. In order to modify these parameters:

12. Click *Probabilistic Defaults* option in the *Project* menu. The default values of the probabilistic parameters are displayed in the window that opens (Figure 13.4). In this tutorial the default values as provided should be used. The defaults under *Strength* and *Pore pressure* are applied to all materials.
13. Click *OK*.

Strength				
	Coef. of var. (Std. dev./mean) [-]	Design value factors		Distribution
		Partial [-]	Std. dev. [-]	
Drained cohesion (c)	0.25	1.25	-1.65	Log normal
Friction angle (phi)	0.15	1.10	-1.65	Log normal
Strength from stress table	0.20	1.15	-1.65	Log normal
Ratio S	0.25	1.15	-1.65	Log normal
Undrained shear strength (Su)	0.25	1.15	-1.65	Log normal

State				
	Coef. of var. (Std. dev./mean) [-]	Design value factors		Distribution
		Partial [-]	Std. dev. [-]	
EOP	0.10	1.10	-1.65	Log normal

Pore pressure				
	Std. dev.	Design value factors		Distribution
		Partial [-]	Std. dev. [-]	
Consolidation coefficient 50% [%]	20.00	1.00	1.65	Normal
Hydraulic pressure [kN/m ²]	0.50	1.00	1.65	Log normal

Model factor				
	Mean	Std. dev.	Distribution	
Limit value stability factor Bishop [-]	1.00	0.08	Log normal	
Limit value stability factor Ven [-]	0.95	0.08	Log normal	

Buttons: Reset, OK, Cancel, Help

Figure 13.4: Probabilistic Defaults window

13.4 Soil

It is possible to modify the probabilistic properties of each material individually by changing the numerical values. In this tutorial the properties for 'Soft Clay' shall be modified by changing the standard deviation of the friction angle from 3 to 5°.

14. Click *Materials* in the *Soil* menu.
15. Select *Soft Clay* in the materials list.
16. Deselect Use Probabilistic defaults.
17. Enter <5.0> for the standard deviation of the friction angle.

The screenshot shows the 'Materials' dialog box with the following settings:

- Material name:** Soft Clay
- Total unit weight:** Above phreatic level: 14.00 [kN/m³], Below phreatic level: 14.00 [kN/m³]
- Soil group:** none
- Shear strength model:** Default (C phi)
- Shear strength input:** Default (Mean) Use probabilistic defaults
- Shear strength parameters:**

	Mean	Design	Std. dev.	Distribution
Cohesion (c) [kN/m²]	8.00	4.14	2.00	Log normal
Friction angle (phi) [deg]	20.00	11.75	5.00	Log normal
Dilatancy (psi) [deg]	20.00			
- Pore pressure parameters:**

	Std. dev.	Distribution
Hydraulic pressure [kN/m²]	0.50	Log normal

Figure 13.5: Materials window for Standard input

It is also possible to describe the materials' properties in more detail, i.e. provide probabilistic information on the use of cohesion and friction angle. This can be done with or without using the probabilistic defaults.

In this tutorial the design value factor for the friction angle of *Berm Sand* must be changed.

18. Select *Berm Sand* in the materials list.
19. Deselect *Use probabilistic defaults*.
20. In the right part of the window, select *Advanced*.
21. Now select the *Shear Strength Advanced* tab.
22. Change the value of *partial* to <1.20> in the *Phi design value factors* sub-window.
23. Click *OK*.

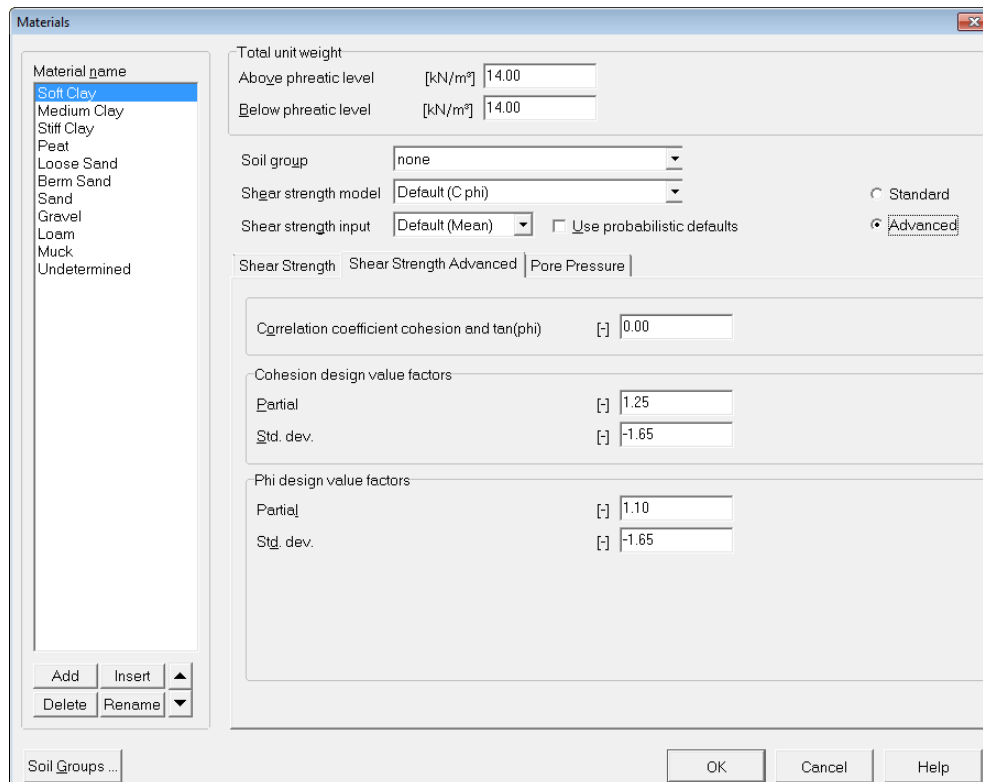



Figure 13.6: Materials window, Shear Strength Advanced tab

13.5 Geometry

For this probabilistic calculation three possible water levels on the left side of the dike are taking into account. To this end, two new PL-lines (called MHW and MLW in Figure 13.1) have to be first inputted into the geometry.

13.5.1 Points

To create two new PL-lines six new points are first added to the existing points.

24. Click *Points* in the *Geometry* menu to open the *Points* window.
25. Click six times the *Add row*  button to add points number <25> till <30> which will be used to create PL-lines 2 and 3 (see section 13.5.2).
26. Modify the coordinates of those points number as given in Figure 13.7.
27. Click *OK*.

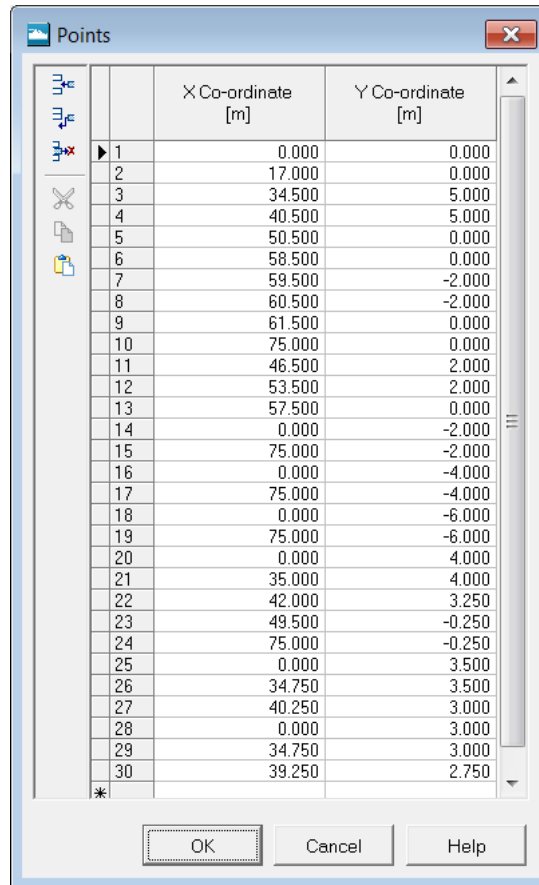


Figure 13.7: Points window

13.5.2 PL-lines

To create two new PL-lines follow these steps:

28. Click *PL-lines* in the *Geometry* menu to open the *PL-Lines* window.

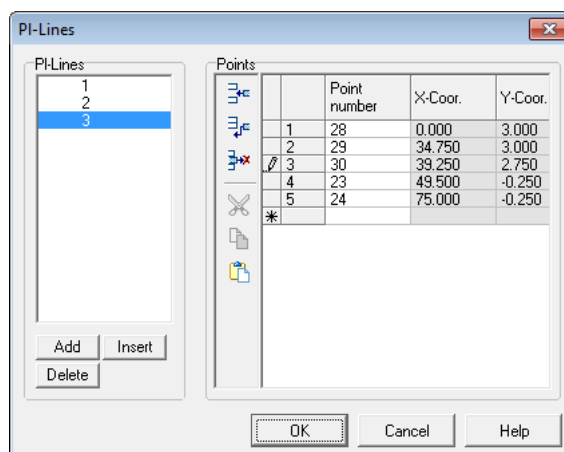


Figure 13.8: PL-Lines window

29. Click the *Add* button to add PL-line number <2>.
30. Enter points number <25>, <26>, <27>, <23> and <24> in the *Point number* column at the right of the *PL-lines* window.

31. Click again the *Add* button to add PL-line number <3>.
32. Enter points number <28>, <29>, <30>, <23> and <24> in the *Point number* column at the right of the *PL-lines* window (Figure 13.8).
33. Click *OK*. This will result in a new geometry in the *View Input* window, as shown in Figure 13.9.

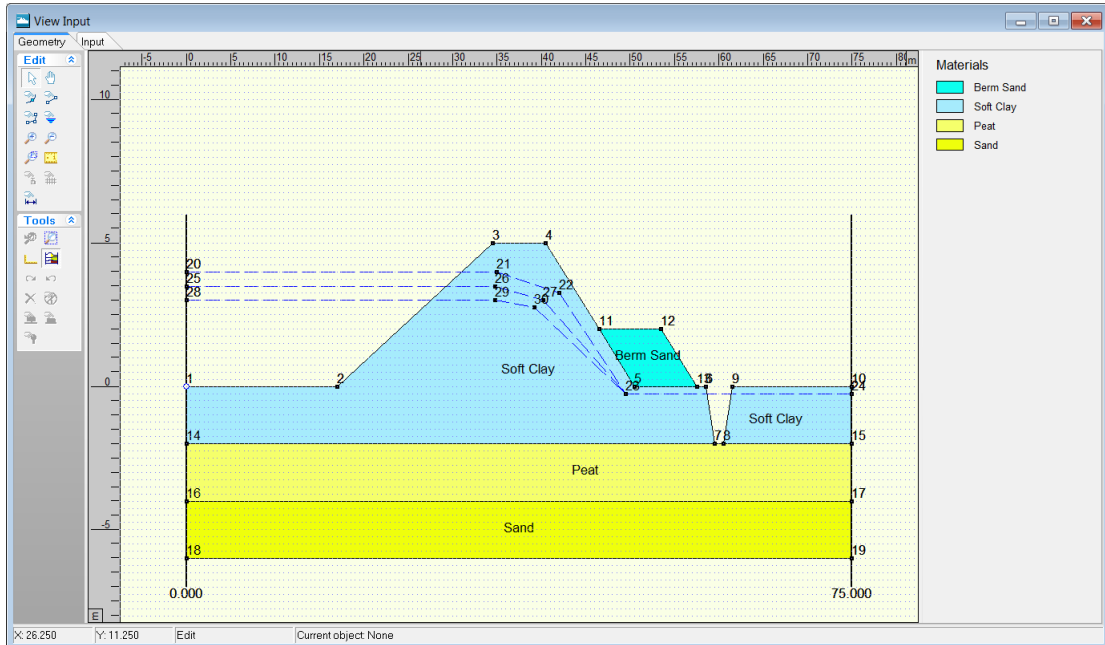


Figure 13.9: View Input window, Geometry tab

13.5.3 PL-lines per Layer

In this tutorial the piezometric level of all the layers coincides with the phreatic line (which is the upper line in Figure 13.1).

13.6 Water

In the geometry three different piezometric level lines are drawn. In the design case, the upper line functions as the phreatic line. The second line has been added to be incorporated as a mean high water level in this probabilistic calculation. The lower line will be incorporated as a mean low water level.

To define how the water levels are to be incorporated, do the following:

34. Click External water levels in the Water menu.
35. Mark the *Use water data* check box.

First, a design level must be set for the calculation.

36. In the *Water level* sub-window, enter <4.0 m> as *Design level* and <0.3 m> as *Decimate height*.
37. Set the level of exceeding to <1/2000>. This means that this water level is exceeded once every 2000 years.

In order to describe the first water level, do the following:

38. Click *Rename* and change the name of the current water level to <MHW> (Mean High Water).
39. In the *PL-lines* sub-window, the *Phreatic line number* for this water level is defined by line number <2>. In other words, all the weight of the soil beneath this level will be calculated by its weight under the phreatic line. To include this in the calculation select phreatic line number 2 from the drop down menu.
40. Enter <3.5 m> for *Level*. In combination with the design level and its frequency of exceeding, an exceeding frequency is established for this particular water level.
41. At this particular water level some of the layers' piezometric levels differ. Enter PL-line at top and PL-line at bottom according to the values shown in [Figure 13.10](#).

	PL-line at top	PL-line at bottom
5	2	2
4	3	3
3	3	3
2	2	2
1	3	3

Figure 13.10: External Water Levels window, MHW

42. To add the second water level to the calculation input, click *Add* in the *Water data name* sub-window.
43. Change the name of this water level to <MLW> (Mean Low Water).
44. In the *PL-lines* sub-window, the *Phreatic line number* for this water level is defined by line number <3>.
45. Set *Level* to <3.0 m>.
46. For all the layers enter <3> as PL-line at top and PL-line at bottom.
47. Click *OK*.

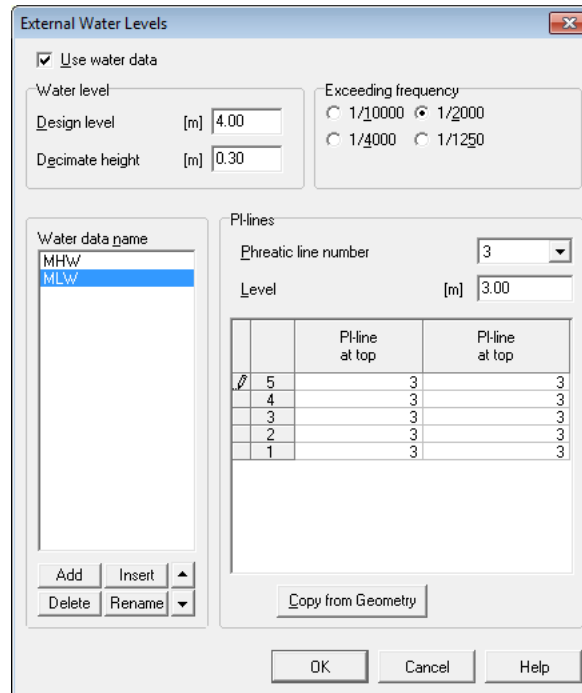


Figure 13.11: External Water Levels window, MLW

13.7 Calculation and Results

The input now includes stochastic values for soil properties and three different water levels have been defined. These inputs are going to be included in a calculation that will result in a safety factor and a probability of failure for each water level.

48. Click *Start* in the *Calculation* menu.
49. Check that the *Probabilistic* calculation type is selected.
50. Click *OK*.

While D-GEO STABILITY performs the calculation, the *Calculation Progress* window shows the current lowest safety factor for the water level that is being calculated.

13.7.1 Stresses

51. Click *Stresses* in the *Results* menu to display the *Critical Circle* window (Figure 13.12). The screen shows the failure mechanism for the design case. The safety factor is the same as in Tutorial-1b (section 8.9.3) with a value of 1.35. At the bottom of the screen the measurements of the slip circle are displayed. Important to this tutorial are the safety factor and the probability of failure.

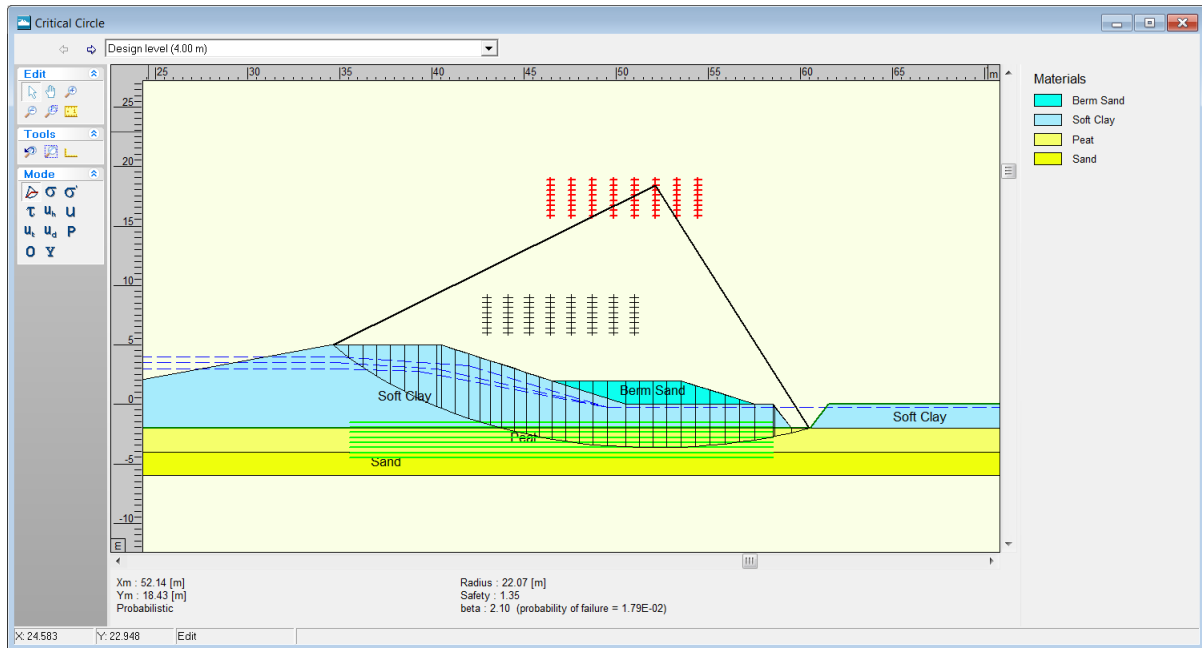


Figure 13.12: Critical Circle window

The drop down menu at the top of the window can navigate between the results for the different water levels.

52. Select *MHW (+3.50 m)* to display the results for Mean High Water (Figure 13.13).

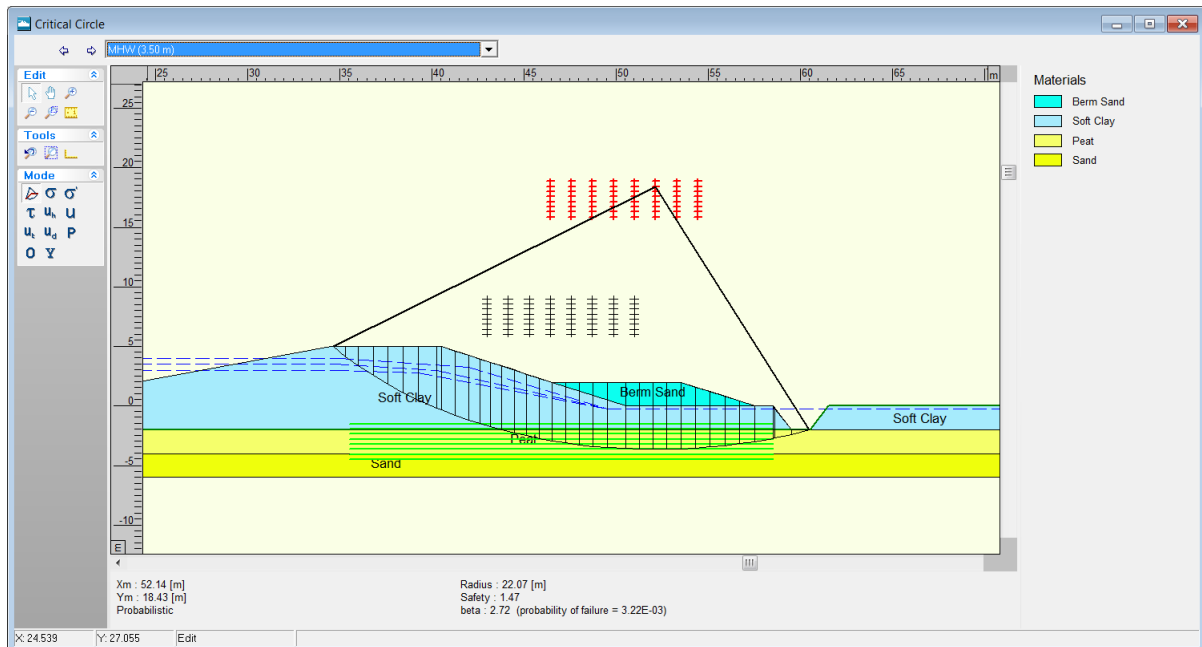


Figure 13.13: Critical Circle window for Mean High Water level

As expected the safety factor (1.47) is higher than in the design case. An overview of the results is given in Table 13.1.

Table 13.1: Safety factor for different water levels

Water levels	Safety factor
Design level (+4.0 m)	1.35
MHW (+3.5 m)	1.47
MLW (+3.0 m)	1.48

13.7.2 FMin Grid

To view the *FMin Grid* window for the case that results in the largest safety factor:

53. Click *FMin grid* in the *Results* menu (Figure 13.14).

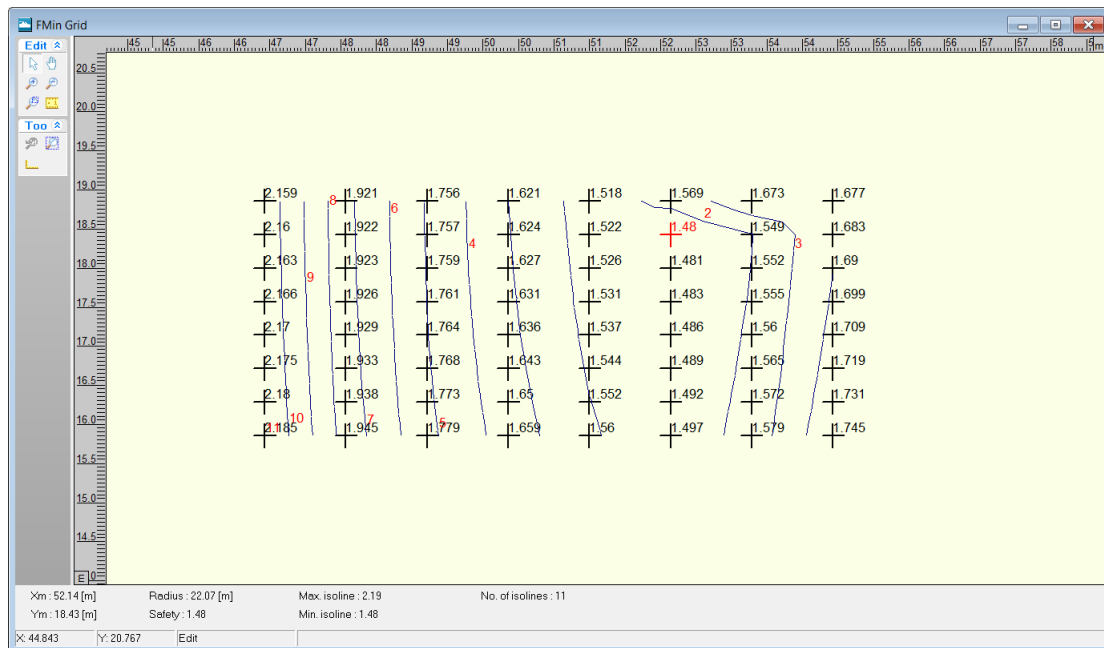


Figure 13.14: *FMin Grid* window

13.7.3 Influence Factors

To get an idea of what parameters in the input contribute most the final outcome of the calculation:

54. Click *Influence Factors* in the *Results* menu. In the *Influence Factors* window displayed the results for the different external water levels can be seen using the drop down menu at the top. In addition, this menu also includes the *Design point water level* which is equal to 3.06 m in this tutorial.
55. Select *Design point water level* (3.06 m) from the drop down menu.

The window displayed (Figure 13.15) shows that the *Model Factor* has a large influence on the outcome of the safety factor and the slope's probability of failure.

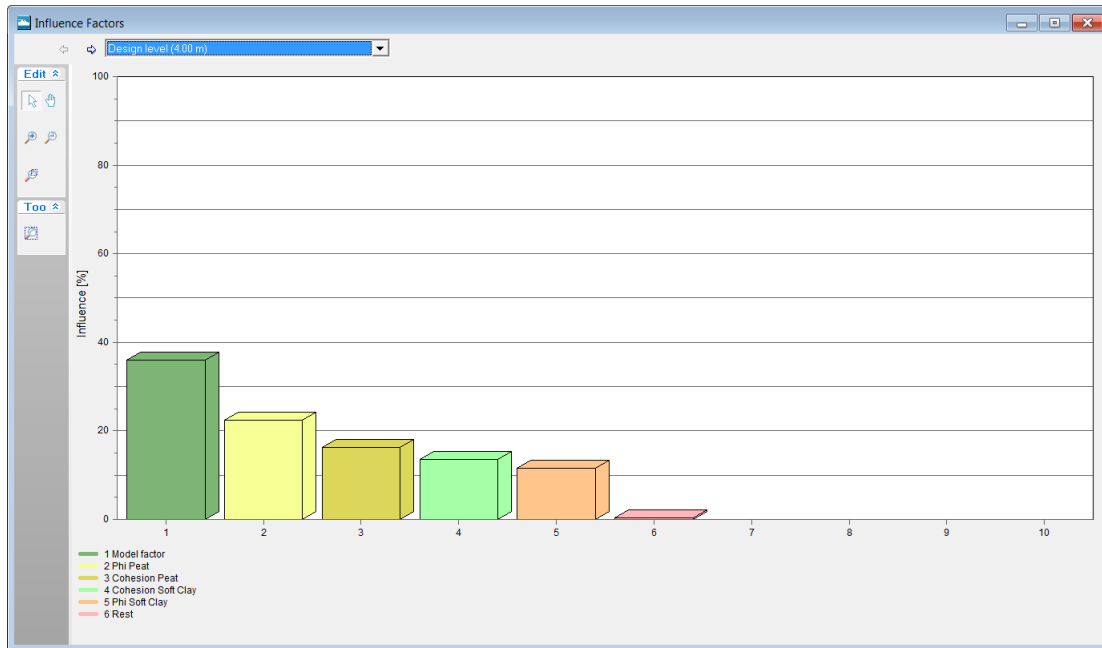


Figure 13.15: Influence Factors window

13.8 Conclusion

The *Reliability Analysis* in D-GEO STABILITY is able to perform a probabilistic calculation incorporating stochastic description of soil properties as well as probabilistic descriptions of external water levels. A design conclusion is that for cases with higher water levels the safety factor is lower.

14 Tutorial 7: Bishop Random Field Method

The case from Tutorial 6 ([chapter 13](#)) is used in this tutorial to determine the probability that the stability of the slope is less than the required value. D-GEO STABILITY performs a probabilistic calculation to determine this probability. Next to this it will calculate sensitivity factors that can be used in the PCRING program.

The objective of this tutorial is:

- ◇ To learn how to perform a calculation using the Bishop Random Field method.

For this example, the following D-GEO STABILITY modules are needed:

- ◇ D-GEO STABILITY Standard module (Bishop and Fellenius).
- ◇ Probabilistic random field model.

This tutorial is presented in the file Tutorial-7.sti.

14.1 Introduction to the case

The Bishop Random Field Method will calculate the probability of failure for each different water level. To this end D-GEO STABILITY requires the input of the values of model factors. The most important one is the required safety factor. Next to this the soil properties can be described stochastically.

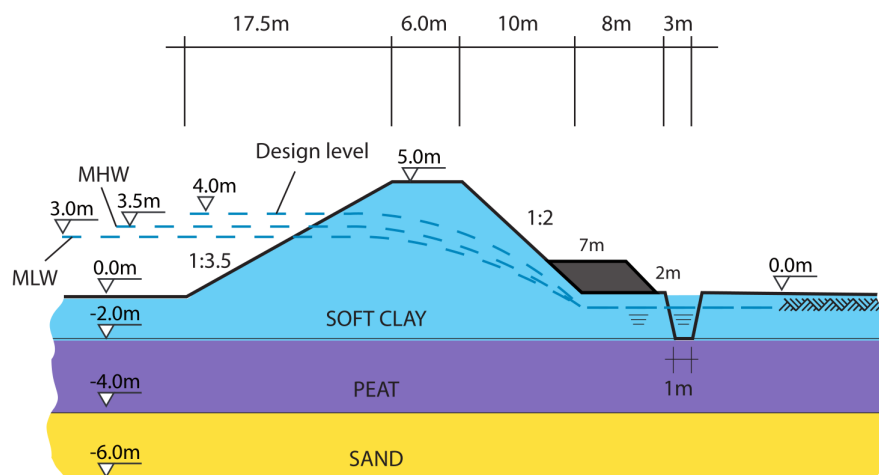


Figure 14.1: Geometry overview (Tutorial 7)

The geometry, soil properties and external water levels show in [Figure 14.1](#) are the same as Tutorial 6:

1. Click *Open* in the *File* menu.
2. Select *Tutorial-6*.
3. Click *Open*.
4. Click *Save as* in the *File* menu.
5. Enter <Tutorial-7> as file name.
6. Click *Save*.

14.2 Project

14.2.1 Model

7. Click *Model* in the *Project* menu.
8. Select the *Bishop prob. random field* method.
9. Click *OK*.

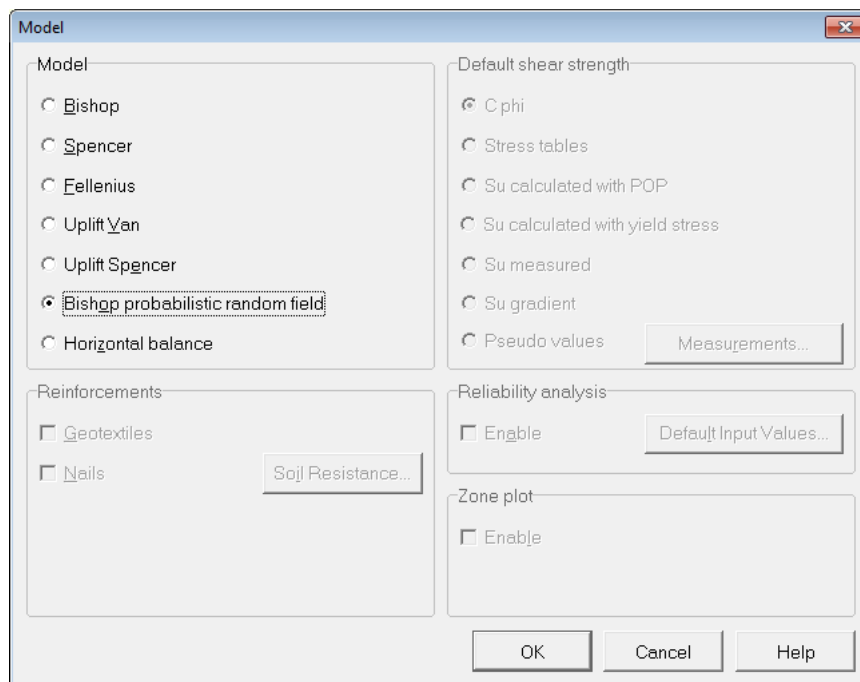


Figure 14.2: Model window

14.2.2 Project Properties

10. On the menu bar, click *Project* and then choose *Properties* to open the *Project Properties* window.
11. Fill in <Tutorial 7 for D-GEO STABILITY > and <Bishop Prob. Random Field model for dike body> for *Title 1* and *Title 2* respectively in the *Identification* tab.
12. Click *OK*.

14.3 Model Factor

The required safety factor for which probability is to be established can be entered.

13. Click *Model Factor* in the *Soil* menu to open the *Model Factor* window.
14. Enter <1.35> for the *Limit value stability factor*. This is a realistic value to consider a slope as safe.
15. Leave the other values unchanged (Figure 14.3).
16. Click *OK*.

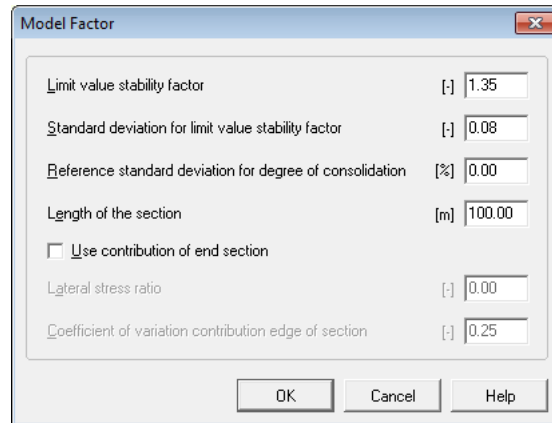


Figure 14.3: Model Factor window

See [section 4.2.5 “Model Factor”](#) for a detailed description of this window.

14.4 Calculation and Results

To start the calculation:

17. Choose *Start* in the *Calculation* menu to open the *Calculation* window.
18. Click *OK*.

To view the results:

19. Choose *Stresses* from the *Results* menu. The *Critical Circle* window will appear ([Figure 14.4](#)).

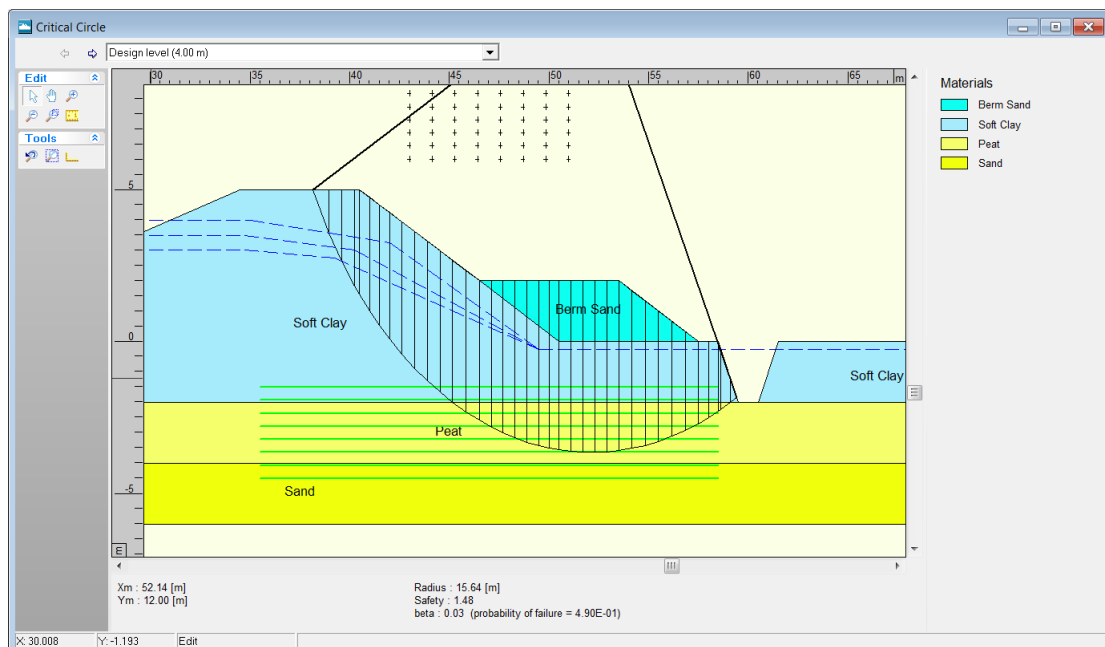


Figure 14.4: Critical Circle window

The results of the Bishop Random Field method (measurements for the critical slip plane and

probability of failure) are given for each of the three described water levels (MLW, MHW and design level) using the drop down menu at the top of the *Critical Circle* window.

14.5 Conclusion

The Bishop Random Field method is capable of performing a probabilistic slope analysis. It can incorporate stochastic descriptions of soil parameters and external water levels. It calculates the probability of failure according to a required safety factor.

2. Select Tutorial-1a.
3. Click *Open*.
4. Click *Save as* in the *File* menu.
5. Enter <Tutorial-8> as file name.
6. Click *Save*.

15.2 Project

15.2.1 Model

7. Click *Model* in the *Project* menu.
8. Mark the *Zone plot* check-box.
9. Click *OK*.

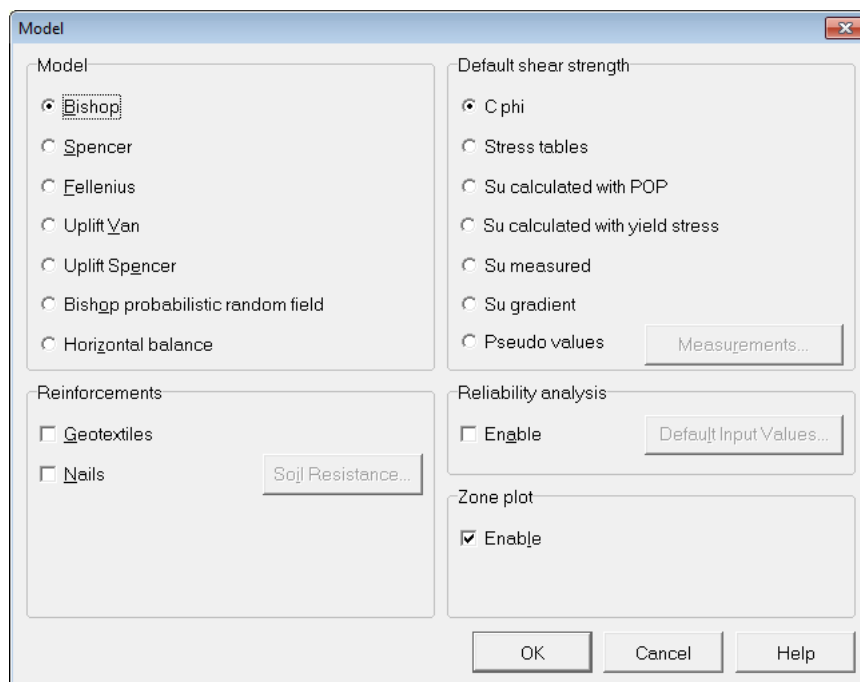


Figure 15.2: Model window

15.2.2 Project Properties

10. On the menu bar, click *Project* and then choose *Properties* to open the *Project Properties* window.
11. Fill in <Tutorial 8 for D-GEO STABILITY > and <Zone Plot model> for *Title 1* and *Title 2* respectively in the *Identification* tab.
12. Click *OK*.

15.3 Zone Areas for Safety

The six zone areas with a different required safety factor should be defined.

13. Click *Zone Areas for Safety* in the *Definitions* menu to open the *Zone Areas for Safety* window.
14. Enter the values given in [Figure 15.3](#) in order to define the zone areas given in [Figure 15.1](#) and the required safety factors given in [Table 15.1](#). The *Stability calculation* is performed at the <Right side> as the river is situated at the left side of the dike.

15. Click *OK*.

Zone 1 and 2		Zone 3	
Dike table height (0.1 l/m/s)	[m] 4.00	Left side of minimal road	[m] 52.00
Dike table width	[m] 3.00	Right side of minimal road	[m] 55.00
Start x co-ordinate restprofile	[m] 32.00	Required safety in zone 3a	[-] 0.93
Boundary of design level influence at x	[m] 36.00	Required safety in zone 3b	[-] 0.90
Boundary of design level influence at y	[m] -3.00	Stability calculation at	
Required safety in zone 1a	[-] 1.19	<input type="radio"/> Left side <input checked="" type="radio"/> Right side	
Required safety in zone 1b	[-] 1.11		
Required safety in zone 2a	[-] 1.05		
Required safety in zone 2b	[-] 1.02		

Figure 15.3: Zone Areas for Safety window

See [section 4.4.4 "Zone Areas for Safety"](#) for a detailed description of this window.

15.4 Rest slope of the soil materials

The slope of the rest profile depends on the soil type: $\frac{1}{4}$ for peat and sand and $\frac{1}{2}$ for clay.

16. Open the *Materials* window from the *Soil* menu.
17. Leave the *Rest slope* of the *Soft Clay* to its default value <1:2>.
18. Select the *Peat* material and define a *Rest slope* of <1:4> as shown in [Figure 15.4](#).
19. Do the same for the *Sand* material.
20. Click *OK*.

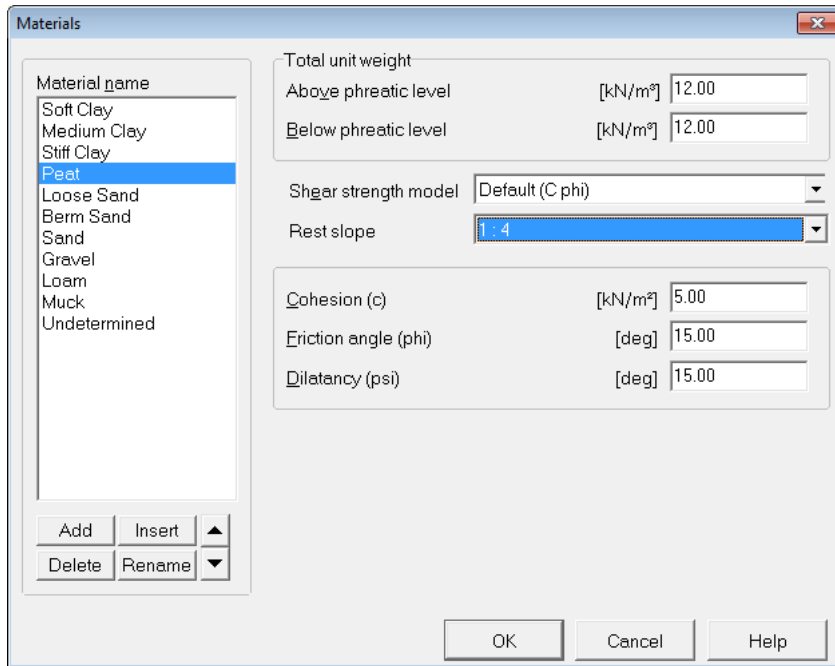


Figure 15.4: Materials window

15.5 Calculation and Results

To start the calculation:

21. Choose *Start* in the *Calculation* menu to open the *Calculation* window.
22. Click *OK*.

15.5.1 Safety Factor per Zone

23. Choose *Safety Factor per Zone* from the *Results* menu to open the *Safety Factor per Zone* window (Figure 15.5).

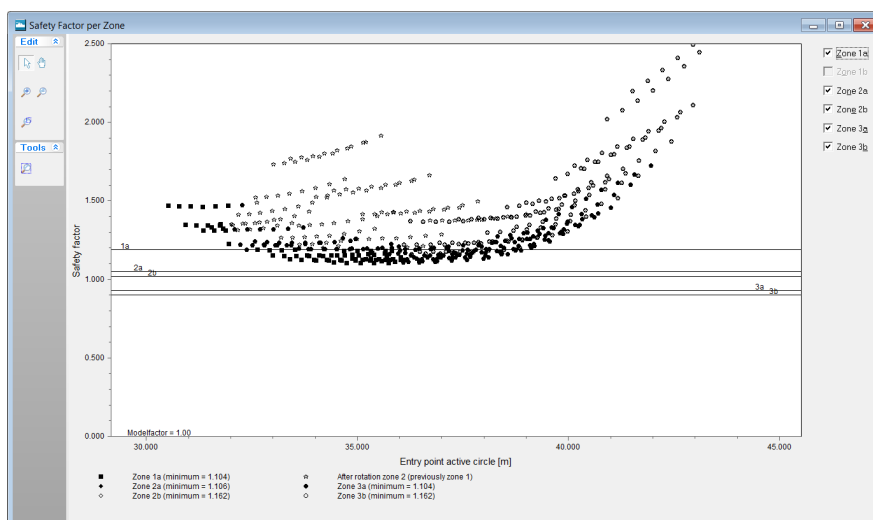


Figure 15.5: Safety Factor per Zone window



This window shows a diagram of the *Safety factor / Model factor* vs. the *Entry point active*

circle (i.e. X coordinate) for the calculated slip circles of each zone. Mark and unmark the available check-boxes at the right side of the window to show the corresponding zone. The horizontal black lines in the diagram correspond to the required safety factors of each zone as defined in the *Zone Areas for Safety* window (section 15.3). Any result is available for Zone 1b which means that any circle pass through this zone. For zone 1a, many points are situated below the required safety factor line which means they are not acceptable.

See section 6.5 “Safety Factor per Zone” for a detailed description of this window.

15.5.2 Stresses per Zone

To view the graphical representation of the zone areas do the following:

24. Click the *Stresses per Zone* option in the *Results* menu to open the *Critical Circle* window (Figure 15.6).
25. Click the *Previous zone* and *Next zone* icons,  , to view various calculated results for each zone.

The bold red line represents the rest profile. The vertical and horizontal dotted black lines represent the boundaries of the design level influence respectively at X and Y. The two inclined dotted black lines at the right side of the window represent the limits of the minimal road influence. Information like the radius and center coordinates of the critical circle and the safety factor are printed in the status panel at the bottom of the window.

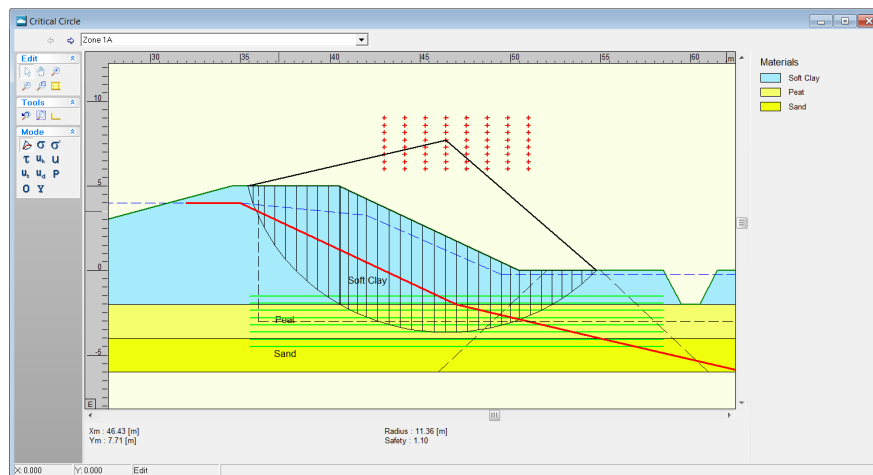


Figure 15.6: Critical Circle window for Zone 1a

See section 6.6 “Stresses per Zone” for a detailed description of this window.

15.6 Conclusion

A calculation using the Zone Plot model has been performed. The body dike is divided into six parts showing the rest profile. The required safety factor for many circles situated in Zone 1a is not reached.

16 Method of slices

This c gives background information on the methods used in the current release of D-GEO STABILITY. Next to this the theories of shear strength model, pore pressures and loads are given. Extensive attention is given to reliability based design.

16.1 Method of slices

For calculating slope stability D-GEO STABILITY uses the method of slices. This method divides the earth mass above the slide plane into a number of vertical slices (see [Figure 16.1](#)) Slices. For each slice, the different soil parameters, effective stresses and pore water pressures are calculated. These values are assumed to be representative for the entire slice. The method assumes a circular shaped slip plane (failure mechanism) with radius r .

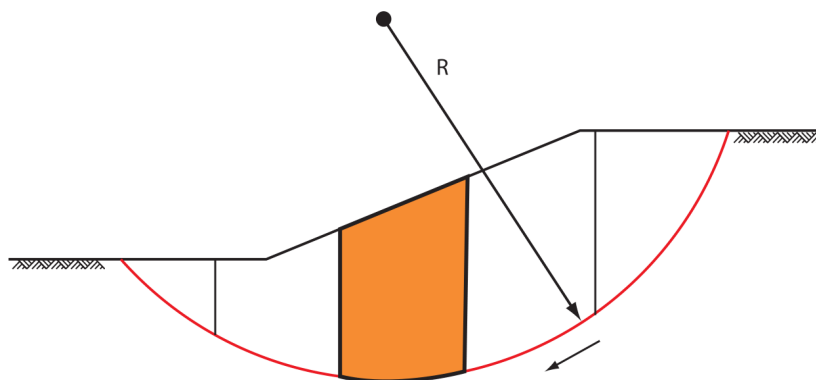


Figure 16.1: Slip plane including method of slices

D-GEO STABILITY automatically divides the slip plane into slices in accordance with the following criteria:

- ◇ Within one slice, there are no intersection points of layer boundaries and/or PL-lines.
- ◇ Within one slice, there are no intersection points of layer boundaries and the phreatic line.
- ◇ The entire base of any slice, which is part of the slip circle, is located totally within one soil layer and completely above or below the phreatic line.

In addition, D-GEO STABILITY follows the following procedures in case a slide plane intersects the soil surface at more than two points. This is possible with a ditch as well as with a dike. In this case the largest area between two intersection points is taken to be the slide plane. If the plane cuts the surface of the geometry at only one point, the plane is rejected and is not processed any further. This latter case may occur when the geometry has not been defined wide enough so that slide planes reach the outer boundaries of the geometry, or when the slide planes just touches the surface at one point.



16.2 Circular slip plane (Bishop and Fellenius)

The Bishop and Fellenius method both consider the driving moments by soil weight, water pressures and loads around the center of a slip circle.

Stability requires that the sum of these driving moments is equal to a certain resisting moment. The resistance moment is generally determined by the shear strength of the soil along the slip circle and by an additional contribution from geotextiles.

Fellenius defines the safety factor by simply using the ratio between the driving moments and the ultimate resistance moment. Bishop defines the safety by the reduction factor that can be applied to cohesion and (the tangent of) the friction. This means that only with Bishop's method the equilibrium of vertical forces is preserved. Therefore Bishop's method is preferred.

The equilibrium evaluation is based on the summation of the influence of the all slices. The equilibrium evaluation of a slice includes the forces and pressures in [Figure 16.2](#).

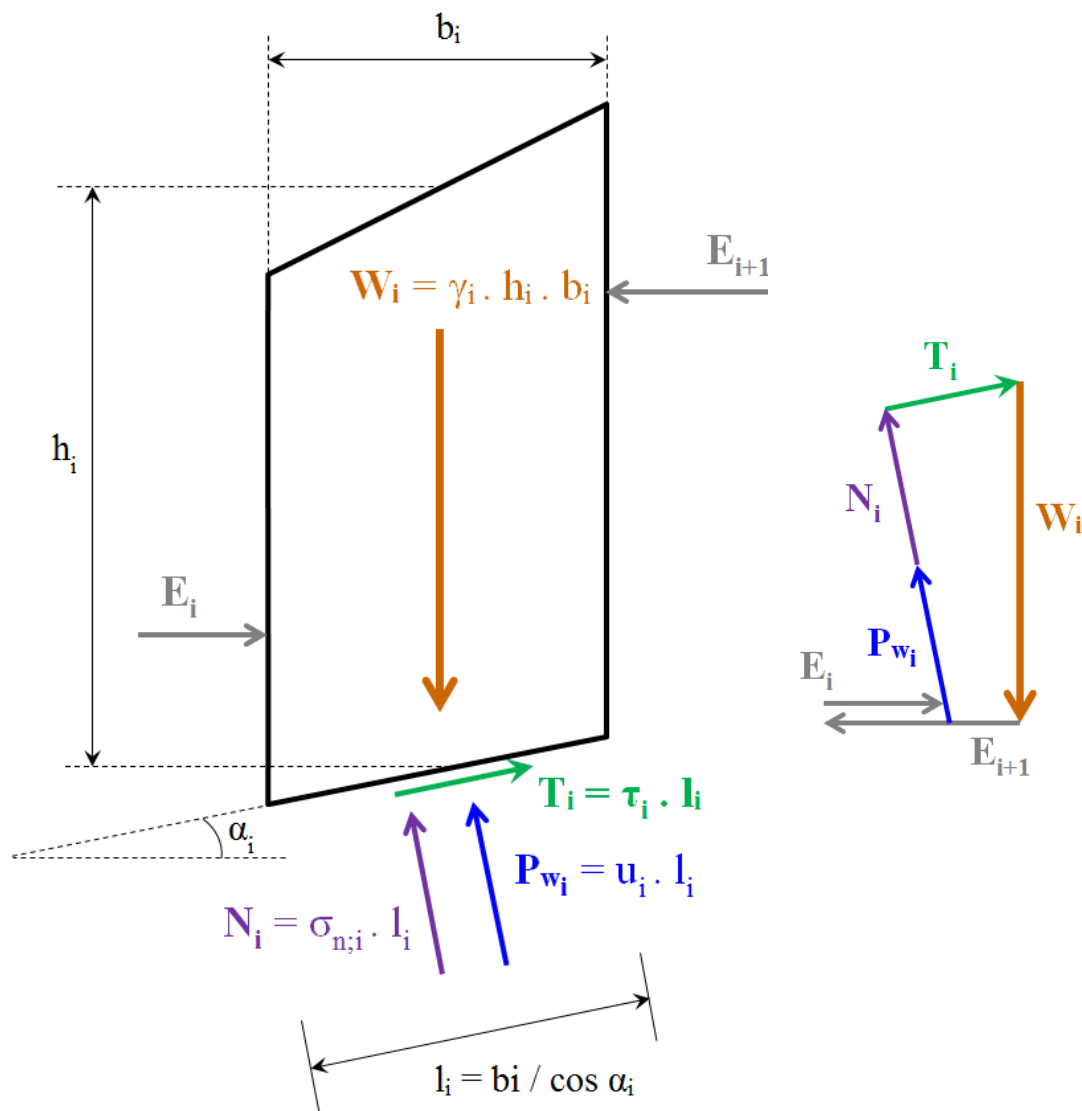


Figure 16.2: Force equilibrium for one slice in the method of slices

The following table gives the definitions of the forces given in [Figure 16.2](#):

- W_i is the weight of slice i , in kN/m;
 T_i is the shear force along of slice i , in kN/m;
 E_i is the interaction force of slice i with the slice at the left side, in kN/m;
 E_{i+1} is the interaction force of slice i with the slice at the right side, in kN/m;
 Pw_i is the water force acting on the base of slice i , in kN/m;
 N_i is the (total) normal reaction of the soil acting on the base of slice i , in kN/m;
 Refer to [section 1.8](#) for the definition of the other symbols used in [Figure 16.2](#).

The next section describes how the different moments are calculated for a slice.

16.2.1 Driving moments

16.2.1.1 Driving soil moment

The driving soil moment $M_{D;\text{soil}}$ is the moment caused by the mass of the soil within the slip circle around its center:

$$M_{D;\text{soil}} = \sum_{i=1}^n G_i \times (X_i - X_c) \quad (16.1)$$

with:

$$G_i = \sum_{j=1}^{k_i} \gamma_j \times h_j \times b_i \quad (16.2)$$

where:

- G_i is the weight of the soil in slice i (see [Figure 16.2](#)), in kN/m;
 h_j is the thickness of layer j in slice i ;
 k_i is the number of layers along slice i ;
 n is the number of slices;
 γ_j is the unit weight of soil layer j in slice i , in kN/m³;
 Refer to [section 1.8](#) for the definition of the other symbols.

16.2.1.2 Driving water moment

The water moment is the contribution of two water moments:

$$M_{D;\text{water}} = M_{\text{Water};\text{Top}} + M_{\text{Water};\text{Side}} \quad (16.3)$$

where:

- $M_{\text{Water};\text{Top}}$ is caused by the water forces (due to free water on surface) acting on the top of the slice, see [Equation 16.4](#);
 $M_{\text{Water};\text{Side}}$ is caused by the water forces (due to free water on surface) acting on the side of the slice, see [Equation 16.5](#) and [Equation 16.6](#).

Water forces (due to free water on surface) acting on the top of the slice

The water forces acting on and within the soil slice. When there is free water on the surface of the geometry and within the boundaries of the slip circle, it can have a positive or negative effect on the safety factor. The driving water moment M_{water} for a slice is calculated as follows:

$$M_{\text{Water;Top}} = \sum_{i=1}^n (X_i - X_c) \times W_{v;i} \times + (Z_c - Z_{i;\text{top}}) \times W_{h;i} \tag{16.4}$$

where:

$W_{v;i}$ is the vertical component of the water force on top of slice i , in kN:

$$W_{v;i} = - \max [0; (Z_{\text{phreatic}} - Z_{\text{top};i})] \times \gamma_w \times b_i$$

$W_{h;i}$ is the horizontal component of the water force on top of slice i , in kN:

$$W_{h;i} = \max [0; (Z_{\text{phreatic}} - Z_{\text{top};i})] \times \gamma_w \times b_i \times \tan \beta_i$$

Refer to [section 1.8](#) for the definition of the other symbols.

Water forces (due to free water on surface) acting on the side of the slice

With the introduction of vertical layer boundaries, it became possible to have a surface with a vertical component. If this vertical component is part of the slip circle, D-GEO STABILITY will place a slice to the left and right of this vertical. The moment caused by the free water on the top of both slices is calculated using the above formula ([Equation 16.4](#)). The force and moment of the free water against the vertical component of the surface (now also the side of a slice) is not taken into account by the above formula. Instead, D-GEO STABILITY separately calculates the horizontal free water force and the moment caused by it.

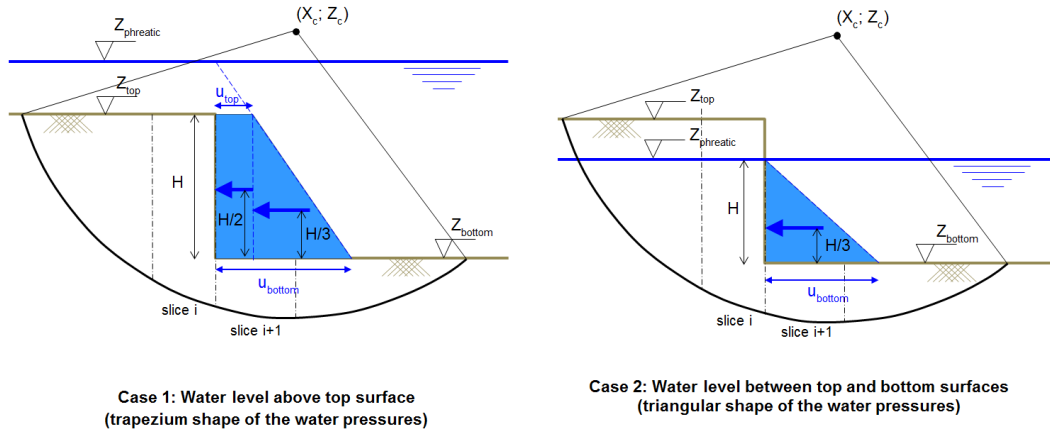


Figure 16.3: Horizontal water pressures (due to free water) acting on the side of a slice in case of vertical layer boundary

- ◇ If the phreatic line is above the top surface, the shape of the horizontal water pressures against the side of the slice is trapezium (case 1 in [Figure 16.3](#)):

$$M_{\text{Water;Side}} = u_{h;\text{top}} H \left(Z_c - \left(Z_{\text{bottom}} + \frac{H}{2} \right) \right) + \frac{H}{2} (u_{h;\text{bottom}} - u_{h;\text{top}}) \left(Z_c - \left(Z_{\text{bottom}} + \frac{H}{3} \right) \right) \tag{16.5}$$

- ◇ If the phreatic line is between the top and the bottom surfaces, the shape of the horizontal water pressures against the side of the slice is triangular (case 2 in [Figure 16.3](#)):

$$M_{\text{Water;Side}} = \frac{H}{2} u_{h;\text{bottom}} \left(Z_c - \left(Z_{\text{bottom}} + \frac{H}{3} \right) \right) \quad (16.6)$$

where:

H is the height of the saturated soil along the vertical layer boundary:

$$H = \min(Z_{\text{phreatic}}; Z_{\text{top}}) - \min(Z_{\text{phreatic}}; Z_{\text{bottom}})$$

If the soil within the slip plane height is dry, then $H = 0$.

$u_{h;\text{top}}$ is the hydrostatic pressure at level Z_{top}

$$u_{h;\text{top}} = (Z_{\text{phreatic}} - \min(Z_{\text{phreatic}}; Z_{\text{top}})) \times \gamma_w$$

$u_{h;\text{bottom}}$ is the hydrostatic pressure at level Z_{bottom} :

$$u_{h;\text{bottom}} = (Z_{\text{phreatic}} - Z_{\text{bottom}}) \times \gamma_w$$

Z_{top} is the top level of the vertical part;

Z_{bottom} is the bottom level of the vertical part.

Refer to [section 1.8](#) for the definitions of the other symbols.

16.2.1.3 Driving load moment

The (part of the) uniform loads and the line loads located within the confines of a slip circle creates a moment $M_{\text{D;load}}$ around the slip-circle center point.

$$M_{\text{D;load}} = \sum_{j=1}^{n_{\text{loads}}} F_j \times \Delta w_j \times (X_c - X_j) + \sum_{l=1}^{n_{\text{lines}}} F_l \times \Delta (X_c - X_l) \quad (16.7)$$

with:

$$X_j = \frac{\max(X_{1;\text{left}}; X_{\text{begin};j}) + \min(X_{n;\text{right}}; X_{\text{end};j})}{2}$$

$$X_l = \frac{\max(X_{1;\text{left}}; X_l) + \min(X_{n;\text{right}}; X_l)}{2}$$

$$\Delta w_j = \min(X_{n;\text{right}}; X_{\text{end};j}) - \max(X_{1;\text{left}}; X_{\text{begin};j})$$

where:

F_j is the magnitude of uniform-load number j , in kN/m^2 ;

F_l is the magnitude of line-load number l , in kN/m ;

n_{lines} is the total number of lines-loads;

n_{loads} is the total number of uniform-loads;

$X_{\text{begin};j}$ is the X-coordinate of the starting point of load j ;

$X_{\text{end};j}$ is the X-coordinate of the ending point of load j ;

X_l is the X coordinate of line-load l ;

$X_{1;\text{left}}$ is the X-coordinate of the left side of slice 1 (i.e. entry point of the slip circle);

$X_{n;\text{right}}$ is the X-coordinate of the right side of slice n (i.e. exit point of the slip circle);

Δw_j is the width of the part of the uniform-load j located within the confines of a slip circle;

X_j is the X-coordinate at the middle of the part of the uniform-load j located within the confines of a slip circle;

X_l is the X-coordinate of the line-load l located within the confines of a slip circle;

Refer to [section 1.8](#) for the definitions of the other symbols.

16.2.2 Resisting moments

16.2.2.1 Resisting moment from soil

Shear stresses and normal effective stresses act along the slip circle. The shear stresses prevent the circular soil mass from slipping. The resisting moment $M_{R;\text{soil}}$ is defined as the moment caused by the shear stresses along the circular arc around the center of the slip circle.

$$M_{R;\text{soil}} = R \times \sum_{i=1}^n \tau_i \cdot l_i \quad (16.8)$$

where:

τ_i is the shear stress along bottom of slice, in kN/m^2 , see [Equation 16.11](#) for Bishop method and [Equation 16.16](#) for Fellenius method;
Refer to [section 1.8](#) for the definitions of the other symbols.

16.2.2.1.1 Shear stress - Bishop

The vertical equilibrium of the force acting on the slice ([Figure 16.2](#)) writes:

$$\begin{aligned} \sum F_v = 0 &= -W_i + U_i \cdot \cos \alpha_i + N'_i \cdot \cos \alpha_i + T_i \cdot \sin \alpha_i \\ &= -\gamma_i \cdot h_i \cdot b + u_i \cdot l_i \cdot \cos \alpha_i + \sigma'_{n;i} \cdot l_i \cdot \cos \alpha_i + \frac{\tau_i}{F_s} \cdot l_i \cdot \sin \alpha_i \end{aligned}$$

which leads to:

$$\sigma'_{n;i} = \sigma'_{v;i} - \frac{\tau_i}{F_s} \cdot \tan \alpha_i \quad (16.9)$$

where $\sigma'_{v;i}$ is the effective stress at the base of slice i : $\sigma'_{v;i} = \gamma_i \cdot h_i - u_i$

According to Mohr-Coulomb, the relation between the shear stress $\tau_{\text{max};i}$ and the normal effective stress $\sigma'_{n;i}$ is:

$$\tau_i = c_i + \sigma'_{n;i} \cdot \tan \varphi_i \quad (16.10)$$

Substitution of [Equation 16.9](#) into [Equation 16.10](#) leads to:

$$\tau_i = \frac{c_i + \sigma'_{v;i} \times \tan \varphi_i}{1 + \tan \alpha_i \times \frac{\tan \varphi_i}{F_s}} \quad (16.11)$$

where:

c_i is the cohesion at the bottom of slice i , in kN/m^2 ;
 $\sigma'_{v;i}$ is the vertical effective stress at the bottom of slice i , in kN/m^2 , see [Equation 18.6](#);
 φ_i is the internal friction angle of the soil at the bottom of slice i , in degree;
 α_i is the angle at bottom of slice, in degree;
 F_s is the safety factor, see [Equation 16.34](#) in [section 16.2.3](#).

16.2.2.1.2 Shear stress - Fellenius

For the ordinary method of slices of Fellenius, the resultant vertical and horizontal forces of a slice (Figure 16.2) are:

$$\sum F_v = 0 = -W_i + U_i \cdot \cos \alpha_i + N'_i \cdot \cos \alpha_i + T_i \cdot \sin \alpha_i \quad (16.12)$$

$$\sum F_h = 0 = T_i \cdot \cos \alpha_i - U_i \cdot \sin \alpha_i - N'_i \cdot \sin \alpha_i \quad (16.13)$$

Substitution of Equation 16.12 into Equation 16.13 leads to:

$$N'_i = W_i \cdot \cos \alpha_i - U_i \quad (16.14)$$

The effective normal stress $\sigma'_{n;i}$ is therefore:

$$\sigma'_{n;i} = \sigma_{v;i} \cdot \cos^2 \alpha_i - u_i \quad (16.15)$$

where $\sigma_{v;i} = \gamma_i \cdot h_i$ is the total soil stress at the base of slice i and u_i the total pore pressure.

Substitution of Equation 16.15 into Equation 16.10 gives the shear stress τ_i :

$$\tau_i = c_i + (\sigma_{v;i} \cdot \cos^2 \alpha_i - u_i) \cdot \tan \varphi_i \quad (16.16)$$

16.2.2.2 Resisting moment from geotextiles

Geotextiles can be used to reinforce and improve the stability of slopes. The geotextile introduces a force that can act at the boundary of a slip circle (see Figure 16.4).

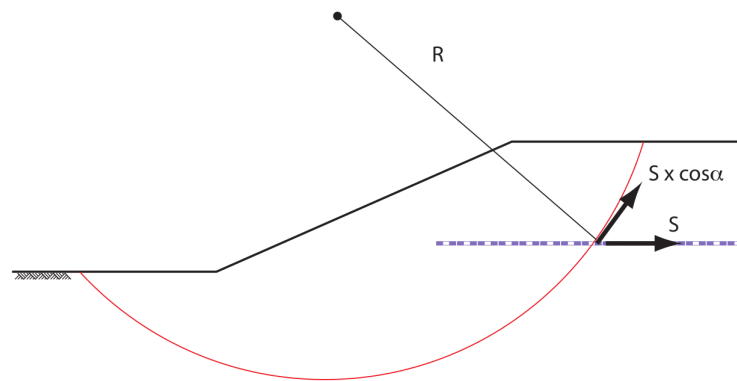


Figure 16.4: Resisting contribution by geotextiles

When calculating the safety factor for the Bishop method, an extra resisting moment due to the geotextile $M_{R;\text{geotextile}}$ is introduced:

$$M_{R;\text{geotextile}} = R \times T_f \times \cos \alpha \quad (16.17)$$

where:

- T_f is the tensile strength in kN/m, as defined in the *Geotextiles* window (section 4.5.1);
- R is the radius of the slip circle;
- α is the angle between the geotextile and the tangent line along the circle where the geotextile intersects the slip circle, in degree.

The contribution of the geotextile depends on the vertical distance between the slip circle center and the geotextile. Therefore, for acquiring a larger safety factor, it is required that this distance is relatively large. Only geotextiles that intersect a slip circle contribute to the resisting moment.

16.2.2.3 Resisting moment from nails

Soil nailing is a technique to reinforce and strengthen the existing ground by installing closely spaced steel bars, called nails. The bars are usually installed into a pre-drilled hole and then grouted into place or drilled and grouted simultaneously. They are usually installed at a slight downward inclination. A rigid or flexible facing (often pneumatically applied concrete otherwise known as shotcrete) or isolated soil nail heads may be used at the surface.

Nails are taken into account in the calculation by considering the forces generated at the intersection with the slip circle (Figure 16.5):

- ◇ the lateral force F_N , parallel to the nail;
- ◇ the shear force F_D , perpendicular to the nail.

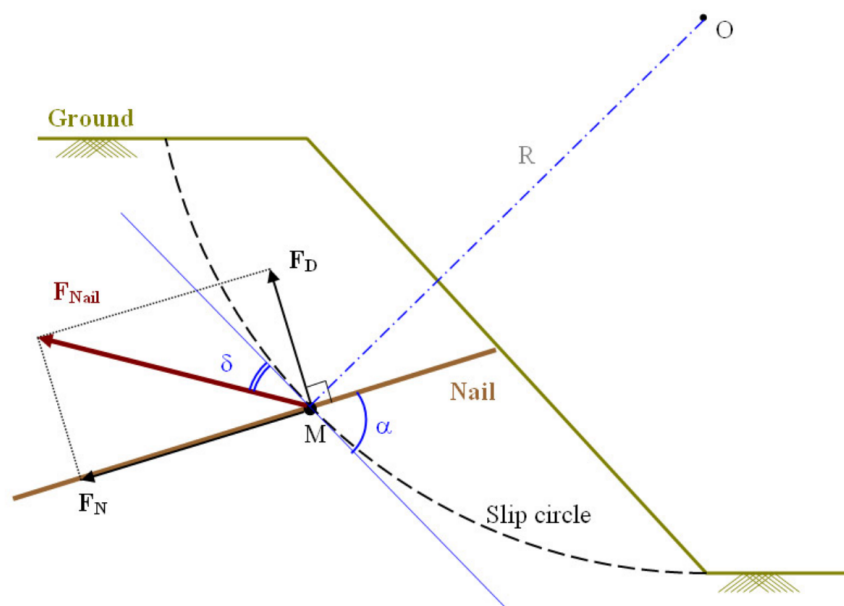


Figure 16.5: Resisting contribution by nails

The design method used for the calculation of both forces F_N and F_D is based on the Clouterre recommendations (Clo, July 1993) considering four failure criteria:

- ◇ section 16.2.2.3.1 the tensile resistance at the soil-nail interface is reached;
- ◇ section 16.2.2.3.2 the soil fails in bearing below the nail;
- ◇ section 16.2.2.3.3 the tensile and shear resistance of the nail is reached;
- ◇ section 16.2.2.3.4 the (stiff) nail breaks in bending.

The vector F_{nail} (F_N , F_D) must be located within the stability domain satisfying the four criteria mentioned above. The program determines the vector giving the maximum F_N and the minimum F_D . This is illustrated in Figure 16.6 where criteria 1 and 3 are relevant.

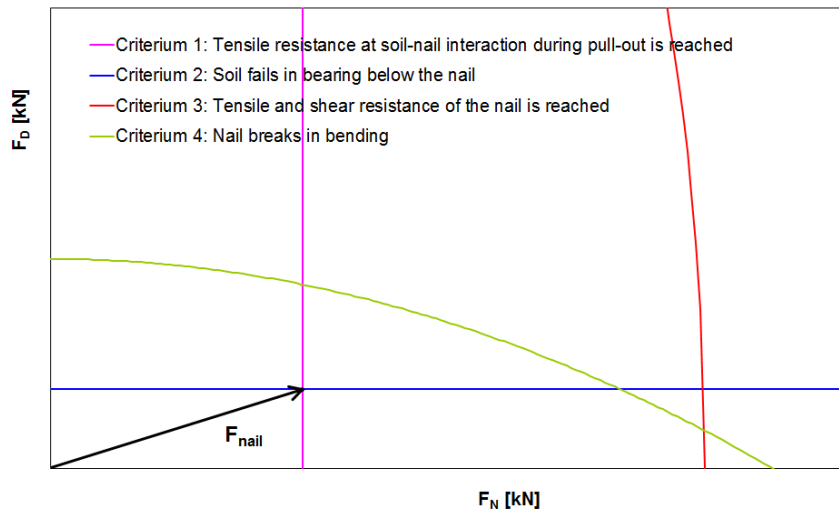


Figure 16.6: Representation of the four criteria in the $F_N - F_D$ diagram to determine F_{nail}

Influence of the critical angle

Depending on the value of α (angle between the nail and the tangent line along the circle where the nail intersects the slip circle) compared to the value of the critical angle $\alpha_{critical}$ (inputted in the *Nails* window, see Figure 4.72), F_N or F_D can be neglected:

- ◇ If $\alpha < \alpha_{critical}$, the shear force is neglected:

$$\begin{aligned} F_N &= \min(F_{N;1}; F_y) \\ F_D &= 0 \end{aligned} \quad (16.18)$$

- ◇ If $\alpha \geq 90^\circ - \alpha_{critical}$, the lateral force is neglected:

$$\begin{aligned} F_N &= 0 \\ F_D &= \min\left(F_{D;2}; \frac{F_y}{2}; F_{D;4}\right) \end{aligned} \quad (16.19)$$

where:

- $F_{N;1}$ is the limit resistance to pull-out between ground and bond, given by Equation 16.22;
- $F_{D;2}$ is the limit shear force when soil fails in bearing below the nail, given by Equation 16.25;
- $F_{D;4}$ is the limit shear force when nail breaks in bending, given by Equation 16.30;
- F_y is the yield force in tension, as inputted in the *Nail Type* tab of the *Nails* window (Figure 4.70);

The total force in the nail is:

$$F_{nail} = \sqrt{F_D^2 + F_N^2} \quad (16.20)$$

The extra resisting moment $M_{R;nail}$ due to the nail is:

$$M_{R;nail} = M_D + M_N \quad (16.21)$$

with:

$$M_D = F_{\text{nail}} \times \cos \delta \times R$$

$$M_N = F_{\text{nail}} \times \sin \delta \times \tan \varphi \times R$$

where:

- M_D is the moment due to the projection of F_{nail} on the tangent line along the circle, in kNm;
- M_N is the moment due to soil friction, in kNm;
- r is the radius of the slip circle, in m;
- δ is the angle between the nail force F_{nail} and the tangent line along the circle where the nail intersects the slip circle, in degree:
- $$\delta = \alpha - \arctan \left(\frac{F_D}{F_N} \right)$$
- α is the angle between the nail and the tangent line along the circle where the nail intersects the slip circle, in degree.

16.2.2.3.1 Tensile resistance at soil-nail interaction during pull-out

Reaching the pull-out capacity of soil nails can be assessed by the following criteria:

$$F_N \leq F_{N;1} = \tau_{\text{max}} \times \pi \times D \times L_a \quad (16.22)$$

where:

- τ_{max} is the ultimate frictional resistance to pull-out between ground and bonded length, in kN/m².
If *Input of ultimate shear stress along nail* is selected in the *Soil Resistance* window (Figure 4.2), then τ_{max} is determined using the table inputted in the *Shear Stress* tab of the *Nails* window (Figure 4.72) using distance L_{shear} .
If *Input of bond stress diagram (sigma, tau)* is selected in the *Soil Resistance* window (Figure 4.2), then τ_{max} is determined using the table inputted in the *Bond Stress Diagrams* window (Figure 4.17).
- D is the borehole diameter, in m;
- L_a is the adherence length beyond the failure surface, in m.
- L_{shear} is the distance from nail head used in the shear stress curve ($L - \tau_{\text{max}}$ curve), in m:
- $$L_{\text{shear}} = \begin{cases} L_2 + 0.5 L_1 & \text{if facing or bearing plate is used} \\ L_2 + 0.5 L_1 & \text{if no facing or bearing plate is used and if } L_1 < L_2 \\ 0.5 L_2 & \text{if no facing or bearing plate is used and if } L_1 \geq L_2 \end{cases}$$
- L_1 is the length from failure surface to end nail, in m;
- L_2 is the length from failure surface to head nail, in m: $L_2 = L - L_1$.

16.2.2.3.2 Soil/nail normal reaction: soil fails in bearing below the nail

The nail is consider as a beam on elastic supports (i.e. soil):

$$EI \frac{d^4 y}{dz^4} + E_s \times y = 0 \quad (16.23)$$

where:

- EI is the stiffness of the nail, in kNm²;

E_s is the Young's modulus of the soil determined from the following empirical formula, in kN/m^2 :

$$E_s = \frac{\alpha \times \sigma'_v}{CR \times \left[\left(\frac{2}{9} \right) 2.65^\alpha + \frac{1}{6} \alpha \right]}$$

α is the rheological coefficient of the soil, in m;

CR is the compression ratio of the soil:

$$CR = \frac{C_c}{1 + e_0}$$

σ'_v is the effective stress of the soil at the intersection point between the nail and the slip circle, in kN/m^2 .

The soil plastification occurs at:

$$y = \frac{p_u \times D}{E_s} \quad (16.24)$$

The limit shear force is therefore:

$$F_{D;2} = \frac{1}{2} \times p_u \times D \times L_0 \quad (16.25)$$

where:

p_u is the ultimate lateral stress. In D-GEO STABILITY, it can either be:
 – user-defined if *Input of ultimate lateral stress along nail* is selected in the *Soil Resistance* window (Figure 4.2). In this case, p_u is determined using the table inputted in the *Lateral Stress* tab of the *Nails* window (Figure 4.71) using distance L_2 .
 – automatically calculated by the program if *Use soil parameters c, phi / su* is selected in the *Soil Resistance* window (Figure 4.2). In this case, the program uses the following empirical formulas, depending on the shear strength model, in kN/m^2 :

$$p_u = \begin{cases} 3 \sigma'_v \times K_p & \text{with } K_p = \frac{1 + \sin \varphi}{1 - \sin \varphi} \text{ for } c, \varphi \text{ models} \\ 9 s_u & \text{for } s_u \text{ models} \end{cases}$$

D is the borehole diameter, in m;

L_0 is the reference length, in m, defined as:

$$L_0 = \left(\frac{4EI}{E_s} \right)^{1/4}$$

L_2 is the length from failure surface to head nail, in m.

16.2.2.3.3 Tensile and shear resistance of the nail

The maximum shear stress criterion, also known as Tresca's criterion, predicts that failure of a ductile material (e.g. nail in this case) occurs when the maximum shear stress (τ_{\max}) at a given point in the nail reaches the yield shear stress (τ_y) obtained from a uni-axial tensile test:

$$\tau_{\max} = \tau_y \quad (16.26)$$

With respect to 2D stress, the maximum shear stress (τ_{\max}) is related to the difference in the two principal stresses σ_1 and σ_3 by the following equation:

$$\tau_{\max} = \frac{1}{2} (\sigma_1 - \sigma_3) \quad (16.27)$$

For a tensile test, $\sigma_1 = \sigma$ and $\sigma_3 = 0$, so that:

$$\tau_{\max} = \frac{1}{2} \sigma \quad (16.28)$$

Similarly, the yield strength in shear (τ_y) is related to the yield strength in tension (σ_y) by:

$$\tau_y = \frac{1}{2}\sigma_y \quad (16.29)$$

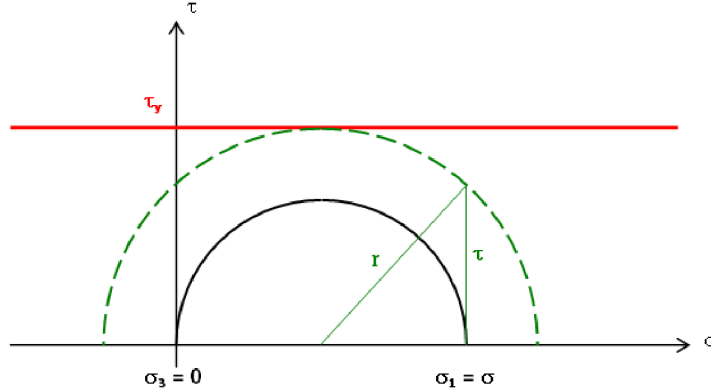


Figure 16.7: Representation of the Tresca's criterion by Mohr's circle

To represent this yield criterion graphically, Mohr's circles are used (Figure 16.7). It indicates that the yielding occurs if the radius of the Mohr's circle reaches τ_y , which writes:

$$r^2 = \tau^2 + \left(\frac{1}{2}\sigma\right)^2 \leq \tau_y^2 = \left(\frac{1}{2}\sigma_y\right)^2 \quad (16.30)$$

After integration of this equation over the cross-section S of the nail, the maximum shear stress criterion finally becomes:

$$4F_D^2 + F_N^2 \leq F_y^2 \quad (16.31)$$

where $F_y = S \times \sigma_y$ is the yield force in tension, as inputted in the *Nail Type* tab of the *Nails* window (Figure 4.70).

16.2.2.3.4 Soil/nail normal reaction: nail breaks in bending

The plastification of the nail occurs for a limit shear force of:

$$F_{D;4} = 1.62 \frac{M_{\max}}{L_0} \left(1 - \left[\frac{F_N}{F_y} \right]^2 \right) + 0.24 \times p_u \times D \times L_0 \quad (16.32)$$

where:

- D is the borehole diameter, in m;
- F_y is the yield force in tension, as inputted in the *Nail Type* tab of the *Nails* window (Figure 4.70);
- p_u is the ultimate lateral stress, see Equation 16.25;
- L_0 is the reference length, in m, defined as:

$$L_0 = \left(\frac{4EI}{E_s} \right)^{1/4}$$

16.2.2.4 Resisting moment from end section

The resisting moment is increased by $M_{R;\text{end section}}$, the resistance at the edges of a sliding section in the out-of-plane direction, due to the undrained shear strength:

$$M_{R;\text{end section}} = \frac{1}{F_s} \frac{1}{L/2} \sum_{i=1}^n \left(b_i \times \sum_{j=1}^{k_i} M_{j;su} \right) \quad (16.33)$$

with:

$$M_{j;su} = h_j s_{u;j;\text{min}} (Z_c - Z_{j;\text{avg}}) + \frac{h_j}{2} |s_{u;j;\text{bot}} - s_{u;j;\text{top}}| (Z_c - Z_{j;\text{cg}})$$


$$s_{u;j;\text{min}} = \min (s_{u;j;\text{bot}}; s_{u;j;\text{top}})$$

$$Z_{j;\text{avg}} = \frac{Z_{j;\text{bot}} + Z_{j;\text{top}}}{2}$$

$$Z_{j;\text{cg}} = Z_{j;\text{bot}} - \begin{cases} h_j/3 & \text{if } s_{u;j;\text{top}} < s_{u;j;\text{bot}} \\ 2h_j/3 & \text{if } s_{u;j;\text{top}} > s_{u;j;\text{bot}} \end{cases}$$

where:

- F_s is the safety factor, see [Equation 16.34](#) in [section 16.2.3](#);
 - h_j is the thickness of layer j in slice i ;
 - k_i is the number of layers along slice i ;
 - L is the expected length of the sliding surface in the out-of-plane direction (i.e. cross section perpendicular to the cross section plane), as defined in the *Calculation Options* window in [section 5.1](#);
 - n is the number of slices;
 - $s_{u;j;\text{bot}}$ is the undrained shear strength at the bottom of layer j in slice i ;
 - $s_{u;j;\text{top}}$ is the undrained shear strength at the top of layer j in slice i ;
 - $Z_{j;\text{bot}}$ is the level at the bottom of layer j in slice i ;
 - $Z_{j;\text{top}}$ is the level at the top of layer j in slice i .
- Refer to [section 1.8](#) for the definition of the other symbols.

Note: This extra resisting moment is calculated only if the option *Use friction of end section* in the *Calculation Options* window ([section 5.1](#)) is enabled and only for the *Bishop* model in combination with an undrained shear strength model. 

16.2.3 Safety factor

The safety factor F_s for stability of slip circles is expressed by:

$$F_s = \frac{M_{R;\text{soil}} + M_{R;\text{geotextile}} + M_{R;\text{nail}} + i |M_{R;\text{end section}}|}{M_{D;\text{soil}} + M_{D;\text{water}} + M_{D;\text{water;quake}} + M_{D;\text{load}} + M_{D;\text{soil;quake}}} \quad (16.34)$$

with:

$$M_{D;\text{soil;quake}} = M_{D;\text{soil;quake;V}} + j |M_{D;\text{soil;quake;H}}|$$

where:

- $M_{R;\text{soil}}$ is the resisting soil moment, in kNm/m, see [Equation 16.8](#);
- $M_{R;\text{geotextile}}$ is the resisting moment from geotextiles, in kNm/m, see [Equation 16.17](#);
- $M_{R;\text{nail}}$ is the resisting moment from nails, in kNm/m, see [Equation 16.21](#);

$M_{R;\text{end section}}$	is the resisting moment due to the additional friction caused by a limited end section of the slip plane, in kNm/m, see Equation 16.33 (only for Bishop model in combination with s_u shear strength models);
$M_{D;\text{soil}}$	is the driving soil moment, in kNm/m, see Equation 16.1 ;
$M_{D;\text{water}}$	is the driving water moment, in kNm/m, see Equation 16.3 ;
$M_{D;\text{water};\text{quake}}$	is the additional driving water moment due to the temporary draw down of the water during the earthquake, in kNm/m, see Equation 17.7 ;
$M_{D;\text{load}}$	is the driving load moment, in kNm/m, see Equation 16.7 .
$M_{D;\text{soil};\text{quake};\text{V}}$	is the additional driving soil moment due to vertical acceleration of the earthquake, in kNm/m, see Equation 17.4 ;
$M_{D;\text{soil};\text{quake};\text{H}}$	is the additional driving soil moment due to horizontal acceleration of the earthquake, in kNm/m, see Equation 17.3 ;
i	is the sign of $M_{R;\text{end section}}$: – If $M_R < 0$, $i = -1$; – If $M_R > 0$, $i = 1$
j	is the sign of $M_{D;\text{soil};\text{quake};\text{H}}$: – If $M_D < 0$, $j = -1$; – If $M_D > 0$, $j = 1$
M_D	is the total driving moment without the contribution of $M_{D;\text{soil};\text{quake};\text{H}}$: $M_D = M_{D;\text{soil}} + M_{D;\text{water}} + M_{D;\text{water};\text{quake}} + M_{D;\text{load}} + M_{D;\text{soil};\text{quake};\text{V}}$
M_R	is the total resisting moment without the contribution of $M_{R;\text{end section}}$: $M_R = M_{R;\text{soil}} + M_{R;\text{geotextile}} + M_{R;\text{nail}}$



Note: The unit kNm/m indicates the moment per 1 meter of the cross section perpendicular to the cross section plane.

For Bishop, substitution of [Equation 16.11](#) in the expression for the safety factor [Equation 16.34](#) yields to [Equation 16.35](#), an expression in which the safety factor occurs at both sides. D-GEO STABILITY therefore determines the safety value for Bishop in iterative fashion, starting with a first estimate of the safety factor of 1.0. The result of the calculation (on the left) is used as a next estimate and this process continues until $|F_N - F_{N-1}| = 0.001$ or a maximum number of iterations has been made in which case no result is obtained.

$$F_s = \frac{R \sum_{i=1}^n \left(\frac{b_i}{\cos \alpha_i} \frac{c_i + \sigma'_{v;i} \tan \varphi_i}{1 + \tan \alpha_i \frac{\tan \varphi_i}{F_s}} \right) + M_{R;\text{geotextile}} + M_{R;\text{nail}} + i |M_{R;\text{end section}}|}{M_{D;\text{soil}} + M_{D;\text{water}} + M_{D;\text{water};\text{quake}} + M_{D;\text{load}} + M_{D;\text{soil};\text{quake}}} \quad (16.35)$$

16.2.4 Limited inclination of the slip plane

In the formula for the calculation of the shear stresses (τ), a problem arises for large negative values of the angle α . For these negative values, a large value for τ will be calculated, but this is unrealistic. To prevent this from happening, the value for α is restricted to $\varphi/2 - 45^\circ$. This means that α never obtains a value less than $\varphi/2 - 45^\circ$. To illustrate this, see the following table where the τ and restricted τ' are given for various values of α and restricted α' .

In [Figure 16.8](#), the value of the other parameters in the formula for τ is as follows:

$$c = 0 \text{ kN/m}^2$$

$$\varphi = 20^\circ$$

$$\sigma'_v = 10 \text{ kN/m}^2$$

$$F_s = 1$$

The minimum value for α becomes: $\varphi/2 - 45^\circ = -35^\circ$. The relation plus the assumption is displayed in Figure 16.8.

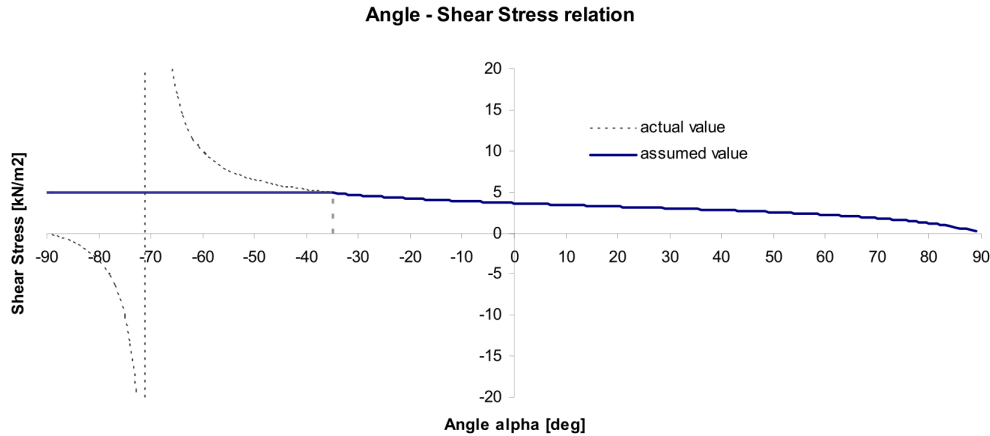


Figure 16.8: Relation angle α - Shear Stress for $\alpha_{\min} = 35^\circ$

16.2.5 Search algorithm for critical circle

D-GEO STABILITY applies a search algorithm that automatically moves the grid and tangent lines towards the direction of the minimal safety factor. During this procedure, the size of the grid is not changed. This procedure can only be used when there are three or more center points in both the X and Z directions.

If a minimum safety factor is found that is enclosed within the grid, this is not a definite guarantee that it is the absolute minimum safety factor for the problem at hand. In a large grid of center points, it is possible to have several local minimums in the grid. Therefore, when using a smaller grid it is possible to find one of the minimums. With some experience however it is possible to make a good first estimate of the position of the center point of the critical slip circle and choose a reasonable grid around that estimate.

Care needs to be taken when the grid is moved several times automatically. In that case, the grid may 'move' in such a way that, ultimately, micro-stability is being calculated. Micro-stability is the safety factor of a very small slice out of the soil structure, typically only a few centimeters deep. If this is not desired, automatic movement of the grid should be stopped.

16.3 Uplift Van

High pore pressures at the horizontal interface of weak layers with an underlying sand layer will cause reduction or even complete loss of shear resistance at this plane. This can yield an uplift failure mechanism, which is schematically drawn in Figure 16.9.

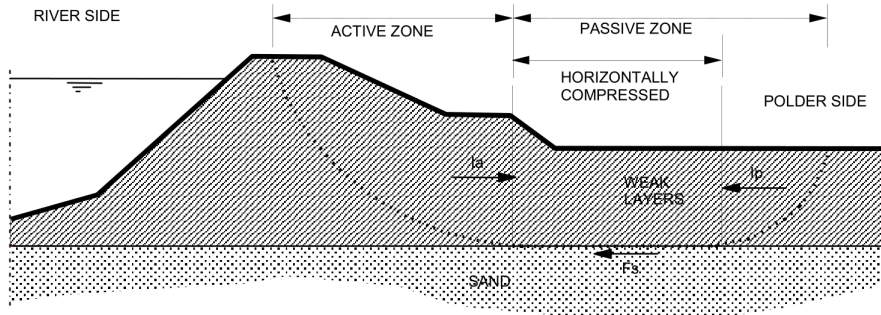


Figure 16.9: Uplift failure mechanism

The passive side of the slip plane is elongated in order to find equilibrium of horizontal forces.

Van's method therefore assumes that the total slip plane is composed of a horizontal part bounded by two circular parts. The safety factor is determined using equilibrium of the horizontal forces acting on the compressed area between the active and passive slip circles. The method becomes equal to Bishop's method if the length of the horizontal part reduces to zero.

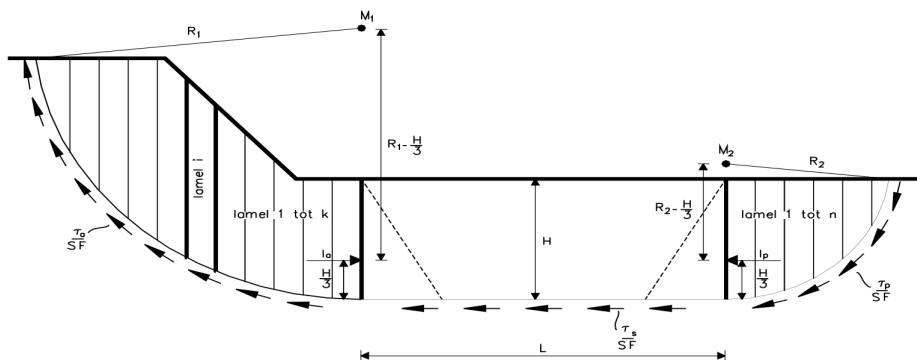


Figure 16.10: Van-Uplift Stability derivation

16.3.1 Driving moments of the circular parts

16.3.1.1 Driving soil moment

The driving soil moment is the moment caused by the mass of the soil within the slip circle around its centre:

$$M_{D,soil;left} = \sum_{i=1}^{n_{left}} G_i \times (1 + a_v) \times (X_{c;left} - X_{i;top}) \quad (16.36)$$

$$M_{D,soil;right} = \sum_{i=n_{right}}^n G_i \times (1 + a_v) \times (X_{c;right} - X_{i;top}) \quad (16.37)$$

with:

$$G_i = \sum_{j=1}^{k_i} \gamma_j \times h_j \times b_i$$

where:

a_v is the vertical earthquake factor (i.e. acceleration coefficient) as defined in the *Earthquake* window in [section 4.7.3](#).

G_i is the weight of the soil in slice i , in kN/m;

h_j is the thickness of layer j in slice i ;

k_i is the number of layers along slice i ;

γ_j is the unit weight of soil layer j in slice i , in kN/m³;

Refer to [section 1.8](#) for the definition of the other symbols.

The unit kNm/m indicates the moment per 1 meter of the cross section perpendicular to the cross section plane.

16.3.1.2 Driving water moments

The water moment is the contribution of three water moments:

$$M_{D;\text{water};\text{left}} = M_{\text{WaterTop};\text{left}} + M_{\text{WaterSide};\text{left}} + M_{\text{WaterBar};\text{left}} \quad (16.38)$$

$$M_{D;\text{water};\text{right}} = M_{\text{WaterTop};\text{right}} + M_{\text{WaterSide};\text{right}} + M_{\text{WaterBar};\text{right}} \quad (16.39)$$

where:

$M_{\text{WaterTop};\text{left}}$ is caused by the water forces (due to free water on surface) acting on the top of the slice at left side, see [Equation 16.40](#);

$M_{\text{WaterTop};\text{right}}$ is caused by the water forces (due to free water on surface) acting on the top of the slice at right side, see [Equation 16.41](#);

$M_{\text{WaterSide};\text{left}}$ is caused by the water forces (due to free water on surface) acting on the side of the slice at left side, see [Equation 16.42](#) and [Equation 16.44](#);

$M_{\text{WaterSide};\text{right}}$ is caused by the water forces (due to free water on surface) acting on the side of the slice at right side, see [Equation 16.43](#) and [Equation 16.45](#);

$M_{\text{WaterBar};\text{left}}$ is caused by the pore pressures acting on the left bar, see [Equation 16.46](#);

$M_{\text{WaterBar};\text{right}}$ is caused by the pore pressures acting on the right bar, see [Equation 16.47](#).

Water forces (due to free water forces on surface) acting on the top of the slice

The water moment is the moment caused by the water forces acting on and within the soil slice. When there is free water on the surface of the geometry and within the boundaries of the slip circle, it can have a positive or negative effect on the safety factor. The driving water moment due to free water forces acting on slices is calculated as follows:

$$M_{\text{WaterTop};\text{left}} = \sum_{i=1}^{n_{\text{left}}} (X_i - X_{c;\text{left}}) \times W_{v;i} + (Z_{c;\text{left}} - Z_{i;\text{top}}) \times W_{h;i} \quad (16.40)$$

$$M_{\text{WaterTop};\text{right}} = \sum_{i=n_{\text{right}}}^n (X_i - X_{c;\text{right}}) \times W_{v;i} + (Z_{c;\text{right}} - Z_{i;\text{top}}) \times W_{h;i} \quad (16.41)$$

where:

- $W_{v;i}$ is the vertical component of the water force on top of slice i , in kN/m:
 $W_{v;i} = -\max [0; (Z_{\text{phreatic}} - Z_{\text{top};i})] \times \gamma_w \times b_i$
- $W_{h;i}$ is the horizontal component of the water force on top of slice i , in kN/m:
 $W_{h;i} = \max [0; (Z_{\text{phreatic}} - Z_{\text{top};i})] \times \gamma_w \times b_i \times \tan \beta_i$
- Refer to [section 1.8](#) for the definitions of the other symbols.

Horizontal water forces (due to free water forces) acting on the side of the slice

With the introduction of vertical layer boundaries, it became possible to have a surface with a vertical component. If this vertical component is part of the slip circle, D-GEO STABILITY will place a slice to the left and right of this vertical. The force and moment of the free water against the vertical component of the surface (now also the side of a slice) must be taken into account (see [Figure 16.3](#)).

- ◇ If the phreatic line is above the top surface, the shape of the horizontal water pressures against the side of the slice is trapezium (case 1 in [Figure 16.3](#)):

$$M_{\text{WaterSide;left}} = u_{h;\text{top}} \times H \times \left(Z_{c;\text{left}} - \left(Z_{\text{bottom}} + \frac{H}{2} \right) \right) + \frac{H}{2} (u_{h;\text{bottom}} - u_{h;\text{top}}) \times \left(Z_{c;\text{left}} - \left(Z_{\text{bottom}} + \frac{H}{3} \right) \right) \quad (16.42)$$

$$M_{\text{WaterSide;right}} = u_{h;\text{top}} \times H \times \left(Z_{c;\text{right}} - \left(Z_{\text{bottom}} + \frac{H}{2} \right) \right) + \frac{H}{2} (u_{h;\text{bottom}} - u_{h;\text{top}}) \times \left(Z_{c;\text{right}} - \left(Z_{\text{bottom}} + \frac{H}{3} \right) \right) \quad (16.43)$$

- ◇ If the phreatic line is between the top and the bottom surfaces, the shape of the horizontal water pressures against the side of the slice is triangular (case 2 in [Figure 16.3](#)):

$$M_{\text{WaterSide;left}} = \frac{1}{2} H \times u_{h;\text{bottom}} \times \left(Z_{c;\text{left}} - \left(Z_{\text{bottom}} + \frac{H}{3} \right) \right) \quad (16.44)$$

$$M_{\text{WaterSide;right}} = \frac{1}{2} H \times u_{h;\text{bottom}} \times \left(Z_{c;\text{right}} - \left(Z_{\text{bottom}} + \frac{H}{3} \right) \right) \quad (16.45)$$

where:

- H is the height of the saturated soil along the vertical part:
 $H = \min (Z_{\text{water}}; Z_{\text{top}}) - \min (Z_{\text{water}}; Z_{\text{tangent}})$
 If the soil within the slip plane height is dry, then $H = 0$.
- $u_{h;\text{top}}$ is the hydrostatic pressure at level Z_{top} :
 $u_{h;\text{top}} = (Z_{\text{water}} - \min (Z_{\text{water}}; Z_{\text{top}})) \times \gamma_w$
- $u_{h;\text{bottom}}$ is the hydrostatic pressure at level Z_{bottom} :
 $u_{h;\text{bot}} = (Z_{\text{water}} - Z_{\text{bottom}}) \times \gamma_w$
- Z_{top} is the top level of the vertical part.
- Z_{bottom} is the bottom level of the vertical part.

Horizontal pore pressures acting on both bars of the horizontal part (i.e. circle's end)

An Uplift-Van calculation consists of two circle parts and an horizontal part. Equilibrium for the circle parts must include pore pressure against such a part, as illustrated in [Figure 16.11](#).

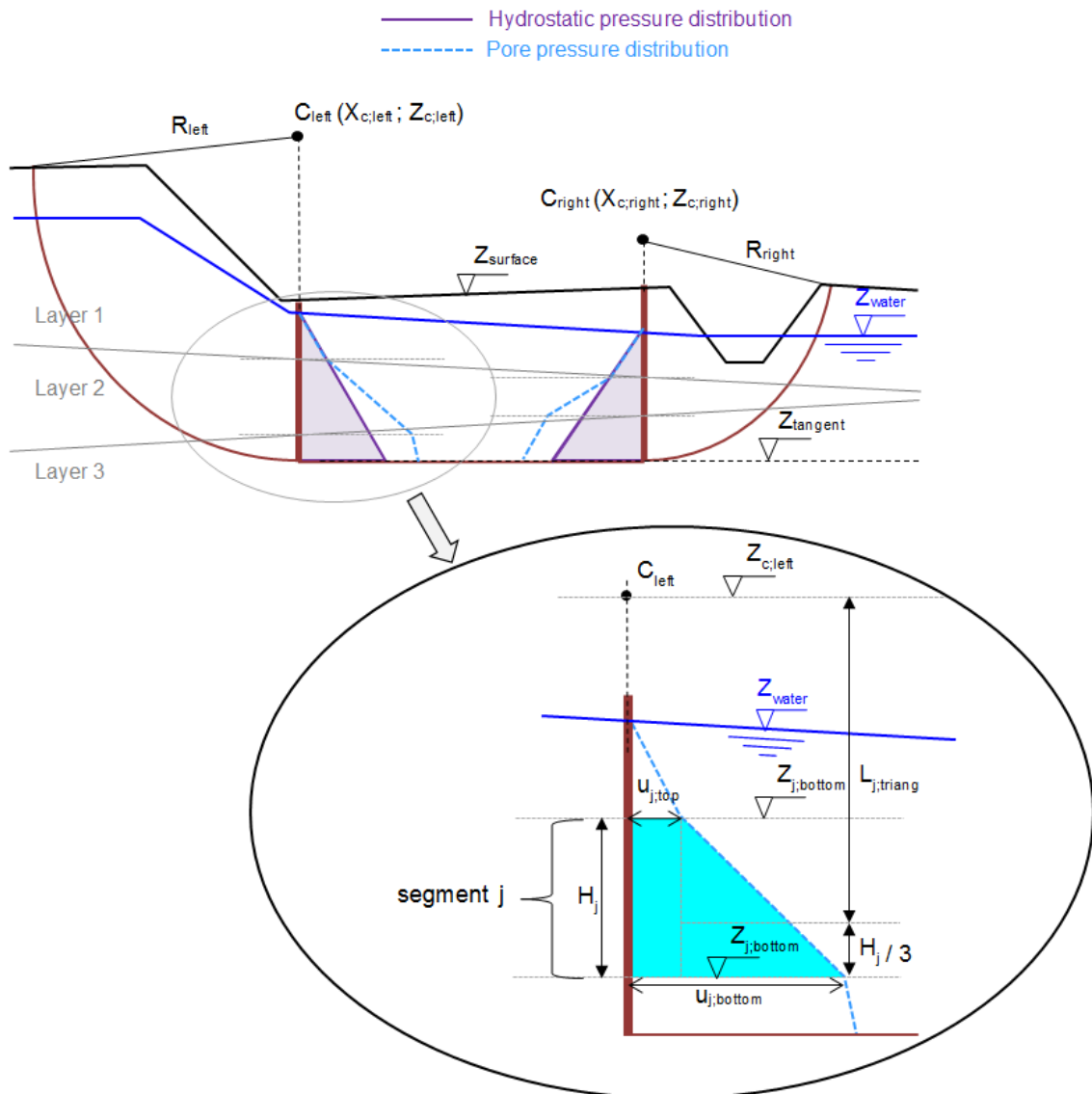


Figure 16.11: Schematization of the pore pressure distribution on bars

$$M_{\text{PoreBar:left}} = \sum_{j=1}^{n_{\text{segments:left}}} \min(u_{j;\text{top}}; u_{j;\text{bottom}}) \times H_j \times \left| Z_{c;\text{left}} - \frac{1}{2}H_j \right| \quad (16.46)$$

$$+ |u_{j;\text{top}}; u_{j;\text{bottom}}| \times \frac{1}{2}H_j \times L_{j;\text{triang}}$$

$$M_{\text{PoreBar:right}} = \sum_{j=1}^{n_{\text{segments:right}}} \min(u_{j;\text{top}}; u_{j;\text{bottom}}) \times H_j \times \left| Z_{c;\text{right}} - \frac{1}{2}H_j \right| \quad (16.47)$$

$$+ |u_{j;\text{top}}; u_{j;\text{bottom}}| \times \frac{1}{2}H_j \times L_{j;\text{triang}}$$

where:

$n_{\text{segments;left}}$ is the number of segments having a linear pore pressure distribution along the left bar;

$n_{\text{segments;right}}$ is the number of segments having a linear pore pressure distribution along the right bar;

H_j is the height of segment j along the considered bar;

$u_{j;\text{top}}$ is the pore pressure at level $Z_{j;\text{top}}$;

$u_{j;\text{bottom}}$ is the pore pressure at level $Z_{j;\text{bottom}}$;

$Z_{j;\text{top}}$ is the top level of segment j along the considered bar;

$Z_{j;\text{bottom}}$ is the bottom level of segment j along the considered bar;

$L_{j;\text{triang}}$ is the arm of the resulting force of the triangular part of the pore pressure distribution for segment j along the considered bar:

$$L_{j;\text{triang}} = \begin{cases} \left| Z_{c;\text{left}} - \left(Z_{j;\text{bottom}} + \frac{1}{3} H_j \right) \right| & \text{if } u_{j;\text{top}} < u_{j;\text{bottom}} & \text{for left bar} \\ \left| Z_{c;\text{left}} - \left(Z_{j;\text{top}} - \frac{1}{3} H_j \right) \right| & \text{if } u_{j;\text{top}} \geq u_{j;\text{bottom}} & \text{for left bar} \\ \left| Z_{c;\text{right}} - \left(Z_{j;\text{bottom}} + \frac{1}{3} H_j \right) \right| & \text{if } u_{j;\text{top}} < u_{j;\text{bottom}} & \text{for right bar} \\ \left| Z_{c;\text{right}} - \left(Z_{j;\text{top}} - \frac{1}{3} H_j \right) \right| & \text{if } u_{j;\text{top}} \geq u_{j;\text{bottom}} & \text{for right bar} \end{cases}$$

16.3.1.3 Driving load moments

The (part of the) uniform loads and the line loads located within the confines of a slip circle creates a moment around the slip-circle center point:

$$M_{D;\text{load;left}} = \sum_{j=1}^{n_{\text{loads}}} F_{j;\text{left}} \times \Delta w_{j;\text{left}} \times (X_{c;\text{left}} - X_{j;\text{left}}) + \sum_{l=1}^{n_{\text{lines}}} F_l \times (X_{c;\text{left}} - X_{l;\text{left}}) \quad (16.48)$$

$$M_{D;\text{load;right}} = \sum_{j=1}^{n_{\text{loads}}} F_{j;\text{right}} \times \Delta w_{j;\text{right}} \times (X_{c;\text{right}} - X_{j;\text{right}}) + \sum_{l=1}^{n_{\text{lines}}} F_l \times (X_{c;\text{right}} - X_{l;\text{right}}) \quad (16.49)$$

with:

$$X_{j;\text{left}} = - \frac{\max(X_{1;\text{left}}; X_{\text{begin};j}) + \min(X_{n_{\text{left};\text{right}}}; X_{\text{end};j})}{2}$$

$$X_{j;\text{right}} = - \frac{\max(X_{1;\text{left}}; X_{\text{begin};j}) + \min(X_{n_{\text{left};\text{right}}}; X_{\text{end};j})}{2}$$

$$X_{l;\text{left}} = X_{c;\text{left}} - \frac{\max(X_{n_{\text{right};\text{left}}}; X_l) + \min(X_{n_{\text{right}}}; X_l)}{2}$$

$$X_{l;\text{right}} = X_{c;\text{right}} - \frac{\max(X_{n_{\text{right};\text{left}}}; X_l) + \min(X_{n_{\text{right}}}; X_l)}{2}$$

$$\Delta w_{j;\text{left}} = \min(X_{c;\text{left}}; X_{j;\text{end}}) - \max(X_{1;\text{left}}; X_{j;\text{begin}})$$

$$\Delta w_{j;\text{right}} = \min(X_{n_{\text{right}}}; X_{j;\text{end}}) - \max(X_{c;\text{right}}; X_{j;\text{begin}})$$

where:

F_j is the magnitude of uniform-load number j , in kN/m^2 ;

F_l is the magnitude of line-load number l , in kN/m ;

n_{lines} is the total number of lines-loads;

n_{loads} is the total number of uniform-loads;

$X_{j;\text{begin}}$ is the X-coordinate of the starting point of load j ;

$X_{j;\text{end}}$ is the X-coordinate of the ending point of load j ;

X_l	is the X-coordinate of line-load l ;
$X_{1;\text{left}}$	is the X-coordinate of the left side of slice 1 (i.e. entry point of the left slip circle);
$X_{n;\text{right}}$	is the X-coordinate of the right side of slice n (i.e. exit point of the right slip circle);
$\Delta w_{j;\text{left}}$	is the width of the part of the uniform-load j located within the confines of a left slip circle;
$\Delta w_{j;\text{right}}$	is the width of the part of the uniform-load j located within the confines of a right slip circle;
$X_{j;\text{left}}$	is the X-coordinate at the middle of the part of the uniform-load j located within the confines of a left slip circle;
$X_{l;\text{left}}$	is the X-coordinate of the line-load l located within the confines of a left slip circle;
$X_{j;\text{right}}$	is the X-coordinate at the middle of the part of the uniform-load j located within the confines of a right slip circle;
$X_{l;\text{right}}$	is the X-coordinate of the line-load l located within the confines of a right slip circle.

Refer to [section 1.8](#) for the definitions of the other symbols.

16.3.1.4 Horizontal quake moments

Refer to [section 17.3](#).

16.3.1.5 Total driving moments

The total driving moment is the contribution of different components:

$$M_{D;\text{total};\text{left}} = M_{D;\text{soil};\text{left}} + M_{D;\text{water};\text{left}} + M_{D;\text{load};\text{left}} \quad (16.50)$$

$$M_{D;\text{total};\text{right}} = M_{D;\text{soil};\text{right}} + M_{D;\text{water};\text{right}} + M_{D;\text{load};\text{right}} \quad (16.51)$$

where:

$M_{D;\text{soil};\text{left}}$	is the driving soil moment at left side, in kNm/m, see Equation 16.36 ;
$M_{D;\text{soil};\text{right}}$	is the driving soil moment at right side, in kNm/m, see Equation 16.37 ;
$M_{D;\text{water};\text{left}}$	is the driving water moment at left side, in kNm/m, see Equation 16.38 ;
$M_{D;\text{water};\text{right}}$	is the driving water moment at right side, in kNm/m, see Equation 16.39 ;
$M_{D;\text{load};\text{left}}$	is the driving load moment at left side, in kNm/m, see Equation 16.48 ;
$M_{D;\text{load};\text{right}}$	is the driving load moment at right side, in kNm/m, see Equation 16.49 ;

16.3.1.6 Determination of active and passive sides

The left side is considered as active if:

$$M_{D;\text{total};\text{left}} > M_{D;\text{total};\text{right}}$$

where $M_{D;\text{total};\text{left}}$ is the total driving moment at left side ([Equation 16.50](#)) and $M_{D;\text{total};\text{right}}$ is the total driving moment at right side ([Equation 16.51](#)).

This leads therefore to:

$$M_{D;\text{total};\text{act}} = \max(M_{D;\text{total};\text{left}}; M_{D;\text{total};\text{right}}) \quad (16.52)$$

$$M_{D;\text{total};\text{pas}} = \min(M_{D;\text{total};\text{left}}; M_{D;\text{total};\text{right}}) \quad (16.53)$$

16.3.2 Resisting moments of the circular parts

16.3.2.1 Resisting moment from soil

Shear stresses and normal effective stresses act along the slip circle. The shear stresses prevent the circular soil mass from slipping. The resisting moment is defined as the moment caused by the shear stresses along the circular arc around the center of the slip circle:

$$M_{R;\text{soil};\text{left}} = R_{\text{left}} \times \sum_{i=1}^{n_{\text{left}}} \tau_i \times l_i \quad (16.54)$$

$$M_{R;\text{soil};\text{right}} = R_{\text{right}} \times \sum_{i=n_{\text{right}}}^n \tau_i \times l_i \quad (16.55)$$

with:

$$\tau_i = \frac{c_i + \sigma'_{v;i} \times \tan \varphi_i}{1 + \tan \alpha_i \times \frac{\tan \varphi_i}{F_s}} \quad (16.56)$$

where:

- τ_i is the shear stress along bottom of slice i , in kN/m^2 ;
- $\sigma'_{v;i}$ is the vertical effective stress at the bottom of slice i , in kN/m^2 , see [Equation 18.6](#);
- F_s is the safety factor, see [Equation 16.79](#).

Refer to [section 1.8](#) for the definitions of the other symbols.

16.3.2.2 Resisting moment from geotextiles

Geotextiles can be used to reinforce and improve the stability of slopes. The geotextile introduces a force that can act at the boundary of a slip circle. Refer to [section 16.2.2.2](#) for the calculation of the resisting moments $M_{R;\text{geotextile};\text{left}}$ or $M_{R;\text{geotextile};\text{right}}$ if the geotextile intersects respectively the left or right circle.

16.3.2.3 Resisting moment from nails

The extra resisting moments $M_{R;\text{nail};\text{left}}$ and $M_{R;\text{nail};\text{right}}$ respectively for the left and right circle are calculated in the same way as explained in [section 16.2.2.3](#), see [Equation 16.21](#).

16.3.3 Horizontal forces

16.3.3.1 Soil resistance force along horizontal part I_s

The horizontal resisting force acting along the horizontal part is:

$$I_s = j \times \sum_{i=n_{\text{left}}+1}^{n_{\text{right}}-1} \frac{(c_i + \sigma'_{v;i} \times \tan \varphi_i) \times l_i}{F_s} \quad (16.57)$$

with:

$$j = \begin{cases} -1 & \text{if the left side is active} \\ 1 & \text{if the left side is passive} \end{cases}$$

where:

- j is the sign of the force;
 - $\sigma'_{v;i}$ is the vertical effective stress at the bottom of slice i , in kN/m^2 , see [Equation 18.6](#);
- Refer to [section 1.8](#) for the definitions of the other symbols.

16.3.3.2 Resulting water force along horizontal part $F_{\text{water;horiz}}$

The resulting water force along the horizontal part is the contribution of the water force due to (free) water on surface and of the pore pressures applying on the bars:

$$F_{\text{water;horiz}} = F_{\text{w;surf;left}} - F_{\text{w;surf;right}} + F_{\text{u;left}} - F_{\text{u;right}} \quad (16.58)$$

with:

$$F_{\text{w;surf;left}} = \frac{1}{2} [\max(Z_{\text{phreatic;left}}, Z_{\text{surf;left}}) - Z_{\text{surf;left}}]^2 \times \gamma_w \quad (16.59)$$

$$F_{\text{w;surf;right}} = \frac{1}{2} [\max(Z_{\text{phreatic;right}}, Z_{\text{surf;right}}) - Z_{\text{surf;right}}]^2 \times \gamma_w \quad (16.60)$$

$$F_{\text{u;left}} = \sum_{j=1}^{n_{\text{segments;left}}} \min(u_{j;\text{top}}, u_{j;\text{bottom}}) \times H_j \times \left| Z_{\text{c;left}} - \frac{1}{2}H_j \right| \quad (16.61)$$

$$+ |u_{j;\text{top}}, u_{j;\text{bottom}}| \times \frac{1}{2}H_j \quad (16.62)$$

$$F_{\text{u;right}} = \sum_{j=1}^{n_{\text{segments;right}}} \min(u_{j;\text{top}}, u_{j;\text{bottom}}) \times H_j \times \left| Z_{\text{c;right}} - \frac{1}{2}H_j \right| \quad (16.63)$$

$$+ |u_{j;\text{top}}, u_{j;\text{bottom}}| \times \frac{1}{2}H_j \quad (16.64)$$

where:

$Z_{\text{surf;left}}$	is the surface level at vertical $X = X_{\text{c;left}}$
$Z_{\text{surf;right}}$	is the surface level at vertical $X = X_{\text{c;right}}$
$Z_{\text{phreatic;left}}$	is the phreatic level at vertical $X = X_{\text{c;left}}$
$Z_{\text{phreatic;right}}$	is the phreatic level at vertical $X = X_{\text{c;right}}$
$n_{\text{segments;left}}$	is the number of segments having a linear pore pressure distribution along the left bar;
$n_{\text{segments;right}}$	is the number of segments having a linear pore pressure distribution along the right bar;
H_j	is the height of segment j along the considered bar;
$u_{j;\text{top}}$	is the pore pressure at level $Z_{j;\text{top}}$;
$u_{j;\text{bottom}}$	is the pore pressure at level $Z_{j;\text{bottom}}$;
$Z_{j;\text{top}}$	is the top level of segment j along the considered bar;
$Z_{j;\text{bottom}}$	is the bottom level of segment j along the considered bar.

See also [Figure 16.11](#) for the definition of the symbols.

16.3.3.3 Horizontal nail force

The extra resisting force $F_{\text{R;nail;horiz}}$ in the horizontal part due to a nail is calculated in the same way as explained in [section 16.2.2.3](#), see [Equation 16.20](#).

16.3.3.4 Resulting horizontal force at active side I_a

Moment equilibrium around active circle center yields [Equation 16.65](#) for the resulting force I_a at active side.

$$I_a = \frac{|M_{D;act}| - \frac{|M_{R;soil;act}|}{F_s} - |M_{R;nail;act}| - |M_{R;geotextile;act}|}{R_{act} - \Delta H_{act}} \quad (16.65)$$

with:

$$M_{R;soil;act} = \begin{cases} M_{R;soil;left} & \text{if the left side is active} \\ M_{R;soil;right} & \text{if the right side is active} \end{cases} \quad (16.66)$$

$$M_{R;nail;act} = \begin{cases} M_{R;nail;left} & \text{if the left side is active} \\ M_{R;nail;right} & \text{if the right side is active} \end{cases} \quad (16.67)$$

$$M_{R;geotextile;act} = \begin{cases} M_{R;geotextile;left} & \text{if the left side is active} \\ M_{R;geotextile;right} & \text{if the right side is active} \end{cases} \quad (16.68)$$

$$(16.69)$$

where:

- $M_{D;act}$ is the total active driving moment, see [Equation 16.52](#);
- $M_{R;soil;left}$ is the soil resisting moment at left side, see [Equation 16.54](#);
- $M_{R;soil;right}$ is the soil resisting moment at right side, see [Equation 16.55](#);
- ΔH_{act} is the arm of the active force I_a compare to the tangent level;
- R_{act} is the radius of the active circle;
- F_s is the safety factor that has to be determined;

16.3.3.5 Resulting horizontal force at passive side I_p

Moment equilibrium around passive circle center yields [Equation 16.70](#) for the resulting force I_p at passive side.

$$I_p = \frac{|M_{D;pas}| - \frac{|M_{R;soil;pas}|}{F_s} - |M_{R;nail;act}| - |M_{R;geotextile;act}|}{R_{pas} - \Delta H_{pas}} \quad (16.70)$$

with:

$$M_{R;soil;pas} = \begin{cases} M_{R;soil;left} & \text{if the left side is passive} \\ M_{R;soil;right} & \text{if the right side is passive} \end{cases} \quad (16.71)$$

$$M_{R;nail;pas} = \begin{cases} M_{R;nail;left} & \text{if the left side is passive} \\ M_{R;nail;right} & \text{if the right side is passive} \end{cases} \quad (16.72)$$

$$M_{R;geotextile;pas} = \begin{cases} M_{R;geotextile;left} & \text{if the left side is passive} \\ M_{R;geotextile;right} & \text{if the right side is passive} \end{cases} \quad (16.73)$$

$$(16.74)$$

where:

- $M_{D;pas}$ is the total passive driving moment, see [Equation 16.53](#);
- $M_{R;soil;left}$ is the soil resisting moment at left side, see [Equation 16.54](#);
- $M_{R;soil;right}$ is the soil resisting moment at right side, see [Equation 16.55](#);
- ΔH_{act} is the arm of the active force I_a compare to the tangent level;

ΔH_{pas} is the arm of the passive force I_p compare to the tangent level;
 R_{pas} is the radius of the passive circle;
 R_{act} is the radius of the active circle;
 F_s is the safety factor that has to be determined;

16.3.4 Safety factor

Determination of arm of active force I_a

The resulting horizontal force at passive side of the compressed soil I_p is assumed to act above the interface with the sand, at 1/3 of the height of the weak soil layers. This assumption is relatively correct as no free water on surface is present at the polder side (i.e. $F_{w;\text{surf};\text{left}} = 0$).

$$\Delta H_{\text{pas}} = \frac{1}{3} H_{\text{pas}} \quad (16.75)$$

where H_{pas} is the height of the bar at passive side.

The resulting horizontal force at active side of the compressed soil I_a is assumed to act above the interface with the sand, at a distance ΔH_{act} of the weak soil layers. To determine the arm ΔH_{act} of force I_a , an intern iterative process is used by means of the moments equilibrium:

$$\Delta H_{\text{act}} = \Delta H_{\text{pas}} \times \frac{(I_p + M_{\text{water};\text{pas}} - M_{\text{water};\text{act}})}{I_a} \quad (16.76)$$

with:

$$M_{\text{water};\text{act}} = \begin{cases} M_{\text{water};\text{left}} & \text{if the active side is the left side} \\ M_{\text{water};\text{right}} & \text{if the active side is the right side} \end{cases}$$

$$M_{\text{water};\text{pas}} = \begin{cases} M_{\text{water};\text{left}} & \text{if the passive side is the left side} \\ M_{\text{water};\text{right}} & \text{if the passive side is the right side} \end{cases}$$

$$M_{\text{water};\text{left}} = F_{w;\text{surf};\text{left}} \times \Delta H_{w;\text{surf};\text{left}} + M_{\text{PoreBar};\text{left}} \Big|_{\text{tangent}}$$

$$M_{\text{water};\text{right}} = F_{w;\text{surf};\text{right}} \times \Delta H_{w;\text{surf};\text{right}} + M_{\text{PoreBar};\text{right}} \Big|_{\text{tangent}}$$

$$\Delta H_{w;\text{surf};\text{left}} = Z_{\text{surf};\text{left}} + \frac{1}{3} (Z_{\text{phreatic};\text{left}} - Z_{\text{surf};\text{left}}) - Z_{\text{tangent}}$$

$$\Delta H_{w;\text{surf};\text{right}} = Z_{\text{surf};\text{right}} + \frac{1}{3} (Z_{\text{phreatic};\text{right}} - Z_{\text{surf};\text{right}}) - Z_{\text{tangent}}$$

where:

$F_{w;\text{surf};\text{left}}$ is the horizontal water force on left bar due to (free) water on surface, see [Equation 16.59](#);

$F_{w;\text{surf};\text{right}}$ is the horizontal water force on left bar due to (free) water on surface, see [Equation 16.60](#);

$Z_{\text{surf};\text{left}}$ is the surface level at vertical $X = X_{c;\text{left}}$;

$Z_{\text{surf};\text{right}}$ is the surface level at vertical $X = X_{c;\text{right}}$;

$Z_{\text{phreatic};\text{left}}$ is the phreatic level at vertical $X = X_{c;\text{left}}$;

$Z_{\text{phreatic};\text{right}}$ is the phreatic level at vertical $X = X_{c;\text{right}}$;

Z_{tangent} is the bottom level of the horizontal part;

$M_{\text{PoreBar};\text{left}} \Big|_{\text{tangent}}$ is the moment around the tangent line due to pore pressures along the left bar. It is similar to $M_{\text{PoreBar};\text{left}}$ in [Equation 16.46](#) except that the rotational point $Z_{c;\text{left}}$ is replaced with Z_{tangent} ;

$M_{\text{PoreBar};\text{right}} \Big|_{\text{tangent}}$ is the moment around the tangent line due to pore pressures along the right bar. It is similar to $M_{\text{PoreBar};\text{right}}$ in [Equation 16.47](#) except that the rotational point $Z_{c;\text{left}}$ is replaced with Z_{tangent} .

The substitution of Equation 16.65 and Equation 16.75 in Equation 16.76 yields to Equation 16.77, an expression in which distance ΔH_{act} occurs at both sides. D-GEO STABILITY therefore determines this distance in iterative fashion, starting with a first estimate of the distance of $\Delta H_{act} = \Delta H_{pas} = \frac{1}{3}H_{pas}$. The result of the calculation (on the left) is used as a next estimate and this process continues until $|\Delta H_{act;N} - \Delta H_{act;N-1}| < 0.001$ or a maximum number of iterations has been made in which case no result is obtained.

$$\Delta H_{act} = \frac{1}{3}H_{pas} \times \frac{I_p + M_{water;pas} - M_{water;act}}{|M_{D;act}| - \frac{|M_{R;soil;act}|}{F_s} - |M_{R;nail;act}| - |M_{R;geotextile;act}|} \quad (16.77)$$

$$R_{act} - \Delta H_{act}$$

Equilibrium of horizontal forces

The equation for equilibrium of horizontal forces yields:

$$I_a + I_p + I_s + F_{water;horiz} + F_{nail;horiz} = 0 \quad (16.78)$$

Substitution of Equation 16.65 and Equation 16.70 into the equation for equilibrium of horizontal forces Equation 16.78 finally yields Equation 16.79 for the safety factor. D-GEO STABILITY solves this equation in iterative fashion:

$$F_s = \frac{F_R}{F_D} = \frac{\frac{|M_{R;soil;pas}|}{R_{pas} - \Delta H_{pas}} + \frac{|M_{R;soil;act}|}{R_{act} - \Delta H_{act}} - I_s \times F_s + nail + geotextile}{\frac{|M_{D;pas}|}{R_{pas} - \Delta H_{pas}} + \frac{|M_{D;act}|}{R_{act} - \Delta H_{act}} + F_{water;horiz}} \quad (16.79)$$

where F_R and F_D are respectively the resisting and driving forces.

The substitution of Equation 16.66 and Equation 16.66 in Equation 16.79 yields to an expression in which distance F_s occurs at both sides. D-GEO STABILITY therefore determines the safety factor in iterative fashion, starting with a first estimate of $F_0 = 1$. The result of the calculation (on the left) is used as a next estimate and this process continues until $|F_{s;N} - F_{s;N-1}| < 0.001$ or a maximum number of iterations has been made in which case no result is obtained.

16.4 Spencer

The Spencer method (Spencer, 1993) uses the cohesion and constant friction angle as parameters. These values are obtained in the same way as in the Bishop method, with the difference that only the initial c and φ are used from a stress table. This calculation method is applied in D-GEO STABILITY as described below.

By definition, the safety factor is found when the slide plane is in limit state of equilibrium. To fulfill this requirement, each slice must have equilibrium of moments, horizontal and vertical forces. The Spencer method satisfies this condition of equilibrium with respect to moments and forces.

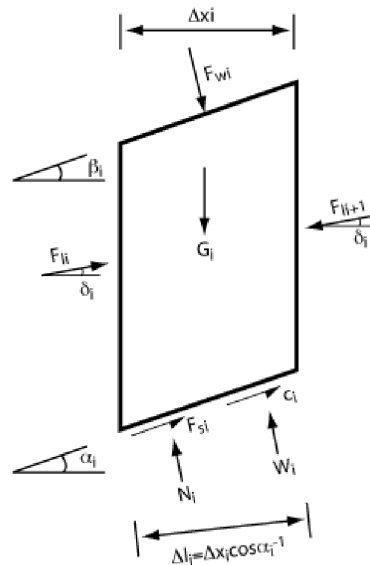


Figure 16.12: Interslice forces according to Spencer method

where:

α_i	Slide plane angle [°]
β_i	Slope angle [°]
δ_i	Interslice force angle [°]
φ_i	Internal friction angle along slip surface [°]
h_i	Slice height [m]
x_i	Slice width [m]
c_i	Cohesion along slip surface [kN/m ²]
F_s	Safety factor [-]
G_i	Weight [kN]
F_{li}	Interslice force [kN]
N_i	Effective normal force at bottom [kN]
F_{si}	Shear force along the bottom [kN]
F_{wi}	Water force on slope [kN]
L_i	Length of sliding plane [m]
W_i	Water pressure against bottom [kN]
x_i	Distance interslice force – sliding plane [m]

Calculation of the interslice force F_{li} at intersection i :

$$F_{l,i+1} \left(\cos(\alpha_i - \delta_{i+1}) + \frac{\tan \varphi_i}{F_s} \sin(\alpha_i - \delta_{i+1}) \right) - F_{l,i} \left(\cos(\alpha_i - \delta_i) + \frac{\tan \varphi_i}{F_s} \sin(\alpha_i - \delta_i) \right) - F_{w,i} \sin(\alpha_i - \beta_i) + G_i \sin(\alpha_i) - \frac{c_i L_i}{F_s} - \frac{F_{w,i} \sin(\alpha_i - \beta_i) + G_i \sin(\alpha_i) - W_i L_i}{F_s} = 0 \quad (16.80)$$

The interslice force is considered as a resultant of three forces acting on a slice side:

- ◇ shear force along this side
- ◇ effective normal force
- ◇ water force

The angle of interslice forces of the first and last (fictitious) interslice force is set to zero implying horizontal forces. The angles of the other forces are set to δ . The fictitious interslice force acting on the first slice is zero. Now the (fictitious) force needed to ensure equilibrium at the end of the slide plane can be calculated.

By considering the equilibrium of moments round the center bottom point of the slice, the position of the resultant of interslice force is found in the following way:

$$\frac{F_{l,i-1} \cos \delta_{i-1} (X_{i-1} + 0.5 \Delta x_i \tan \alpha_i) - 0.5 F_{l,i-1} \sin \delta_{i-1} \Delta x_i}{F_{l,i} \cos \delta_i} - \frac{0.5 \Delta x_i F_{l,i} \sin \delta_i - F_{w,i} \sin \beta_i}{F_{l,i} \cos \delta_i} + 0.5 \Delta x_i \tan \alpha_i \quad (16.81)$$

The distance between the first fictitious interslice force and the sliding plane is zero. Now, calculating from the first to the last but one slice, the distance can be calculated between the last but one interslice force and the sliding plane. To keep the equilibrium of moments a fictitious rest moment (M_{rest}) is required for the last slice. M_{rest} can be calculated in the following way:

$$M_{rest} = F_{l,n} \cos \delta_n (X_n + 0.5 \Delta x_{n+1} \tan \alpha_{n+1}) - 0.5 F_{l,n} \sin \delta_n \Delta x_{i+1} - F_{w,n+1} \sin \beta_{n+1} \quad (16.82)$$

For calculation of the rest moment, a working line for the rest force (F_{rest}) is defined by the horizontal line through point M. The solution procedure of the Spencer method consists of the search for F and δ in such a way that both $F_{rest} = 0$ and $M_{rest} = 0$. The search for the correct values for F and δ is carried out by means of an iterative model, using the following steps:

- ◇ Choose starting values for F and δ .
- ◇ Iterate formula 1 until $F_{rest} = 0$. F is adapted while δ is kept constant.
- ◇ Iterate formula 2 and 3 with the final values of the interslice forces from step 2 until $M_{rest} = 0$. F is kept constant while δ is adapted.
- ◇ With the values of F and δ that were gained by step 2 and 3, repeat the process from step 2 until $F_{rest} = 0$ and $M_{rest} = 0$.

Iteration of [Equation 16.80](#) (step 2) is ended when the absolute value of rest force is less than ϵ . Iteration of [Equation 16.81](#) and [Equation 16.82](#) (step 3) is ended when the absolute value of the rest moment is less than ϵ . The complete iteration process is ended when the absolute values of both the rest force and the rest moment are less than 10° . As a starting value, a

safety factor of 1.1 is assumed. The program calculates a starting value for δ in the following way:

$$\delta_{start} = \frac{\delta_{min} + \delta_{max}}{2} \quad (16.83)$$

In the calculation of the interslice forces from [Equation 16.80](#), a division is made by factor:

$$\cos(\alpha_i - \delta_i) + \frac{\tan \varphi + \sin(\alpha_i - \delta_i)}{F_s} \quad (16.84)$$

At a certain combination of δ and F , this can lead to a division by zero. This critical combination can be found by:

$$\cos(\alpha_i - \delta_i) + \frac{\tan \varphi + \sin(\alpha_i - \delta_i)}{F_s} = 0 \quad (16.85)$$

This leads to:

$$\delta_{i,min} = \alpha_i - \left[\pi + \arctan \left(-\frac{F_s}{\tan \varphi} \right) \right] \quad (16.86)$$

or:

$$\delta_{i,max} = \alpha_i - \arctan \left(-\frac{F_s}{\tan \varphi} \right) \quad (16.87)$$

With this, the critical values of $\delta_{i,max}$ and $\delta_{i,min}$ can be calculated as a function of the starting value of F . The maximum of all $\delta_{i,max}$ is δ_{max} . The denominator of formula 2 includes $\cos(\delta_i)$. The denominator becomes zero when $\delta = -\frac{1}{2} \pi$ or $\delta = +\frac{1}{2} \pi$.

When δ_{min} is less than $-\frac{1}{2} \pi$, then $\delta_{min} = -\frac{1}{2} \pi$

When δ_{max} is larger than $+\frac{1}{2} \pi$, then $\delta_{max} = +\frac{1}{2} \pi$

16.5 Horizontal Balance

This paragraph describes the background of the *Horizontal Balance* calculation method. Different water levels at the left and the right of a dike body causes seepage forces that change the earth pressures. The horizontal force F_w due to water is:

$$F_w = \frac{(Z_{phreatic} - Z_{slip}) \times \gamma_w}{2} \quad (16.88)$$

where:

- $Z_{phreatic}$ is the vertical level of the phreatic line, in m;
- Z_{slip} is the vertical level of the slip plane, in m;
- γ_w is the unit weight of water, in kN/m².

The safety factor is:

$$F_s = \frac{R}{F_w} \quad (16.89)$$

where R is the total resisting force.

17 Loads

Different kinds of loads can be applied in D-GEO STABILITY:

- ◇ [section 17.1](#) Line load
- ◇ [section 17.2](#) Uniform load
- ◇ [section 17.3](#) Earthquake
- ◇ [section 17.4](#) Tree on slope

17.1 Line loads

A line load can be placed in, on or above the soil structure, and is assumed to continue infinitely in the direction perpendicular to the geometry plane. The angle of the load can be chosen freely, as long as there is a vertical downward component. The distribution angle determines the way the load spreads in the soil structure. If the bottom of a slice is located within the dispersion area of the load, the total stress is increased using the following formula:

$$\Delta\sigma_g = \frac{F \times \sin\left(\frac{\pi}{2} - \theta\right)}{2 \times \sqrt{(x_0 - x_1)^2 + (y_0 - y_1)^2} \times \tan \delta} \quad (17.1)$$

where:

- $\Delta\sigma_g$ is the increase of the total stress at bottom of slice, in kN/m²;
- F is the magnitude of the line load, in kN;
- θ is the angle of load with the vertical axis, in degree;
- x_0 is the X co-ordinate center of bottom of slice, in m;
- y_0 is the Z co-ordinate center of bottom of slice, in m;
- x_1 is the X co-ordinate of line load, in m;
- y_1 is the Z co-ordinate of line load, in m;
- δ is the load distribution angle, in degree.

Refer to [section 4.7.1](#) "Line Loads" for the input.



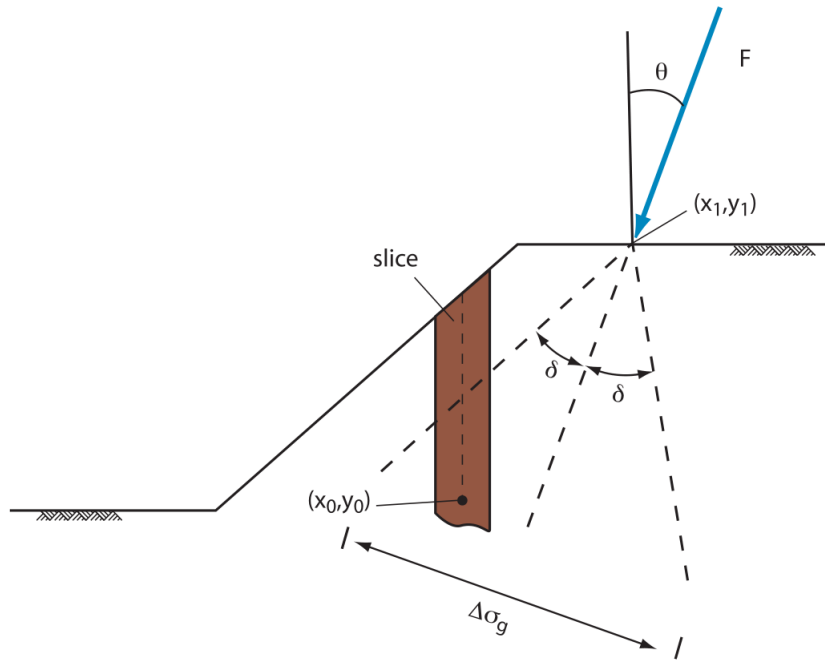


Figure 17.1: Line Load



Note: The line load can be situated in or above the soil structure.

Besides an increase of the total stress, line loads located in the confines of the slip circle also contributes to the driving moment of the slip circle. This moment is added to the driving load moment.

17.2 Uniform loads

A permanent or temporary vertical uniform load can be applied on a surface area. In the direction perpendicular to the geometry plane, the load is assumed to be infinite. The magnitude, the start and end X coordinate and a distribution angle for the load must be specified. For temporary loads, a table of the degree of consolidation must be specified.

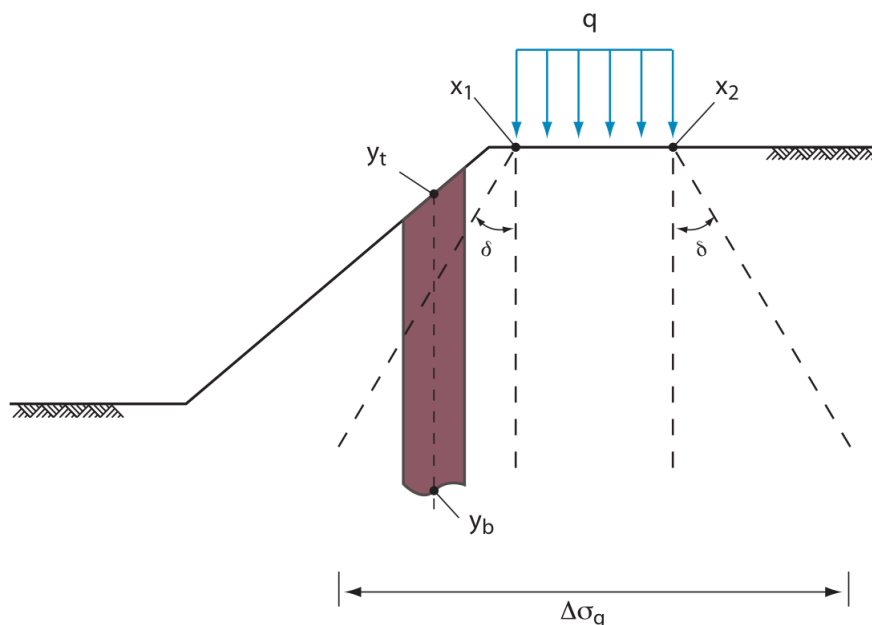


Figure 17.2: Uniform Load

The increase is calculated using the following formula:

$$\Delta\sigma_g = \frac{\alpha \times Q \times (x_2 - x_1)}{(x_2 - x_1) + 2(y_1 - y_b) \times \tan \delta} \quad (17.2)$$

where:

- $\Delta\sigma_g$ is the increase of the total stress, in kN/m²;
- Q is the magnitude of the distributed load, in kN/m²;
- X_1 is the horizontal co-ordinate where load starts, in m;
- y_1 is the vertical co-ordinate where load starts, in m;
- X_2 is the horizontal co-ordinate where load ends, in m;
- y_b is the vertical co-ordinate at the bottom of a slice, in m;
- y_t is the vertical co-ordinate at the top of a slice, in m;
- δ is the distribution angle of the load, in degree;
- α is the degree of consolidation for the load (1 in case of permanent loads).

Refer to [section 4.7.2 "Uniform Loads"](#) for the input.

Besides an increase of the total stress, the load also contributes to the driving moment of the slip circle. The part of the load located within the confines of a slip circle creates a moment around the slip-circle center point. This moment is added to the driving load moment (see [Equation 16.7](#) in [section 16.2.1.3](#)).

17.3 Earthquake

In D-GEO STABILITY it is possible to simulate the influences of earthquake forces. The earthquake forces induce several forces, stresses and moments. The influences of these earthquake forces are incorporated in D-GEO STABILITY by so-called earthquake coefficients.

These coefficients give the mass (of soil and water) an additional horizontal and vertical acceleration.

To simplify the calculation, it is assumed that the groundwater in the soil mass has the same extra acceleration as the soil in this mass.



Note: For the free water on the slope, a different coefficient must be specified.

17.3.1 Additional moment due to horizontal acceleration

The driving moment of slip circles increases due to the earthquake coefficients. This extra moment $M_{D;soil;quake;H}$ called additional horizontal driving soil moment due to earthquake is:

$$M_{D;soil;quake;H} = a_h \times \sum_{i=1}^n G_i \times (Z_{i;cg} - Z_c) \quad (17.3)$$

where:

a_h is the horizontal earthquake factor (i.e. acceleration coefficient) as defined in the *Earthquake* window in [section 4.7.3](#);

G_i is the weight of the soil in slice i (see [Equation 16.2](#)), in kN/m;

$Z_{i;cg}$ is the vertical co-ordinate of the centre of gravity of slice i , in m:

$$Z_{i;cg} = \frac{M_{D;soil;i}}{(G_i \times b_i)}$$

where $M_{D;soil;i}$ is the moment of soil loads at the bottom of slice i from the top to the bottom of slice i , in kNm/m.

Refer to [section 1.8](#) for the definition of the other symbols.

17.3.2 Additional moments due to vertical acceleration

The coefficient to increase the vertical gravitation has the following influence on soil stress, slice weight, driving moment and water pressure:

Additional driving soil moment due to vertical acceleration:

$$M_{D;soil;quake;V} = a_v \times \sum_{i=1}^n G_i \times (X_{i;top} - X_c) \quad (17.4)$$

where:

a_v is the vertical earthquake factor (i.e. acceleration coefficient) as defined in the *Earthquake* window in [section 4.7.3](#);

G_i is the weight of the soil in slice i (see [Equation 16.2](#)), in kN/m;

Refer to [section 1.8](#) for the definition of the other symbols.

Excess pore pressure due to earthquake:

Earthquake forces will generate excess pore pressures in layers that are not fully drained. The excess pore pressures are determined by taking into account the degree of consolidation per layer. This degree of consolidation ensures that part of the vertical acceleration results in an increase in effective stress. The other part results in excess pore pressure. The excess pore pressure $u_{\text{quake;excess}}$ generated by the earthquake is:

$$u_{\text{quake;excess}} = a_v \sum_{j=1}^{k_i} \gamma_j \times h_j \times (1 - \beta_j) \quad (17.5)$$

where:

- a_v is the vertical earthquake factor (i.e. acceleration coefficient) as defined in the *Earthquake* window in [section 4.7.3](#);
 - h_j is the thickness of layer j in slice i ;
 - k_i is the number of layers along slice i ;
 - β_j is the degree of consolidation of layer j ($0 \leq \beta \leq 1$), as defined in the *Earthquake* window in [section 4.7.3](#);
 - γ_j is the unit weight of soil layer j in slice i , in kN/m^3 ;
- Refer to [section 1.8](#) for the definition of the other symbols.

Additional pore pressure at the bottom of the slice:

The additional pore pressure includes the change in hydrostatic pressure as well as the excess pore pressure due to vertical quake component:

$$u_{\text{quake}} = u_{\text{hydro}} \times a_v + u_{\text{quake;excess}} \quad (17.6)$$

where:

- u_{hydro} is the hydrostatic pore pressure, in kN/m^2 :
 $u_{\text{hydro}} = \max [(Z_{\text{phreatic}} - Z) \times \gamma_w; 0]$
- a_v is the vertical acceleration coefficient;
- $u_{\text{quake;excess}}$ is the excess pore pressure due to the earthquake in kN/m^2 , see [Equation 17.5](#).

Water moment:

The free water coefficient simulates the temporary draw down of the water. The free water moment is modified according to equation:

$$M_{\text{D;water;quake}} = -M_{\text{D;water}} \times c_{fw} \quad (17.7)$$

where:

- $M_{\text{D;water}}$ is the driving water moment in kNm , see [Equation 16.3](#);
- c_{fw} is the free water factor as defined in the *Earthquake* window in [section 4.7.3](#).

17.4 Tree on Slope

The effect of the wind in the trees is equivalent to the effect of two uniform loads at both sides of the application point, one positive, the other one negative (Figure 17.3).

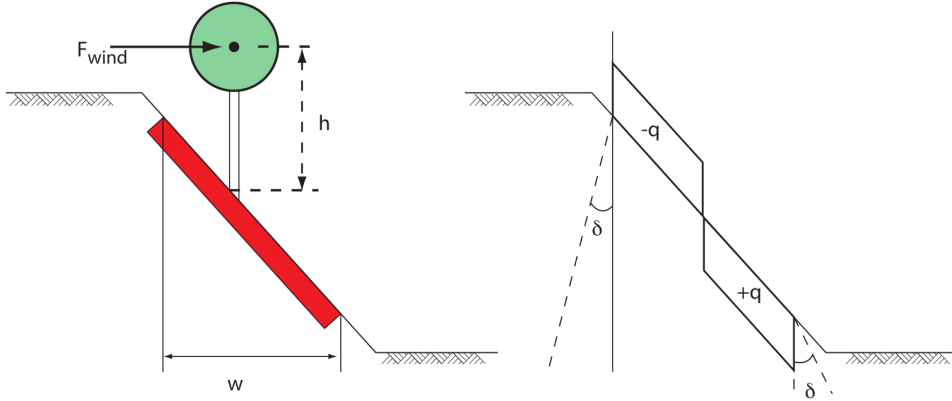


Figure 17.3: Representation of the effect of wind on trees

The magnitude of the equivalent uniform load q is:

$$q = \frac{F_{\text{wind}} \times h}{(w/2)^2} \quad (17.8)$$

where:

- F_{wind} is the magnitude of the wind, in kN/m;
- h is the vertical distance slope/wind, in m;
- w is the horizontal width of the root zone, in m.

The increase of stress is the sum of the stress due to the equivalent load respectively at the left and at the right:

$$\Delta\sigma_{\text{left},i} = \frac{-q \times w}{w + [2(Z_{\text{wind}} - h) + \frac{1}{2}w - 2Z_{b,i}] \times \tan \delta} \quad (17.9)$$

$$\Delta\sigma_{\text{right},i} = \frac{q \times w}{w + [2(Z_{\text{wind}} - h) - \frac{1}{2}w - 2Z_{b,i}] \times \tan \delta} \quad (17.10)$$

where:

- Z_{wind} is the vertical co-ordinate of the application point of the wind, in m;
- $Z_{b,i}$ is the vertical co-ordinate at the bottom of slice i , in m.

The driving moment due to tree on slope is therefore:

$$M_{\text{load}} = -F_{\text{wind}} \times (Z_{\text{wind}} - Z_{\text{circle}}) \quad (17.11)$$

18 Pore pressures

18.1 Phreatic line

The phreatic line (or groundwater level) is used to mark the border between dry and wet soil. The phreatic line is treated as if it was a PL-line, and can also be used as such. The PL-line acting as the phreatic line is determined while the geometry is being defined. If no phreatic line is entered, then all the soil is assumed to be dry.

The phreatic line is also used to determine the water moment in the method of slices. For all slices where the phreatic line is above the soil surface, the load of the 'free' water on the surface is taken into account as a moment around the slip circle centre ($M_{D;water}$), see [Equation 16.3](#).

18.2 Hydraulic pore pressure (from piezometric level line)

A piezometric level line (PL-line) represents the initial and transient hydraulic water head (excluded the excess component). A PL-line can be defined for the top and the bottom of each soil layer ([section 4.3.10](#), [section 4.3.13](#)). One of these PL-lines can be defined as the phreatic line. If no phreatic line or PL-lines are defined, then all the soil is assumed to be dry.

D-GEO STABILITY, calculates the hydraulic pore pressure along a vertical in the following way:

- ◇ The pore pressure inside a layer is calculated by linear interpolation between the pore pressures at top and bottom.
- ◇ The pore pressure at the top or bottom is equal to the vertical distance between this point and the position of the PL-line that belongs to this layer, multiplied by the unit weight of water (see [Equation 18.1](#)).
- ◇ If PL-line number 99 is specified for the top and/or bottom of any soil layer, D-SETTLEMENT will use at that boundary the PL-line of the nearest soil layer above or below, which has a thickness larger than zero and a PL-line number not equal to 99. If the interpolation point is located above the phreatic line, the pore pressure is assumed to be zero or a capillary pressure, depending on the sign of the PL-line number.

$$u_{PL}(z) = \begin{cases} (\varphi(z) - z) \times \gamma_w \geq 0 & \text{if } z < z_{\text{phreatic}} \\ 0 & \text{if } z \geq z_{\text{phreatic}} \end{cases} \quad (18.1)$$

where:

- z_{phreatic} is the level of the phreatic line, see [section 18.1](#);
- $\varphi(z)$ is the hydraulic head at position (x, z) derives from the user-defined PL-lines per layer ([section 4.3.13](#)) in m;
- γ_w is the unit weight of water in kN/m^3 .

The following options are available, therefore, for giving PL-line numbers:

Positive integer:	Capillary pore pressures are not used – that is, if negative pore pressures are calculated for points above the phreatic line they become zero
Zero:	All points within the layer obtain a pore pressure 0 kN/m^2
99:	The pore pressure depends on the first layer above and/or below the point with a PL-line number unequal to 99.



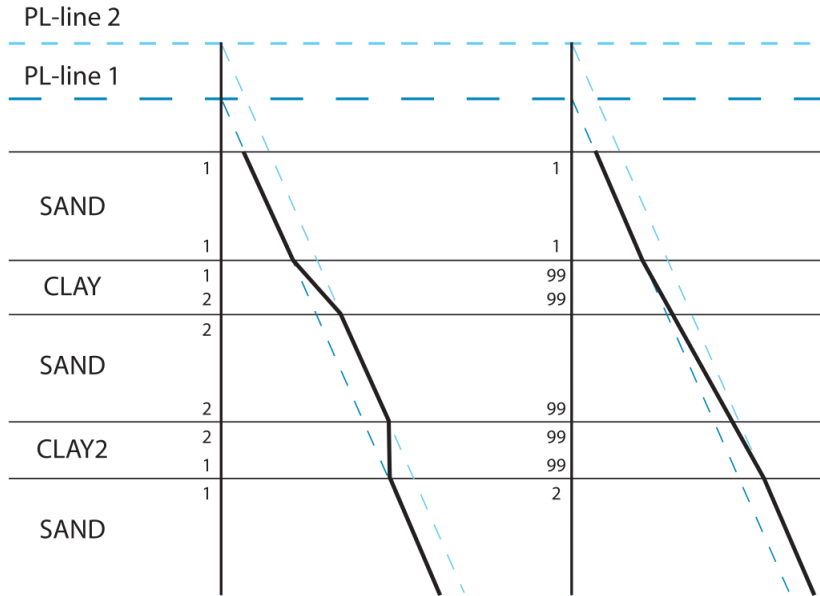


Figure 18.1: PL-lines per layer

18.3 Pore pressure due to degree of consolidation

The degree of consolidation determines which part of the effective weight of an overlying soil layer is carried by effective stress, and which part by (excess) pore pressure. This degree ranges between 0% and 100%.

The effective weight $\sigma'_{v;i}$ of layer i is equal to:

$$\sigma'_{v;i} = \begin{cases} \gamma_{\text{unsat}} \times h & \text{for a layer (part) above the groundwater level} \\ (\gamma_{\text{sat}} - \gamma_w) \times h & \text{for a layer (part) below the groundwater level} \end{cases} \quad (18.2)$$

where:

- h is the thickness of the layer (part) in m;
- γ_{unsat} is the unsaturated (i.e. dry) unit weight of the soil, in kN/m³;
- γ_{sat} is the saturated (i.e. wet) unit weight of the soil, in kN/m³;
- γ_w is the volumetric weight of the water, in kN/m³.

The pore pressure induced by the degree of consolidation U_{ij} in layer i by addition of layer j is:

$$u_{\text{DOC}}(z) = \sum_{i=1}^k \sum_{j=1}^i \sigma'_{v;i} \times \frac{100 - U_{ij}}{100} \quad (18.3)$$

where:

- k is the number of layers;
- $\sigma'_{v;i}$ is the effective vertical stress in layer i , see [Equation 18.2](#);
- U_{ij} is the relative degree of consolidation in layer i due to layer j , in %, as defined in the *Degree of Consolidation* window ([section 4.6.3](#)).

Examples of excess pore pressures by soil self-weight

Table 18.1 shows an example of a three layered soil structure, where there are different degrees of consolidation.

Table 18.1: Different degrees of consolidation in different layers

Layer i (top to bottom)	Degree of consolidation in layer i by addition of layer j	Effective stress [%]	Pore pressures [%]
1	100	1	100	0
2	70	1	70	30
	100	2	100	0
3	60	1	60	40
	90	2	90	10
	100	3	100	0

The effective stress at the bottom of a slice in layer 3 is equal to 60% of the effective weight of layer 1, plus 90% of the effective weight of layer 2, plus 100% of the effective weight of the part of layer 3 above the bottom of the slice.

The excess pore pressure at the same spot is equal to $(100\% - 60\%) = 40\%$ of the effective weight of layer 1 plus $(100\% - 90\%) = 10\%$ of the effective weight of layer 2 plus $(100\% - 100\%) = 0\%$ of the effective weight of the part of layer 3 above the bottom of the slice. This example assumes that the phreatic line is located above layer boundary 2.

By defining the degree of consolidation for the load of each layer above the actual layer, and for the weight of the actual layer itself, it is possible to simulate different stages of a construction process. If, for example, one extra layer is placed on the surface as a new load, the early stages of construction can be calculated by assigning a low degree of consolidation in underlying layers with low permeability due to the weight of the new layer.

For points above the phreatic line, it is possible to choose whether pore (excess/under) pressures are to be used to affect the effective stress.

18.4 Pore pressure from temporary distributed loads

The extra pore pressure due to temporary distributed loads is:

$$u_{\text{temp load}}(z) = \left(1 - \frac{U_{\text{load}}}{100}\right) \times \Delta\sigma_g(z) \quad (18.4)$$

where:

U_{load} is the degree of consolidation due to the temporary load, as defined in the *Uniform Loads* window in [section 4.7.2](#);

$\Delta\sigma_g(z)$ is the increase of the total stress at depth z due to the temporary uniform load, see [Equation 17.2](#) in [section 17.2](#).

18.5 Total pore pressure and effective stress

The total pore pressure u is obtained by adding the following contributions:

$$u = u_{\text{PL}} + u_{\text{DOC}} + u_{\text{temp load}} + u_{\text{quake}} \quad (18.5)$$

where:

- u_{PL} is the pore pressure derived from the PL-lines, see [Equation 18.1](#) in [section 18.2](#);
- u_{DOC} is the pore (excess/under) pressure derived from the degree of consolidation, see [Equation 18.3](#) in [section 18.3](#);
- $u_{temp\ load}$ is the extra pore pressure from temporary distributed loads, see [Equation 18.4](#);
- u_{quake} is the extra pore pressure due to vertical quake, see [Equation 17.6](#) in [section 17.3.2](#).

The pore pressure derived from the PL-lines represents (u_{PL}) the situation without any loads being applied, while the extra pore pressures due to the consolidation process (u_{DOC}) and temporary loads ($u_{temp\ load}$) are the result of the extra loading of soils with a low permeability.

D-GEO STABILITY determines the effective stress at depth z , using:

$$\sigma'(z) = \sigma(z) - u(z) \quad (18.6)$$

where u is the total pore pressure ([Equation 18.5](#)) and $\sigma(z)$ is the total stress at depth z :

$$\sigma(z) = \sigma_{soil}(z) + \Delta\sigma_g(z) + \sigma_{free\ water}(z) \quad (18.7)$$

with:

$$\sigma_{soil}(z) = \sum_{i=1}^k \gamma_i \times h_i$$

$$\sigma_{free\ water}(z) = (z_{phreatic} - z) \times \gamma_w \geq 0$$

where:

- h_i is the thickness of layer i ;
- k is the number of layers until depth z , along the considered vertical;
- $z_{phreatic}$ is the level of the phreatic line, see [section 18.1](#);
- γ_i is the unit weight of soil layer i , in kN/m^3 ;
- $\sigma_{soil}(z)$ is the stress due to soil weight;
- $\sigma_{water}(z)$ is the stress due free water above the soil surface;
- $\Delta\sigma_g(z)$ is the increase of the total stress at depth z due a load, see [Equation 17.1](#) for line loads and [Equation 17.2](#) for uniform loads.

19 Shear strength models

This section gives background on the following shear strength models:

- ◇ [section 19.1 C-Phi model with dilatancy](#)
- ◇ [section 19.2 Stress tables](#)
- ◇ [section 19.3 Measured undrained strength](#)
- ◇ [section 19.4 Calculated undrained shear strength](#)
- ◇ [section 19.5 Pseudo values](#)

For a description of stochastic shear strength modelling, see [section 20.3](#).

19.1 C-Phi model with dilatancy

When using the *C-Phi* shear strength option ([section 4.2.4.1](#)) with dilatancy ψ , D-GEO STABILITY will determine the shear stress along the slip plane using the following equation:

$$\tau_i = c_i \times \frac{\cos \psi_i \cdot \cos \varphi_i}{1 - \sin \psi_i \cdot \sin \varphi_i} + \sigma'_{n;i} \times \frac{\cos \psi_i \cdot \sin \varphi_i}{1 - \sin \psi_i \cdot \sin \varphi_i} \quad (19.1)$$

where:

- c_i is the cohesion at the bottom of slice i , in kN/m²;
- φ_i is the friction angle at the bottom of slice i , in degree;
- ψ_i is the dilatancy at the bottom of slice i , in degree;
- α_i is the angle at the bottom of slice i , in degree;
- $\sigma'_{n;i}$ is the normal effective stress along the bottom of slice i , in kN/m².

Assuming $\varphi = \psi$ is the so called associative behaviour. When using $\varphi = \psi$, the shear strength is $\tau = c + \sigma'_n \times \tan \varphi$. This is the well-known Mohr-Coulomb definition of the failure line.

Assuming $\varphi \neq \psi$ is the so called non-associative behaviour.

When using $\psi = 0$, the shear strength is $\tau = c \times \cos \varphi + \sigma'_n \times \sin \varphi$.

19.2 Stress tables

When using the *Stress Table* shear strength option ([section 4.2.4.1](#)), D-GEO STABILITY will determine the shear strength from user-supplied stress tables, also called (sigma-tau) σ - τ curves ([section 4.2.1](#)). Depending on the stress situation at the bottom of a slice, one of the line segments of this curve is used to find values for c (cohesion) and φ (internal friction angle).

In order to determine which line segment to use, D-GEO STABILITY uses [Equation 16.11](#) and [Equation 16.16](#) for the shear stress of resp. Bishop and Fellenius models and [Equation 19.2](#) for the effective normal stress.

$$\sigma'_n = \frac{F_s \times \sigma'_v - c \times \tan \alpha}{F_s + \tan \alpha \times \tan \varphi} \quad (19.2)$$

where:



- σ'_n is the normal effective stress along the slip plane, in kN/m²;
 F_s is the safety factor;
 σ'_v is the vertical effective stress in kN/m²;
 c is the cohesion in kN/m²;
 α is the angle of slice bottom, in degree.

With this σ'_n value the line segment of the σ - τ curve containing this value is determined, and from the line segment equation the values for c and φ are determined. φ is determined by the angle of the line segment, while c is determined by the point where the line segment would intersect the vertical $\sigma = 0$ kN/m² axis. In the first iteration σ'_n cannot be determined with the above formula because φ is unknown (also stress-dependent); therefore in the first iteration σ'_v is used to determine the first estimate of c and φ .

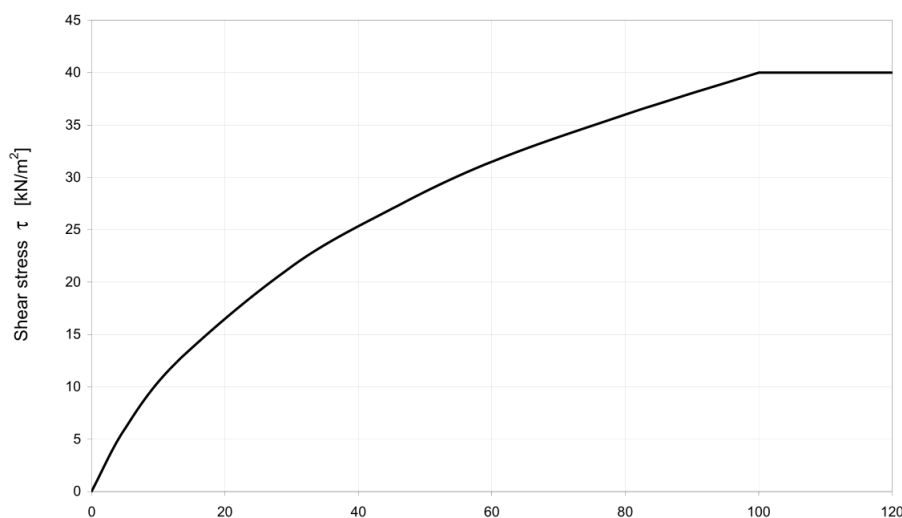


Figure 19.1: Example of σ - τ curve

Figure 19.1 shows an example of a σ - τ curve. Such a curve is usually obtained from test results on the soil. The curve obtained from the test results will normally have to be adjusted in order to include a certain degree of safety.

For the angle at the bottom of the slice, the same restrictions apply as with the standard calculation method explained in the section above. With the c and φ determined as explained above, the safety factor F_s can be determined in an iterative process as explained in [section 16.2.2.1.1](#).

19.3 Measured undrained strength

When using the shear strength option *Su-measured* ([section 4.2.4.1](#)), D-GEO STABILITY will define the shear stress acting at the bottom of each slice as equal to the specified value for the undrained strength.

$$\tau_\alpha = s_u \quad (19.3)$$

Stress induced anisotropy



Note: The stress induced anisotropy is only applicable in the Reliability Analysis module of D-GEO STABILITY, but it can be applied without definition of uncertainties.

The shear strength in an over consolidated soil is larger at the active side of the slip plane, and smaller at the passive side.

An average value at the horizontal part of the slip plane follows from a direct simple shear test (DSS). A small passive value follows from a triaxial test in extension (TE). A high active value follows from a triaxial test in compression (TC).

D-GEO STABILITY can model this stress induced anisotropy by assuming a shear strength that can vary not only top down. Also D-GEO STABILITY can define a sinus function along the orientation of the slip plane. The shear strength then varies horizontally according to this function. The function along the plane is defined by the input of the average value, the minimum value at the passive side and the maximum value at the active side (Figure 19.2).

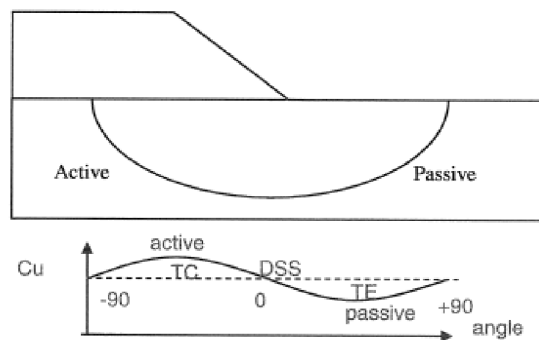


Figure 19.2: Stress induced anisotropy

19.4 Calculated undrained shear strength

Su-calculated with POP

When using the shear strength option *Su-calculated with POP* (section 4.2.4.1), D-GEO STABILITY will calculate the shear stress along the slip plane from the ratio S between the undrained cohesion and the yield stress, according to the following equation:

$$\tau_{\alpha} = S \times \sigma'_{y} \quad (19.4)$$

with:

$$\sigma'_{y} = \max(\sigma'_{v.ref} + \text{POP}, \sigma'_{v}) \quad (19.5)$$

where:

- S is the ratio between the undrained shear strength s_u and the yield stress σ'_{y} . The average value of S ranges between 0.18 and 0.40;
- σ'_{y} is the vertical yield stress in kN/m^2 ;
- $\sigma'_{v.ref}$ is the reference vertical effective stress, calculated from the reference level of the soil surface (Figure 19.3), in kN/m^2 . This reference level defines the initial surface, before embankment addition or excavation;
- σ'_{v} is the actual effective vertical stress, after embankment addition, in kN/m^2 ;
- POP is the pre-overburden pressure, in kN/m^2 , defined per material (see Figure 4.24).

Su-calculated with yield stress

When using the shear strength option *Su-calculated with yield stress* (section 4.2.4.1), D-GEO STABILITY will calculate the shear stress along the slip plane as follows:

$$\tau_{\alpha} = \sigma'_v \times S \times \text{OCR}^m \quad (19.6)$$

with:

$$\text{OCR} = \frac{\sigma'_y}{\sigma'_v} = \frac{\sigma'_v + \text{POP}}{\sigma'_v} \quad (19.7)$$

where:

- OCR is the over-consolidation ratio;
- m is the strength increase exponent;
- POP is the pre-overburden pressure, in kN/m^2 , deduced from the yield stress measurements (see Figure 4.20) using the procedure described below.

Procedure for the determination of the POP from a list of σ'_y -measurements

When one or more yield stress values are measured at certain levels, these data must be assigned to the soils. The following procedure is used in D-GEO STABILITY:

- ◇ First, the geometry is divided in columns, and these columns are divided in areas, see note below for the definition of columns and area's.
- ◇ Next, all the POP-values are calculated ($\text{POP} = \sigma'_y - \sigma'_v$) by D-GEO STABILITY at the specified yield stress positions.
- ◇ Next, per row:
 - If one or more calculated POP are present in the same soil in one column, the soil in the column gets the average value of these POP.
 - If no POP is available in an area, the POP given to that area is the POP with the X-coordinate closest to the X-coordinate of the middle of the area.
 - When more than one POP values in a soil layer are available with the same horizontal distance the soil in the column gets the average value of these POP values.
- ◇ Finally, along a column, the following is done for the areas without a POP:
 - The areas situated above the highest area with a POP get that POP.
 - The areas situated below the lowest area with a POP get that POP.
 - The areas with a POP above and below get an interpolated value over the Z-coordinate at the middle of these areas.
- ◇ In case there are still areas without POP (meaning a column without POP), all the areas in the column get the value of the closest calculated POP.

When determining the POP of a layer, it is not taken into account that the layer changes in thickness or that the surface line above changes.



Note: Columns are defined by drawing vertical lines through all vertex points and intersections of the water lines with the geometry. A vertex is a point in the geometry that does not

lie exactly in between two other points on a line. A column exists of different areas on top of each other. Areas are created because columns are intersected by layer boundaries and a phreatic line. Inside an area, stresses can be interpolated linearly.

Stress induced anisotropy

Note: The stress induced anisotropy is only applicable in the Reliability Analysis module of D-GEO STABILITY, but it can be applied without definition of uncertainties.



The shear strength ratio in over-consolidated soil is larger at the active side of the slip plane, and smaller at the passive side. An average value at the horizontal part of the slip plane follows from a direct simple shear test (DSS). A small passive value follows from a triaxial test in extension (TE). A high active value follows from a triaxial test in compression (TC).

D-GEO STABILITY can model this stress induced anisotropy by assuming a shear strength ratio that varies with a sinus function along the orientation of the slip plane (Figure 19.3). The function is defined by the input of the average value, the minimum value at the passive side and the maximum value at the active side.

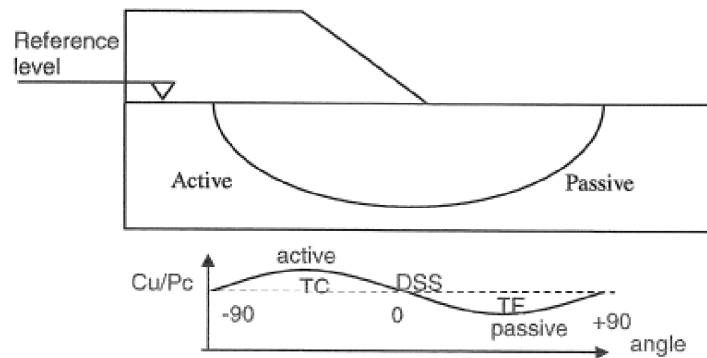


Figure 19.3: Reference level and stress induced anisotropy

19.5 Pseudo values

When using the shear strength option *Pseudo values* (section 4.2.4.1), D-GEO STABILITY will calculate the shear stress along the slip plane assuming a stochastic (normal) shear strength modeling and using three inputted σ - τ curves:

- ◇ the measured values (τ_{meas}),
- ◇ the characteristic values (τ_{char}),
- ◇ the mean values (τ_{mean}).

19.5.1 Local measurements

The pseudo characteristic value for the shear stress $\tau_{ij;pchar}$ at the bottom of slice i in layer j is:

$$\tau_{ij;pchar} = \mu [\tau_{ij}] - 1.65 \times \xi_j \times \sigma [\tau_{ij}] \tag{19.8}$$

and the pseudo measured value for the shear stress $\tau_{ij;pmeas}$ at the bottom of slice i in layer j is:

$$\tau_{ij;pmeas} = \frac{\tau_{ij;meas}}{\tau_{ij;char}} \times \tau_{ij;pchar} \tag{19.9}$$

where:

$\mu[\tau_{ij}]$	is the average shear stress determined from a test boring and inputted in the fourth column of the <i>Sigma-Tau Curves</i> window, see section 4.2.1.2 ;
$\sigma[\tau_{ij}]$	is the standard deviation of the tangential stress: $\sigma[\tau_{ij}] = \frac{\mu[\tau_{ij}] - \tau_{ij;\text{char}}}{1.65}$
$\tau_{ij;\text{char}}$	is the characteristic value of the shear stress determined from a test boring and inputted in the third column of the <i>Sigma-Tau Curves</i> window, see section 4.2.1.2 . It corresponds with the 5%-lower limit.
ξ_j	is the pseudo characteristic factor for layer j : $\xi_j = \frac{\sigma[T_j]}{\sigma[T]}$
$\sigma[T]$	is the standard deviation of the total shear stress T : $\sigma[T] = \sqrt{\sum_{j=1}^{n_l} \sigma^2[T_j]}$
$\sigma[T_j]$	The standard deviation of the shear stress in layer j : $\sigma[T_j] = \sum_{i=1}^{n_j} l_{ij} \sigma[\tau_{ij}]$
n_l	is the number of layers that are cut by the slip circle;
n_j	is the number of slices in layer j .
$\tau_{ij;\text{meas}}$	is the measured shear stress inputted in the second column of the <i>Sigma-Tau Curves</i> window, see section 4.2.1.2 ;

In D-GEO STABILITY, [Equation 19.9](#) is implemented using the following formula:

$$\tau_{ij;\text{pmeas}} = \frac{\tau_{ij;\text{meas}}}{\tau_{ij;\text{char}}} (\mu[\tau_i] - P_j \delta\tau_i) \quad (19.10)$$

with:

$$\delta\tau_i = \mu[\tau_{ij}] - \tau_{ij;\text{char}}$$

where:

$$P_j \quad \text{is the pseudo characteristic factor for layer } j: P_j = \frac{T_j}{\sqrt{\sum_{j=1}^{n_l} T_j}}$$

$$T_j \quad \text{is the total shear stress in layer } j: T_j = \sum_{i=1}^{n_j} l_{ij} \times \delta\tau_i.$$

19.5.2 Global measurements (regional set of tests)

In case of global measurements (from a regional set of *in situ* tests), the variances of the contributions to the total shear stress which come from separate ground layers which are not associated with another ground layer can be calculated using equations of [section 19.5.1](#).

Note: In D-GEO STABILITY, two associated layers are part of the same soil group. For more information about the *Soil Groups* option, refer to [section 4.2.4.3](#).



For the variances of the contributions of associated ground layers, the combined contribution of two associated ground layers must be considered. Assuming that layers j and k are associated (for example: j is the layer under the dike and k is the corresponding layer beside the dike), the combined contribution to the total shear stress along the slip circle is:

$$T_{jk} = \sum_{i=1}^{n_j} l_{ij} \times \tau_{ij} + \sum_{h=1}^{n_k} l_{hk} \times \tau_{hk} \quad (19.11)$$

The variance of this contribution is:

$$\sigma^2 [T_{jk}] = E \left[\left(\sum_{i=1}^{n_j} l_{ij} \delta_{ij} + \sum_{h=1}^{n_k} l_{hk} \delta_{hk} \right)^2 \right] \quad (19.12)$$

This equation leads to:

$$\sigma^2 [T_{jk}] = \sigma^2 [T_j] + \sigma^2 [T_k] + 2R_{jk} \times \sigma [T_j] \times \sigma [T_k] \quad (19.13)$$

where:

- $\sigma [T_j]$ is the standard deviation of the shear stress in layer j : $\sigma [T_j] = \sum_{i=1}^{n_j} l_{ij} \times \sigma [\tau_{ij}]$;
 $\sigma [T_k]$ is the standard deviation of the shear stress in layer k : $\sigma [T_k] = \sum_{h=1}^{n_k} l_{hk} \times \sigma [\tau_{hk}]$;
 n_l is the number of layers that are cut by the slip circle;
 n_j is the number of slices in layer j .

The separate characteristic factors ξ_j and ξ_k for layers j and k are determined using the same procedure as for unassociated layers ([section 19.5.1](#)). Difference is that a correlation factor R_{jk} between the two layers is now introduced:

$$\xi_j = \xi_{jk} \times \frac{(\sigma [T_j] + R_{jk} \times \sigma [T_k])}{\sigma [T_{jk}]} \quad (19.14)$$

$$\xi_k = \xi_{jk} \times \frac{(R_{jk} \times \sigma [T_j] + \sigma [T_k])}{\sigma [T_{jk}]} \quad (19.15)$$

where:

- ξ_{jk} is the pseudo characteristic factor of the soil group containing layers j and k ;
 R_{jk} is the correlation factor between the associated layers j and k :

$$R_{jk} = \frac{1}{\sqrt{\left(1 + \frac{1}{\Gamma^2 N_j}\right) \left(1 + \frac{1}{\Gamma^2 N_k}\right)}}$$

 Γ^2 factor set equal to $\Gamma^2 = 0.25$, according to the Dutch guideline for river dyke (TAW);
 N_j, N_k are the number of tests performed in the regional set of tests of layers j and k .

The pseudo measured value for the shear stress at the bottom of slice i in layer j is determined using the same equation as for unassociated layers ([section 19.5.1](#)):

$$\tau_{ij;pmeas} = \frac{\tau_{ij;meas}}{\tau_{ij;char}} (\mu [\tau_{ij}] - 1.65\xi_j \times \sigma [\tau_{ij}]) \quad (19.16)$$

In D-GEO STABILITY, [Equation 19.16](#) is implemented using the following formula:

$$\tau_{ij;pmeas} = \frac{\tau_{ij;meas}}{\tau_{ij;char}} (\mu [\tau_i] - P_{j;global} \times \delta\tau_i) \quad (19.17)$$

with

$$\delta\tau_i = \mu [\tau_{ij}] - \tau_{ij;\text{char}}$$

$$P_{j;\text{global}} = P_{jk} \times \frac{(P_j + R_{jk} \times P_k)}{\sqrt{P_j^2 + P_k^2 + 2R_{jk} \times P_j \times P_k}}$$

$$P_{jk} = \frac{\sqrt{P_j^2 + P_k^2 + 2R_{jk} \times P_j \times P_k}}{\sqrt{\sum_{i=1}^{n_j} P_i^2 + 2R_{jk} \times P_j \times P_k}}$$

where:

- $P_{j;\text{global}}$ is the global pseudo characteristic factor for layer j ;
- P_{jk} is the pseudo characteristic factor of the soil group containing layers j and k ;
- $P_j; P_k$ is the local pseudo characteristic factors of layers j and k , see [Equation 19.10](#).

20 Reliability analysis

20.1 Supported methods

Commonly used design standards like the Eurocode and the Dutch NEN standard prescribe to apply reliability based approach for both structural and geotechnical design.

For this purpose the standards supply two options:

- ◇ *Design value approach* (semi-probabilistic, level III). In this approach calculations are made with combinations of unfavorable values of input parameters for resistance and loads. The unfavorable values are called design values. They are determined by applying a partial factor on the unfavorable characteristic value, commonly defined by a confidence limit of 95%. The characteristic value of parameter follows from a stochastic distribution, usually defined by mean and standard deviation, where the standard deviation quantifies the uncertainty. In D-GEO STABILITY calculations the calculated safety factor must be larger than the required value: $F_s > F_{\text{required}}$.
- ◇ *Probabilistic approach*. This is an analysis with free variations of stochastically distributed input parameters, defined by mean and standard deviation. A level II analysis with FORM (*First Order Reliability Method*) supplies a reasonable balance between the accuracy required and the efficiency desired. Result of a probabilistic analysis is the *reliability index* β .

D-GEO STABILITY support both these approaches, beside the traditional mean value analysis.

20.2 Stochastic distributions

In order to support a First Order Reliability Method calculation, D-GEO STABILITY can apply a standard normal or lognormal probability distribution for all stochastic parameters. Both distribution types are characterized by a mean μ and a standard deviation σ for a standard normal distribution.

Normal distribution

The probability that a value x is smaller than the value x_{charac} is for a normal distribution expressed by:

$$P(x < x_{\text{charac}}) = \Phi_N(u_{\text{charac}}) = \int_{-\infty}^{u_{\text{charac}}} \varphi_N(u) \times du \quad (20.1)$$

where:

- u is the parameter of a standard normal distribution: $u = \frac{x - \mu[x]}{\sigma[x]}$;
- $\Phi_N(u_{\text{charac}})$ is the integral of the standard normal probability density;
- $\varphi_N(u)$ is the standard normal probability density: $\varphi_N(u) = \frac{\exp(-u^2/2)}{\sqrt{2\pi} \times \sigma[x]}$.



Lognormal distribution

If parameter $y = \ln(x)$ has a normal distribution, then parameter x has a lognormal distribution. A lognormal distribution always yields positive values. The normal and lognormal distributions are similar for small ratios between the standard deviation and the mean. D-GEO STABILITY uses [Equation 20.2](#) and [Equation 20.3](#) respectively to calculate $\mu[y]$ and $\sigma[y]$ from the user input of $\mu[x]$ and $\sigma[x]$.

$$\sigma [y] = \sqrt{\ln \left(1 + \left(\frac{\sigma [x]}{\mu [x]} \right)^2 \right)} \quad (20.2)$$

$$\mu [y] = \ln \left(\mu [x] - \frac{1}{2} \sigma^2 [x] \right) \quad (20.3)$$

20.3 Stochastic shear strength

The following subjects are related to stochastic shear strength modeling. The definitions presented hereafter are applicable to both a design value analysis and a probabilistic analysis.

- ◇ [section 20.3.1](#) Mean value
- ◇ [section 20.3.2](#) Determination of the standard deviation
- ◇ [section 20.3.3](#) Stress tables
- ◇ [section 20.3.4](#) Characteristic value from a normal distribution
- ◇ [section 20.3.5](#) Characteristic value from a lognormal distribution
- ◇ [section 20.3.6](#) Design value

Note that dilatancy angle is not a stochast when using the *C phi* model with dilatancy.

20.3.1 Mean

To calculate the mean value of parameter x , one can straightforwardly evaluate the following equation:

$$\mu [x] = \frac{1}{n} \sum_{i=1}^n x_i \quad (20.4)$$

where n is the number of samples.

D-GEO STABILITY is able determine the mean value from the input of a design value ([section 20.3.6](#)). For this purpose D-GEO STABILITY uses a calculated characteristic value ([section 20.3.4](#), [section 20.3.5](#)), a partial factor and standard deviation ([section 20.3.2](#)) associated with the design value. The values D-GEO STABILITY derives for default standard deviation and partial factors are largely based on Dutch design standards (NEN).

20.3.2 Standard deviation

The standard deviation quantifies the uncertainty in a parameter. D-GEO STABILITY supplies defaults via the variation coefficient V :

$$V = \frac{\sigma [x]}{\mu [x]} \quad (20.5)$$

The default values for the coefficient of variation are mainly based on the Dutch NEN standard [NEN \(1997\)](#). In practice the following guidelines are used to determine a value for the standard deviation when processing soil test results.

The input value of the standard deviation is composed of a statistical contribution of several factors:

- ◇ inherent soil variability
- ◇ systematic uncertainty contribution by soil testing
- ◇ the transformation from measurements to parameters

D-GEO STABILITY assumes a homogeneous soil distribution. For a complete description of the uncertainty in the soil the effect of spatial fluctuations in the standard deviation must be included. A suitable expression for the standard deviation can be derived, by applying Van Marcke's random field theory (Van Marcke, 1983). Combination of this expression with a systematic contribution yields:

$$\sigma_{\text{total}} = \sqrt{(\mu V_{\text{sys}})^2 + \left(\frac{1}{n} + \Gamma^2 + \gamma_v (1 - \Gamma^2)\right) \left(\frac{t}{u} \sigma_{\text{statistical}}\right)^2} \quad (20.6)$$

with:

$$\sigma_{\text{statistical}}^2 = \frac{1}{n-1} \sum_{i=1}^n (x_i - \mu)^2 \quad (20.7)$$

$$\Gamma^2 = 1 - \frac{1}{n_{\text{verticals}}} \frac{\sum_{i=1}^{n_{\text{verticals}}} \sigma_{\text{statistical},i}^2}{\sigma_{\text{statistical}}^2} \quad (20.8)$$

$$\gamma_v = \max\left(\Pi \frac{D_v}{d_{\text{layer}}}; 1\right) \quad (20.9)$$

where:

- t is the parameter from a Student distribution, which depends on the number of samples n . The parameter becomes equal to u for large values of n ;
- V_{sys} is the coefficient of variation that quantifies the systematic uncertainty by soil testing and by the transformation from measurements to parameters. A usual value is 0.1 for cohesion, and 0.04 for the angle of friction (Phoon and Kulhawy, 1999b,a);
- Γ defines the ratio between the average standard deviation along separate verticals and the global standard deviation. The value is 0 if the standard deviation expresses the uncertainty in horizontal direction on the mean value. The value is 1 if the standard deviation expresses the uncertainty in horizontal direction on a local value. A value of 0.5 is often applicable, assuming regular dimensions for (a) the width of the shearing volume, (b) the horizontal correlation length and (c) the regions of test sampling;
- γ_v defines the ratio between the vertical scale of fluctuation (correlation length) D_v and the thickness of the layer d_{layer} that is intersected by the slip plane. A usual value for $D_v = 0.25$ m.

20.3.3 Stress tables

D-GEO STABILITY determines a standard deviation of the shear strength from stress tables (section 4.2.1) by application of the following procedure:

- ◇ D-GEO STABILITY calculates per layer the average normal stress along the slip plane $\sigma_{\text{normal.ref}}$;
- ◇ D-GEO STABILITY determines the value of the standard deviation at this reference normal stress from the characteristic and mean value of the shear strength:

$$\sigma [\tau] = \frac{\tau_{\text{ref.characteristic}} - \mu [\tau_{\text{ref}}]}{u_{\text{charac}}} \quad (20.10)$$

During probabilistic analysis, D-GEO STABILITY will use the shear strength at the reference normal stress τ_{ref} as the random stochastic parameter per layer, and scale the shear strength values at other normal stress levels:

$$\tau = \frac{\sigma_{\text{normal}}}{\sigma_{\text{normal.ref}}} \times \tau_{\text{ref}} \quad (20.11)$$



Note: Stress tables are characterized by this one stochastic parameter, whereas the c-phi model is characterized by two.

20.3.4 Characteristic value from a normal distribution

D-GEO STABILITY determines a characteristic value of a normally distributed shear strength parameter x from the following equations:

$$x_{\text{charac}} = \mu [x] + u_{\text{charac}} \times \sigma_{\text{total}} \quad (20.12)$$

$$P(x < x_{\text{charac}}) = \Phi_N(u_{\text{charac}}) \quad (20.13)$$

where u is the parameter of a standard normal distribution and σ_{total} the value of the standard deviation.

D-GEO STABILITY supplies defaults for the value of u_{charac} per parameter type. A probability $P(x < x_{\text{charac}}) = 0.05$ corresponds for example to $u_{\text{charac}} = -1.65$.

20.3.5 Characteristic value from a lognormal distribution

D-GEO STABILITY determines a characteristic value of a lognormal distributed shear strength parameter x by using the following equation:

$$x_{\text{charac}} = \exp(\mu [y] + u_{\text{charac}} \cdot \sigma [y]) \quad (20.14)$$

where:

$$\mu [y] = \frac{1}{2} \ln \left(\frac{\mu^2 [x]}{V^2 + 1} \right) \quad (20.15)$$

$$\sigma [y] = \sqrt{\ln(1 + V^2)} \quad (20.16)$$

$$V = \frac{\sigma_{\text{total}} [x]}{\mu [x]} \quad (20.17)$$

20.3.6 Design value

D-GEO STABILITY determines the design value x_{design} of a shear strength parameter x by using the following formula:

$$x_{\text{design}} = \frac{x_{\text{charac}}}{f_{\text{partial}}} \quad (20.18)$$

where f_{partial} is the partial factor, used by D-GEO STABILITY to reduce the characteristic strength to lower values. D-GEO STABILITY supplies defaults for the value of f_{partial} that are based on the Dutch NEN code.

20.4 Probabilistic analysis

The following subjects are specifically related to probabilistic analysis with D-GEO STABILITY's Reliability module.

- ◇ (section 20.4.1) The probabilistic procedure (FORM)
- ◇ (section 20.4.2) The assumptions and limitation when using this procedure
- ◇ (section 20.4.3) The stochastic hydraulic pore pressure
- ◇ (section 20.4.4) The stochastic excess pore pressure
- ◇ (section 20.4.5) The stochastic external water level
- ◇ (section 20.4.6) The stochastic model factor

See section 21.5 for specific background on probabilistic analysis with the Bishop probabilistic random field model.

20.4.1 FORM procedure

All combinations of parameter values where the safety factor equals the required value are together called the *Limit State Surface*.

The FORM procedure determines the most likely parameter combination on this surface (the *design point*), by iteratively calculating the probability of failure, using a linearization of the *limit state function* Z .

$$Z = F - F_{\text{required}} \quad (20.19)$$

D-GEO STABILITY calculates the derivatives for the linearization numerically, via small parameter variations (perturbation method). An example of the Limit State Surface is given in Figure 20.1.

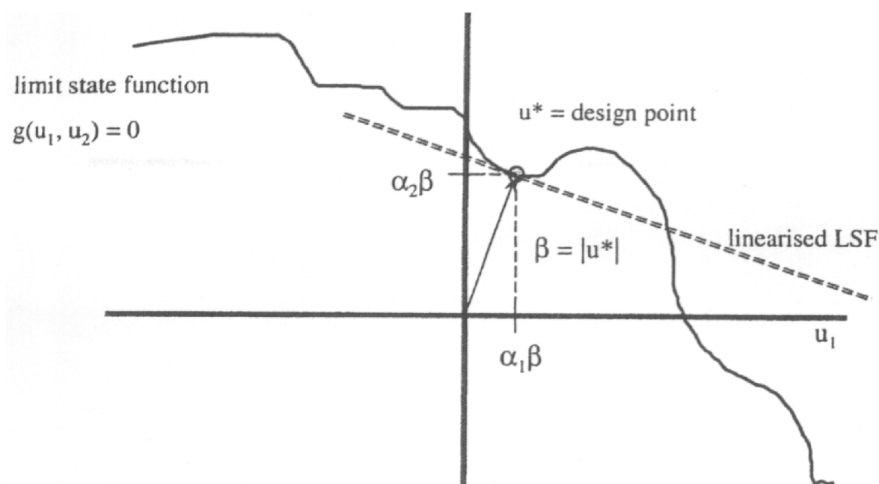


Figure 20.1: Limit Surface and Limit State Function

A FORM analysis results in the reliability index which is calculated with the following equation.

$$\beta = \frac{\mu [F_s] - F_{required}}{\sigma [F_s]} \quad (20.20)$$

where:

$\mu [F_s]$ is the expected mean value of the safety factor
 $\sigma [F_s]$ is the standard deviation of the safety factor

In D-GEO STABILITY the FORM analysis results are also used to determine so-called *influence factors* per parameter. The influence factor for parameter x_i is defined by:

$$\alpha_i = \frac{\sigma [x_i] \frac{\partial Z}{\partial x_i}}{\sqrt{\sum_{i=1}^n \sigma^2 [x_i] \left(\frac{\partial Z}{\partial x_i} \right)^2}} \quad (20.21)$$

The influence factor therefore reflects the sensitivity of the safety factor for the variation of parameters with significant uncertainty (standard deviation). Reduction of the standard deviation will reduce the value of the influence factor.

20.4.2 Assumptions and limitations of the Reliability module

- ◇ D-GEO STABILITY can model the shear strength parameters and the pore pressures as stochastic data. The uncertainty in geometry, unit weight and loads is not directly taken into account.
- ◇ Spatial variability can only be modeled explicitly by using the *Bishop probabilistic random field* module, formerly known as the *MProStab* module. The *Reliability analysis* module of D-GEO STABILITY assumes homogeneous soil parameters.
- ◇ Out-of-plane effects can only be modeled with the *Bishop probabilistic random field* module. The *Reliability analysis* module does not model the out-of-plane effects.
- ◇ The probabilistic FORM procedure is available in combination with the Bishop model and the Uplift Van model.
- ◇ The *Reliability analysis* module applies the probabilistic FORM procedure only on the slip surface position that has been determined from a preceding mean value analysis.

It is possible to manually check if this position results in the lowest value of the reliability index, by performing separate calculations for fixed adjacent positions.

- ◇ The FORM procedure can not be used to determine the probability of failure that is caused by significant contributions from multiple failure modes.
- ◇ The FORM procedure is not guaranteed to give a minimum value for the probability of failure.

20.4.3 Stochastic hydraulic pore pressure

Hydraulic pressure is caused by gravity (hydrostatic part) and by hydraulic boundary conditions. D-GEO STABILITY derives the hydraulic pressure from the user-defined PL-lines at the top and bottom of each layer, using a linear interpolation.

D-GEO STABILITY assumes that the standard deviation of the phreatic line equals the user-defined standard deviation of the hydraulic pressure of the soil type to which the phreatic line is attached. The standard deviation of the hydrostatic pressure component in all layers is equal to the standard deviation of the phreatic surface.

User-defined standard deviations of hydrostatic pore pressures in layers below the phreatic surface should not be less than the standard deviation of the hydrostatic pressure. In case this condition is not fulfilled, D-GEO STABILITY assumes negative correlations among the hydrostatic and the remaining pressure component, in order to obtain a consistent stochastic model.

20.4.4 Stochastic excess pore pressure

Excess pore pressure is caused by loading. D-GEO STABILITY can attribute a degree of consolidation to a soil layer. D-GEO STABILITY also takes into account which layer's load causes the excess pore pressure. The degree of consolidation expresses the adjustment of effective stresses in this layer and is denoted in percentages. For example, 100 percent in a layer means that the weight of an (predefined) overlying layer is fully consolidated. 0 percent means an undrained condition.

The estimation of excess pore pressures is often based on very rough guesses of permeability and poor calculation methods. Consequently, substantial uncertainties may be involved. It is assumed that these uncertainties greatly overrule local fluctuations of pore pressures, for example due to small scale heterogeneity of permeability.

In case excess pore pressures are specified in terms of degrees of consolidation, a reference value for the standard deviation must be provided: σ_{ref} (percents).

The standard deviation of uncertainty of a specified degree of consolidation is calculated as:

$$\sigma_{\text{layer}} = 4\sigma_{\text{ref}} \left(1 - \frac{P_{\text{layer}}}{100}\right) \times \left(\frac{P_{\text{layer}}}{100}\right) \quad (20.22)$$

Thus, standard deviations of excess pore pressures equal zero in the case of fully undrained and completely consolidated conditions. Excess pore pressures, specified by this option are assumed to be perfectly spatially correlated within a soil layer and not correlated among different soil layers.

20.4.5 Stochastic water level model

The Bishop probabilistic random field model determines the probability of failure given a safety factor. It can do so for differing external water levels. The external water levels provide a basis for a stochastic description of the water level. The model incorporates the uncertainty in the external water level by the execution of the following steps.

- ◇ D-GEO STABILITY determines the conditional probability of failure for different user-specified external water levels and their associated hydraulic fields.
- ◇ D-GEO STABILITY combines the resulting relationship between the reliability index and the external water level, using linear interpolation, with a Gumbel assumption for the water level distribution. This is in order to find the integrated probability of failure that is shown in the report. D-GEO STABILITY applies a FOSM procedure for this purpose.

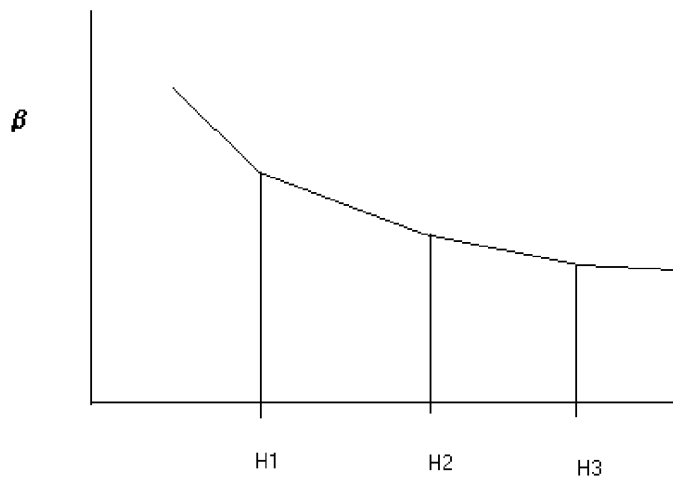


Figure 20.2: Linear interpolation between the conditional reliability index β and the external water level h

Equation 20.23 shows the exceeding probability for the design level, according to the Gumbel distribution. This distribution is determined by the Gumbel parameters B and u_{gumbel} .

$$P(h > h_{\text{design}}) = 1 - \exp \left[- \exp \left(- \frac{2.3}{B} (h_{\text{design}} - u_{\text{gumbel}}) \right) \right] \quad (20.23)$$

Parameter B is the *decimate height*; the increase of the external water level that reduces the exceeding probability with a factor 10.

D-GEO STABILITY determines the parameter u_{gumbel} from the input values of B , the design level h_{design} and the allowed exceeding frequency at the design level.

20.4.6 Stochastic model factor

It is possible to model all remaining uncertainty on the 2D calculation model, the loads and the geometry via the global model factor. This factor represents the required safety factor F_{required} by a mean value and a standard deviation.

The default D-GEO STABILITY values are safe values, obtained from Dutch research on water retaining structures.

Experience with these safe values indicates that the model factor will generally dominate the probability of failure. To eliminate this influence, for example for the purpose of an automated sensitivity analysis, then it is also possible to set the assumed distribution for the model factor to none and set the mean value of F_{required} equal to the value, normally used for a design value analysis.

21 Bishop probabilistic random field

This chapter describes the specific usage and background of the Bishop probabilistic random field module, formerly known as MProStab. This module has been developed by Deltares.

21.1 About the Bishop probabilistic random field

The Bishop probabilistic random field model performs a probabilistic slope stability analysis, in order to determine the probability that the safety factor is less than the required value. Furthermore, this model calculates sensitivity factors, which are used by the computer program PCRING for the analysis of dike systems. The computation model is based on Bishop's method of slices for equilibrium analysis, random field modeling of spatial variability of soil strength and pore pressures, and first order second moment probabilistic reliability analysis. The probability of the external water level can be taken into account optionally. Contributions to the failure resisting moment from the edges of a finite width cylindrical failure model (Van Marcke, 1983) can also be taken into account optionally.

21.2 History

The original MProStab program has been developed since 1980 by GeoDelft, with major sponsorship of the Dutch Ministry of Transport, Public Works and Water Management (Rijkswaterstaat).

The first DOS based release from April 1990 contained already almost all of the current functionality. The option for probabilistic external water levels was added in the extended version from November 2000. MProStab has been incorporated in the windows-based D-GEO STABILITY program version 9.8 in the course of 2003 and is now called the *Bishop probabilistic random field* model. In this version, the original MProStab features for a posteriori analysis are no longer supported.

21.3 Introduction

The Bishop probabilistic random field model is applicable when the stability requirements are stated in terms of acceptable probability of failure instead of the conventional safety factors. Such situations occur when a risk analysis based approach is used for the design of a structure, involving earth slopes. For example, the probabilistic design of water retaining systems in the Netherlands is executed by application of the PCRing program, in connection with this model for the stability of cross-sections. Functional performance of these systems is stated in term of accepted probabilities of flooding due to extreme high tides or river discharge or structural failure due to other causes, among which breach triggered by embankment slope failure. The Bishop probabilistic model was developed for this purpose, but it has been successfully applied in various other projects.

Since 2003, the original MProStab is a special module of the computer program D-GEO STABILITY. This chapter describes only the specific extensions and differences for this module, assuming familiarity with the regular D-GEO STABILITY program and the concepts of probabilistic analysis. The other chapters of the D-GEO STABILITY manual contain a comprehensive description of the regular D-GEO STABILITY usage and backgrounds, including a tutorial introduction.

This section deals with the following topics:

- ◇ [section 21.3.1](#) Special files used by Bishop probabilistic model
- ◇ [section 21.3.2](#) How to select the Bishop probabilistic module and model



21.3.1 Special Files

*.pcr	Output file (ASCII) with sensitivity factors for PCRING.
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21.3.2 Selecting the module and model

On the menu bar, click *Tools* and then select *Options* to open the *Program Options* window. If the D-GEO STABILITY installation is based on floating licenses, then it is possible to use the *Modules* tab to claim a license for the particular modules that are to be used. This window (Figure 21.1) will also be shown directly at start-up, as long as the *Show at start program* box marked.

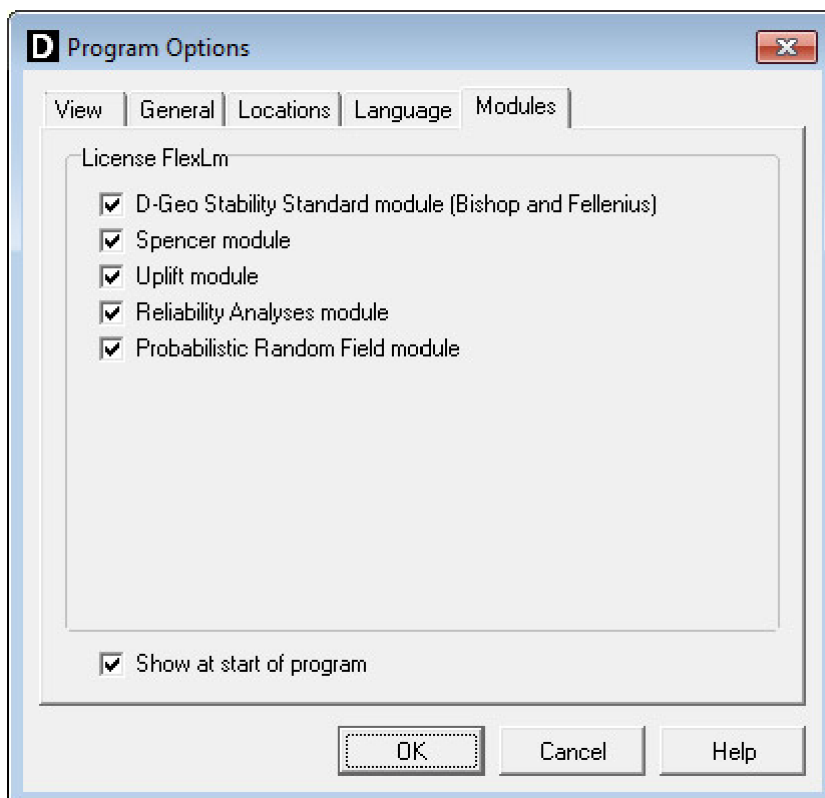


Figure 21.1: Program Options window

On the menu bar, click *Project* and then select *Model* to open the *Model* window (see Figure 21.2). Select the *Bishop prob. random field* option.

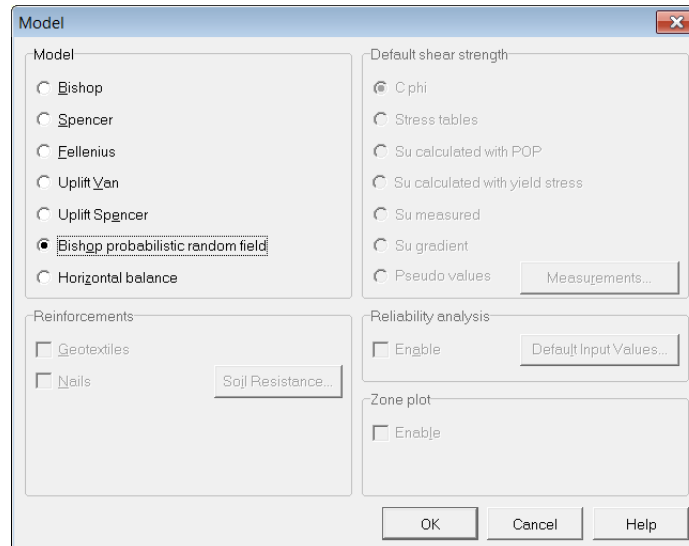


Figure 21.2: Model window

21.4 Working with the model

The following menu options are associated with the Bishop Random Field Method. They deal with inputting stochastic data to obtain factors for the PCRing program:

- ◇ *Model Factor* window
All general stochastic data is entered. See [section 4.2.5](#) for the input description;
- ◇ *Materials* window
All data related to the soil type is entered. Note that dilatancy angle is not used in the *C phi* model in this probabilistic random field model. See [section 4.2.4.5](#) for the input description;
- ◇ *External Water Levels* window
The Bishop probabilistic model determines the conditional probability of failure for a possible maximum of five different external water levels, and then apply a Gumbel distribution assumption for the water level in order to determine the integrated probability. See [section 4.6.2](#) for the input description. See [section 20.4.5](#) for background information.

Note: Special for the Bishop probabilistic random field model is that the output from the separate water levels (in the .pcr file) serves as direct input for PCRING.



21.5 Background

The Bishop probabilistic model is a strongly modified version of Van Marcke's model ([Van Marcke, 1983](#)). Some basic features of the model are discussed in this section. For more detailed descriptions, refer to [Calle \(1985\)](#) and [Calle \(1990\)](#).

21.5.1 Random field model for shear strength

Properties of soils in natural deposits may exhibit considerable spatial variability as a result of large and small scale differences (in space and in time) of the deposition regime and loading conditions during its geological history. The purpose of soil investigation is to model the relevant patterns of spatial variability as accurately as possible.

Common soil investigation acquires data at single spatial points of the deposit, or -semi-continuous data at distinct lines. In general, soil investigation programs allow fairly accurate modeling of the global patterns of variability, such as soil stratification and average trends of variation of soil properties. Patterns of small scale variability within each soil layer, however, remain unrevealed, and evaluation of its effects on stability of slopes can only be dealt with by statistical analysis.

In the Bishop probabilistic random field model, the following assumptions regarding the geometrical soil model and soil properties have been adopted.

- ◇ The geometry of soil layers is considered to be deterministic data, no uncertainty about geometrical data is taken into account.
- ◇ From earlier reported studies on probabilistic stability analysis (Alonso, 1976), it may be concluded that spatial variability of unit weights is of minor importance. Therefore, this parameter is also left out of consideration in the stochastic model, both for the soil and the water.

The background on the stochastic model for the pore pressures is equal to D-GEO STABILITY's reliability module. The background on the random field model for the (drained) shearing strength parameters will be discussed in detail hereafter.

The *Bishop probabilistic random field* model applies a lognormal probability distribution in combination with a certain auto correlation function to define the stochastic model for both the drained cohesion c' , and the tangent of the internal friction angle $\tan \varphi$.

Lognormal distribution

If parameter $y = \ln(x)$ has a normal distribution $\Phi_N(y)$, then parameter x has a lognormal distribution. A lognormal distribution yields always positive values. The normal and lognormal distributions are similar for small ratios between the standard deviation and the mean $\sigma[x]/\mu[x]$. The model derives $\mu[y]$ and $\sigma[y]$ from the user input of $\mu[x]$ and $\sigma[x]$, using equations [Equation 20.2](#) and [Equation 20.3](#).

$$\sigma [y] = \sqrt{\ln \left(1 + \left(\frac{\sigma [x]}{\mu [x]} \right)^2 \right)} \quad (21.1)$$

$$\mu [y] = \ln \left(\mu [x] - \frac{1}{2} \sigma^2 [x] \right) \quad (21.2)$$

Auto Correlation Function

The Bishop probabilistic model describes the pattern of fluctuation within a soil layer as a weak stationary random function in space. This means that in each spatial point of the layer the actual shear strength parameter value is considered to be a sample realization of a random variable. Weak stationary means that for any two spatial points (X_1, Y_1, z_1) and (x_2, y_2, z_2) , x and z being the horizontal and y the vertical spatial coordinates, the (marginal) probability

distributions are identical and that the correlation among the random variables is a function of the distance between these points.

The selected auto-correlation function, which expresses the correlation among any two points as a function of the distance lags, is of a modified Gaussian type:

$$\rho(\delta_x, \delta_y, \delta_z) = \left[1 - \alpha + \alpha \times \exp\left(-\frac{\delta_y^2}{D_v^2}\right) \right] \times \exp\left(-\frac{\delta_x^2 + \delta_z^2}{D_v^2}\right) \quad (21.3)$$

with:

$$\delta_x = |x_1 - x_2|, \quad \delta_y = |y_1 - y_2| \quad \text{and} \quad \delta_z = |z_1 - z_2|$$

where D_h and D_v are the so-called *correlation lengths*, which are related to the scales of fluctuation as introduced by Van Marcke (Van Marcke, 1983). Typical values of D_h range between 25 m and 100 m and values of D_v may range between 0.1 m and 3 m.

The parameter α is a variance parameter, which equals the ratio of local variance, i.e. the variance of fluctuations relative to the mean value along a vertical line, and the total variance, which is the variance relative to the mean value taken over the whole deposit space.

$$\alpha = \frac{\sigma_{vertical}^2}{\sigma_{total}^2} \quad (21.4)$$

For $\alpha = 1$, the auto-correlation function takes on the classical Gaussian form, which is often suggested in literature. It was found, however, that such type may be inconsistent with actual measurements.

Figure 21.3 shows typical fluctuation behavior of cone resistances in a soft clay layer. It appears that averages over depth of the CPT-record show considerable differences from one test location to another, which cannot be explained when a classical Gaussian function type is assumed. The α -parameter enables consistent modeling of the presence of overall weak and strong locations within a layer. For fluctuations of cone resistance in clayey layers, α values ranging between 0.5 and 1.0 have been found.

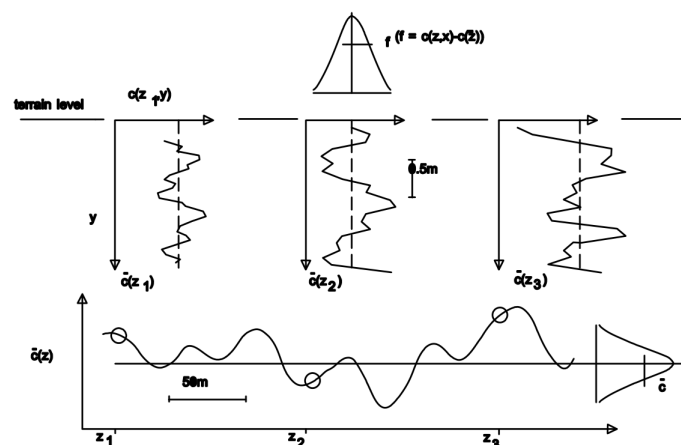


Figure 21.3: Typical pattern of spatial fluctuations of cone resistances in a soft cohesive layer

Parameters of the probability distributions, i.e. expected mean values and standard deviations, must be estimated on the basis of series of laboratory or *in situ* test results. Usually the

number of available test results will be limited, which implies that estimates are statistically biased. Bias of the estimation of the expected mean value is a source of uncertainty which is correlated throughout the soil layer and it must be taken into account in the probabilistic analysis. This has been done in the computation model by adjusting the field variance with a factor $(n+1)/n$ and modifying the auto-correlation function into:

$$r(\delta_x, \delta_y, \delta_z) = \frac{n}{n+1} \rho(\delta_x, \delta_y, \delta_z) + \frac{1}{n+1} \quad (21.5)$$

where n is the number of test samples.

If both c and $\tan(\varphi)$ are estimated from test results of the same experiment, e.g. triaxial test, the estimates are (negatively) correlated. In the stochastic field model it is assumed that the fluctuation fields of the two parameters are not correlated. Correlation among estimates c and $\tan(\varphi)$ from the test result of a sample, results in correlated estimates of the expected mean values of these parameters. The larger the number of tests, the smaller the coefficient of correlation among estimates of expected mean values of the parameters (Calle, 1990). Correlation can be taken into account in the Bishop probabilistic model. The assumption of zero correlation, however, is slightly conservative.

21.5.2 Failure mechanism, probability of slope failure

The Bishop probabilistic random field model assumes a failure mode and equilibrium analysis of the Bishop type, i.e. circular failure modes and the method of slices, is used for equilibrium analysis.

In the conventional deterministic analysis it is assumed that soil data are constant in the along slope direction and that failure modes are of infinite width. As a consequence, no shearing forces in the cross sectional plane of slope must be considered in the equilibrium analysis.

In the probabilistic model it is assumed that shearing strength of the soil may fluctuate stochastically from one cross section to another in the along slope direction. Consequently, the resulting safety factor will be a stochastic function in the along slope direction. Strictly speaking, the assumption of absence of shearing forces in the cross sectional plane is no longer valid, unless it is assumed that failure modes behave as perfectly rigid 3-D bodies. Such assumption is only justifiable if the width of a failure mode (initially) equals the width of a stretch where the safety factor is less than 1.0 (Calle, 1985). The occurrence of such stretch is therefore a necessary, though not sufficient, condition for failure. Whether or not real failure occurs depends on the contribution to the resisting moment, which comes from shearing forces at the edges of the finite width failure mode (Calle, 1985).

The probability of occurrence of a stretch where the Bishop safety factor is less than 1.0 will be referred to as the probability of a potential failure zone. The probability of failure, taking the edge contributions to the failure resisting moment into account, will be referred to as the probability of slope failure.

21.5.3 Probabilistic analysis

The Bishop probabilistic random field module determines the probability of failure for one water level in two steps, i.e.:

Cross-Section analysis

First order second moment probabilistic (FOSM) analysis of the slip circle equilibrium according to Bishop's method. The Bishop probabilistic model determines probabilities by linearization of the limit state function at the mean value and at the so-called design point value.

The latter approach is also known as the FORM method. Based on input data regarding geometry and soil parameters and statistical data regarding soil strength parameters and pore pressures, as previously discussed, the computer program calculates statistical parameters of the Bishop stability factor. The calculated parameters are the mean expected value μ_F , the standard deviation σ_F , and the auto-correlation function r_F in the out-of-plane direction.

Out-of-plane analysis

The Bishop probabilistic model calculates for each of the failure circles the probability of occurrence of a potential failure zone, based on the results of the first step. Calculation is based on the concept of first exceeding events in the theory of stationary stochastic processes, assuming the occurrence of an event $F(Z) < 1$ somewhere in a stretch of length L as a rare Poisson event.

The last step is explained below.

The probability of occurrence of a potential failure zone may, by approximation, be calculated as:

$$P(F(Z) < F_{required}, Z \in [0, L]) = \Phi(-\beta_F) + \Phi(\beta_F) [1 - \exp(-N_F L)] \quad (21.6)$$

with:

$$N_F = \frac{1}{2\pi} \exp\left(-\frac{1}{2}\beta_F^2 \sqrt{-r_F''(0)}\right)$$

where $r_F''(0)$ denotes the second derivative at zero lag of the modified auto-correlation function of the safety factor (see [Equation 21.5](#)).

The width of a potential failure zone, l , is exponentially distributed. Its expected mean value equals:

$$\mu_l = \frac{\Phi(-\beta_F)}{N_F} \quad (21.7)$$

The above approximation is valid for small probabilities, i.e. for β_F values greater than, say, 1.5.

Finally, the Bishop probabilistic model calculates the probability of real occurrence of a 3D failure mode with finite width equal to μ_l as:

$$P(F_l < l) \approx \frac{\Phi(-\beta_l)}{\Phi(-\beta_F)} P(F(z) < 1, z \in [0, L]) \quad (21.8)$$

with:

$$\beta_l \approx \frac{\mu_F + \frac{\mu_{Me}}{\mu_l M_0} - 1}{\sqrt{\sigma_F^2 + \frac{\sigma_{Me}^2}{\mu_l^2 M_0^2}}} \quad (21.9)$$

where F_l denotes the stability factor of the failure mode, including the edge contributions to the failure resisting moment.

In this equation, M_0 denotes the overturning moment of the corresponding slip circle, and μ_{Me} and σ_{Me} are the expected mean value and standard deviation of the edge contribution to the failure resisting moment.

21.5.4 Stochastic water level model

The Bishop probabilistic random field model incorporates the uncertainty in the external water level in the same way as D-GEO STABILITY's Reliability module ([chapter 20](#)).

22 Zone Plot

This chapter describes the background of the *Zone Plot* module.

22.1 Differentiation of safety factors

The zone plot method is based on the requirement that the rest profile of a dike remains always intact in case of high water turning back. This rest profile is defined by (see [Figure 22.1](#)):

- ◇ a crest of 3 meters width, with a level corresponding to the dike table height (DTH), and an overtopping flow of 0.1 l/s/m;
- ◇ an inside talus, with a slope depending on the material of the dike and the underground: 1:2 for clay and 1:4 for sand and peat.

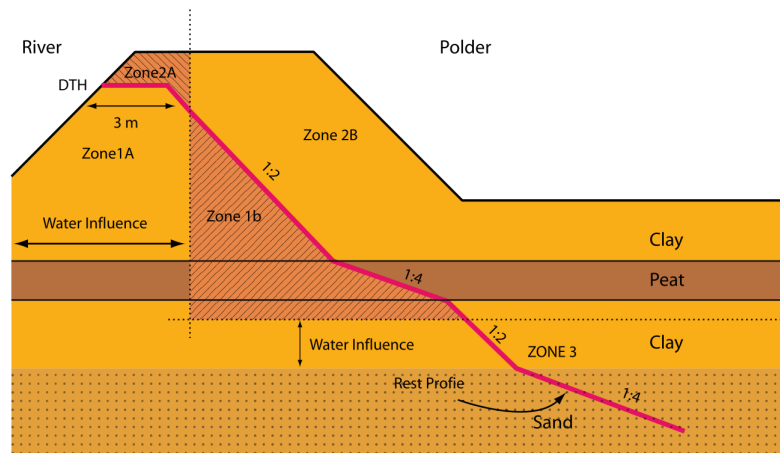


Figure 22.1: Schematization of the zones 1A, 1B, 2A, 2B and 3 of the zone plot method

A high safety factor applies below this rest profile (zone 1). Slip surfaces which damage this rest profile must have a safety factor which is higher than (or at least equal to) the safety factor for macro stability recommended by the Dutch TAW guidelines ([TAW, 1985, 1989, 1994](#)). If a slip surface leaves intact this rest profile, a lower required safety factor can be used (zone 2).

A third zone, called zone 3, is also defined. This zone contains all the slip surfaces which are important for the traffic function of the dike.

It is also determined if the action of the high water has an influence on the slip surface. If it is the case, then the slip surface is situated in zone A and a high required safety factor must be used. If the action of the high water has no influence on the slip surface, then a less strict required safety factor can be used in the zone B.

22.2 Determination of the modified slip surface

A slip surface passing through zone 1, but with an entrance point in zone 2, is according to the zone plot method defined as a slip surface in zone 2 only if the modified slip surface (deformed situation) leaves the rest profile intact. For this deformed situation, an additional calculation is carried out. The (original) entrance point of the slip surface is dropped down to come just in the rest profile. The entrance point of this modified slip surface lies then in zone 1 and therefore must satisfy the required safety of zone 1. If the modified slip surface satisfies the required safety of zone 1, then the original slip surface (non-deformed situation) is in zone 2. If the modified slip surface does not satisfy the required safety of zone 1, then the slip surface

is in zone 1 (see [Figure 22.2](#)).

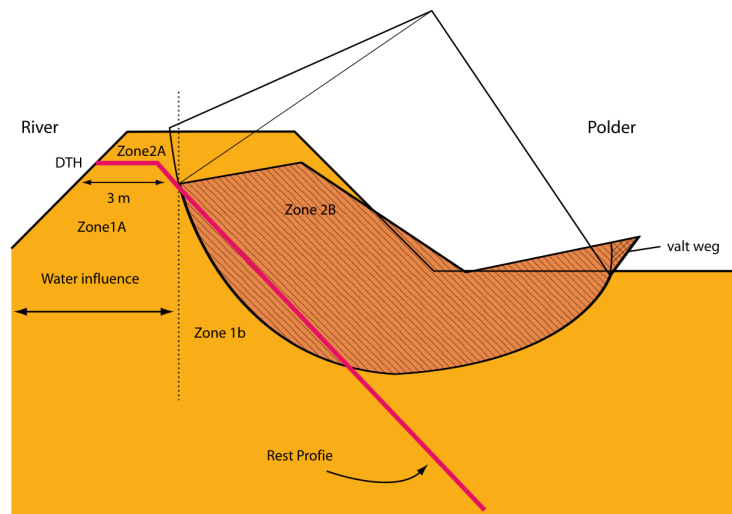


Figure 22.2: Schematization of the modified slip surface (deformed situation after rotation)

The additional calculation makes the assumption that if the slip surface slides the stability factor changes. The driving moment decreases, whereas the resisting moment increases. Because the ground will deform, the sliding force of the ground decreases. This decrease of the force is taken into account in the using a factor called remolding reduction factor. Based on tests and literature, the default value of this factor is set to 0.5 in D-GEO STABILITY, however it can be changed in the *Calculation Options* window ([section 5.1](#)). Additional calculation is carried out as a supplement to the standard calculation. It is assumed that the ground which is beyond the exit point after rotation (and therefore above the surface level) is no more part of the slip surface. During the calculation of the stability of the sliding slip surface, an extra model factor called schematization reduction factor is used. Its default value is set to 0.8 but it can be changed in the *Calculation Options* window ([section 5.1](#)).

23 Benchmarks

Deltares Systems commitment to quality control and quality assurance has led them to develop a formal and extensive procedure to verify the correct working of all of their geotechnical engineering tools. An extensive range of benchmark checks have been developed to check the correct functioning of each tool. During product development these checks are run on a regular basis to verify the improved product. These benchmark checks are provided in the following sections, to allow the users to overview the checking procedure and verify for themselves the correct functioning of D-GEO STABILITY.

The benchmarks for Deltares Systems are subdivided into five separate groups as described below.

- ◇ **Group 1 – Benchmarks from literature (exact solution)**
Simple benchmarks for which an exact analytical result is available.
- ◇ **Group 2 – Benchmarks from literature (approximate solution)**
More complex benchmarks described in literature, for which an approximate solution is known.
- ◇ **Group 3 – Benchmarks for additional options**
Benchmarks which test program features specific to the program being verified.
- ◇ **Group 4 – Benchmarks generated with D-GEO STABILITY**
The benchmarks in this chapter have no exact solution, but are compared with other programs (using the same method).
- ◇ **Group 5 – Benchmarks compared with other programs**
The benchmarks in this chapter have no exact solution, but are compared with other programs (using the same method).

The number of benchmarks in group 1 will probably remain the same in the future. The reason for this is that they are very simple, using only the most basic features of the program.

The number of benchmarks in group 2 may grow in the future. The benchmarks in this chapter are well documented in literature. There are no exact solutions for these problems available, however in the literature estimated results are available. When verifying the program, the results should be close to the results found in the literature.

Groups 3, 4 and 5 of benchmarks will grow as new versions of the program are released. These benchmarks are designed in such a way that (new) features specific to the program can be verified. The benchmarks are kept as simple as possible so that, per benchmark, only one specific feature is verified.

As much as software developers would wish they could, it is impossible to prove the correctness of any non-trivial program. Re-calculating all the benchmarks in this report, and making sure the results are as they should be, will prove to some degree that the program works as it should.

Nevertheless there will always be combinations of input values that will cause the program to crash or produce wrong results. Hopefully by using the verification procedure the number of times this occurs will be limited.

The benchmarks will all be described to such detail that reproduction is possible at any time. In some cases, when the geometry is too complex to describe, the input file of the benchmark is needed. The results are presented in text format with each benchmark description.

The input files belonging to the benchmarks can be found on CD-ROM or can be downloaded

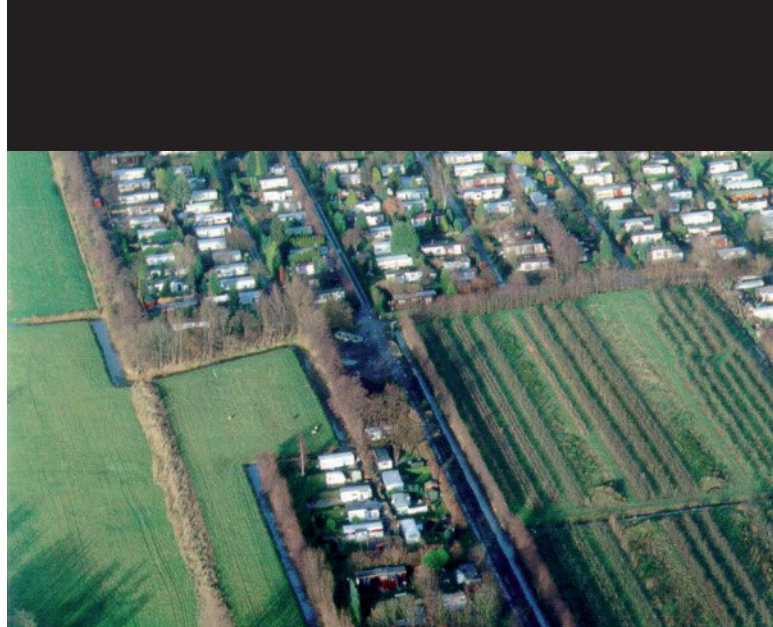


from our website www.deltaressystems.com.

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