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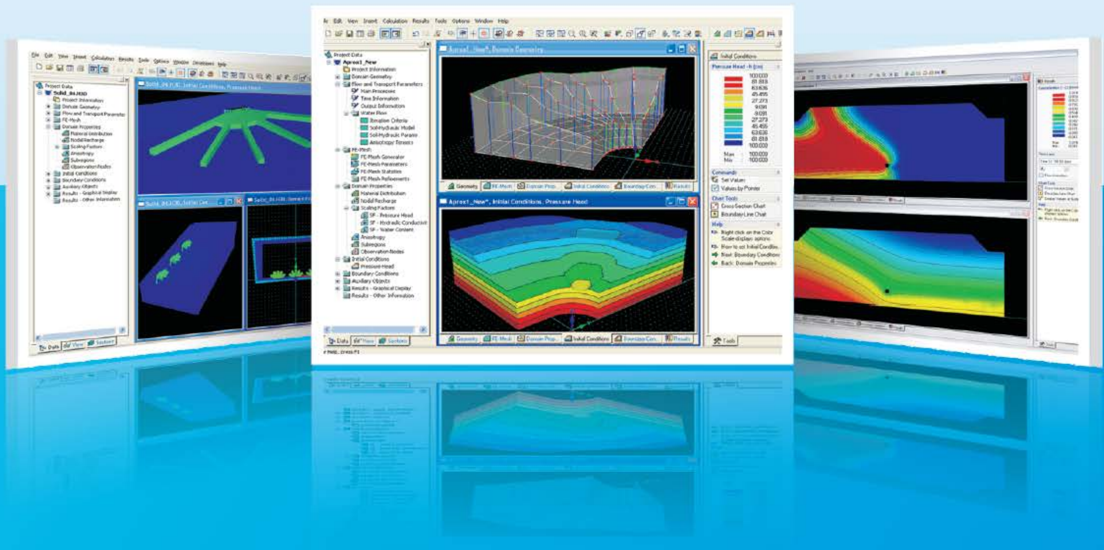
HYDRUS

Slope Stability Module
User Manual



HYDRUS add-on module for stability checks of embankments, dams, earth cuts and anchored sheeting structures with the influence of water

June 2014

The HYDRUS Software Package for Simulating
the Two- and Three-Dimensional Movement
of Water, Heat, and Multiple Solutes
in Variably-Saturated Porous Media

SLOPE STABILITY

HYDRUS add-on Module

User Manual

Version 2.04

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Introduction

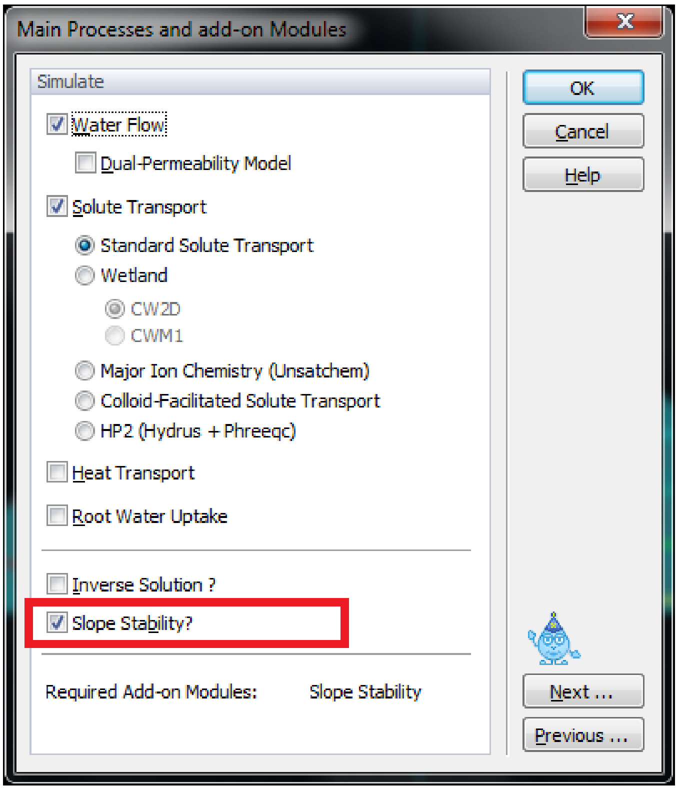
HYDRUS add-on module Slope Stability is intended to be used mainly for stability checks of embankments, dams, earth cuts and anchored sheeting structures. The influence of water is modeled using the distribution of pore pressure, which is imported automatically from the HYDRUS results for specified times. Each time step of water distribution can be analyzed separately. The slip surface is considered as circular (and is evaluated using the Bishop, Fellenius/Petterson, Morgenstern-Price or the Spencer method).

Main features

- Presence of water modeled by pore pressure imported from HYDRUS results
- Arbitrary number of surcharges (strip, trapezoidal, concentrated loading)
- Arbitrary number of anchors
- Simple modeling of rigid bodies
- Earthquake effects
- Geo-reinforcement may be included
- Analysis according to safety factor
- Analyses methods - Bishop, Fellenius/Petterson, Spencer, Morgenstern-Price

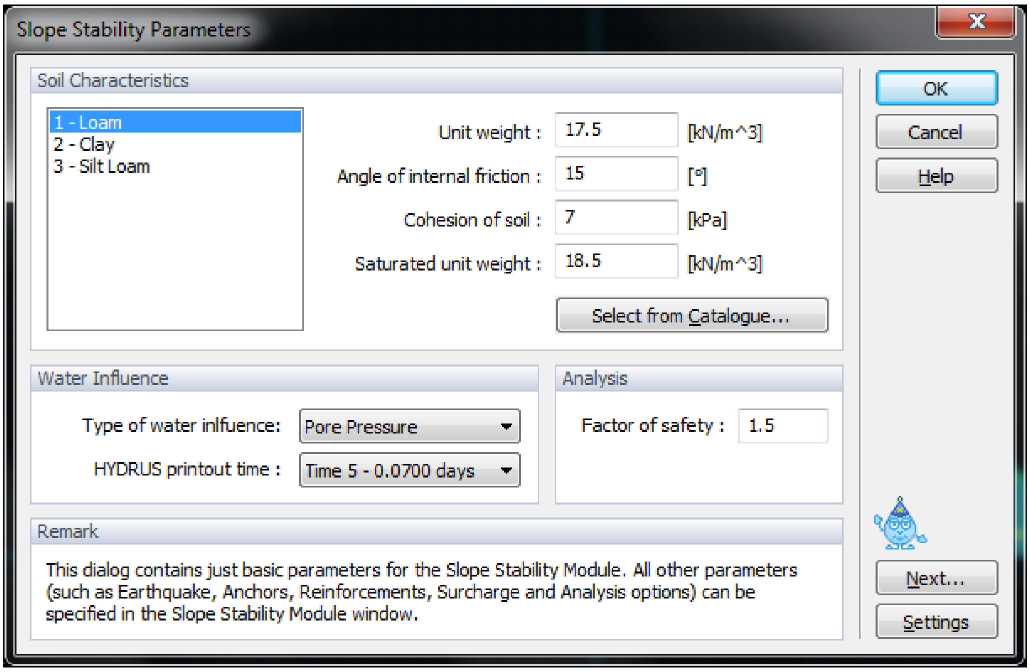
Integration with HYDRUS

The module can be activated in HYDRUS in the Main Processes window and is only available in projects with 2D-General Domain Type. Once the module is active, related commands can be found in the main menu (Modules -> Slope Stability) or in the Navigator data tree (item Slope Stability).



Input Data

The basic input parameters of the Slope Stability module, such as basic Soil Characteristics, Water Influence, and the Factor of Safety are specified in HYDRUS dialog “**Slope Stability Parameters”**:



Soil Characteristics: Additional parameters needed for the calculations of slope stability for all materials used in HYDRUS. Parameters for each particular material can be selected from the catalog using the "Select from Catalogue" button or can be defined individually.

Water Influence: Select whether the effects of the soil water pore pressure should be taken into account when carrying out Slope Stability calculations (Type of water influence) and for what time level should the calculations be carried out (Hydrus printout time; corresponds to Hydrus printing times).

Analysis: A Safety Factor, for which slope stability is considered satisfactory. Its value must be in the interval of (1; 5).

Opening the Slope Stability Module

Command “Open Slope Stability Module” opens the module window. The user can then define additional parameters, such as for Earthquake, Anchors, Reinforcements, Surcharge and Analysis options, and run the analysis. More information about the module, running the analysis and viewing results can be found in further sections of this manual.

Demo examples

Hydrus installation program contains several examples for the calculation of slope stability, which are located in the “**Slope Stability**” Project Group (see HYDRUS Project Manager).

Theory

The slope stability problem is solved in a two dimensional environment. The soil in a slope body can be found below the ground water table, water can also exceed the slope ground, which can be either partially or completely flooded. The slope can be loaded by a surcharge of a general shape either on the ground or inside the soil body. The analysis allows for including the effect of anchors expected to support the slope or for introduction of horizontal reinforcing elements – reinforcements. An earthquake can also be accounted for in the analysis.

The analysis can be performed according to following theories:

- Fellenius/Petterson
- Bishop
- Spencer
- Morgenstern-Price

Soil body

The soil body is formed by a **layered profile**. An arbitrary number of layers can be used. Each layer is defined by its geometry and material. The material of a layer is usually represented by a **soil** with specified properties. The geostatic stress in a soil body is determined during the analysis.

Geostatic stress, uplift pressure

Stress analysis is based on existence of soil layers specified by the user during input. The program further inserts fictitious layers at the locations where the stress and lateral pressure (GWT, points of construction, etc.) change. The normal stress in the i^{th} layer is computed according to:

$$\sigma_i = \sum h_i . \gamma_i$$

where: h_i - thickness of the i^{th} layer

γ_i - unit weight of soil

If the layer is found below the **ground water table**, the unit weight of soil below the water table is specified with the help of inputted parameters of the soil as follows:

$$\gamma_{su} = \gamma_{sat} - \gamma_w$$

where: γ_{sat} - saturated unit weight of soil

γ_w - unit weight of water

Unit weight of water is assumed in the program equal to $10\ kN/m^3$.

Effective / total stress in soil

Vertical normal stress σ_z is defined as:

$$\sigma_z = \gamma_{ef} . z + \gamma_w . z$$

where: σ_z - vertical normal total stress

γ_{ef} - submerged unit weight of soil

z - depth bellow the ground surface

γ_w - unit weight of water

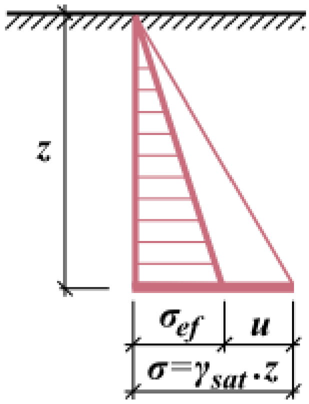
This expression in its generalized form describes so called concept of effective stress:

$$\sigma_z = \sigma_{ef} + u$$

where: σ - total stress (overall)

σef - effective stress (active)

u - neutral stress (pore water pressure)



Total, effective and neutral stress in the soil

Effective stress concept is valid only for the normal stress σ, since the shear stress τ is not transferred by the water so that it is effective. The total stress is determined using the basic tools of theoretical mechanics, the effective stress is then determined as a difference between the total stress and neutral (pore) pressure (i.e. always by calculation, it can never be measured). Pore pressures are determined using laboratory or in-situ testing or by calculation. To decide whether to use the total or effective stresses is no simple. The following table may provide some general recommendations valid for majority of cases. We should realize that the total stress depends on the way the soil is loaded by its self weight and external effects. As for the pore pressure we assume that for flowing pore water the pore equals to hydrodynamic pressure and to hydrostatic pressure otherwise. For partial saturated soils with higher degree of it is necessary to account for the fact that the pore pressure evolves both in water and air bubbles.

Assume conditions	**Drained layer**	**Undrained layer**
short – term	effective stress	total stress
long – term	effective stress	effective stress

In layered subsoil with different unit weight of soils in individual horizontal layers the vertical total stress is determined as a sum of weight of all layers above the investigated point and the pore pressure:

$$\sigma_z = \int_0^z \gamma dz + \gamma_w (z - d)$$

where: σz - vertical normal total stress

γ - unit weight of soil

- unit weight of soil in natural state for soils above the GWT and dry layers

- unit weight of soil below water in other cases

d - depth of the ground water table below the ground surface

z - depth bellow the ground surface

γw - unit weight of water

Influence of water

Ground water can be assigned to the slope plane section using one of the two options:

1) Ground water table

The ground water table is specified as a polygon. It can be arbitrarily curved, placed totally within the soil body or introduced partially **above the ground surface**.

Presence of water influences value of pore pressure acting within a soil and reducing its shear bearing capacity. The pore pressure is considered as the hydrostatic pressure, i.e. unit weight of water is multiplied by reduced height of the water table:

$$u = \gamma_w . h_r$$

where: γw - unit weight of water

hr - reduced height of water table

where:

$$h_r = h.cos^2 \alpha$$

where: h - vertical distance of point, where pore pressure is calculated and point on the water table

α - inclination of the water table

Resultant force of pore pressure at certain section of the block is used in the calculation:

$$U = u.l$$

where: u - pore pressure in the point

l - length of section

Below the ground water table the analysis proceeds using the unit weight of saturated soil γsat and uplift pressure; above the ground water table the analysis assumes the inputted unit weight of soil γ.

The shear forces along the slip surface are provided by:

$$T = (N - U) tg \varphi + c.d$$

where: T - shear force along slip surface segment

N - normal force along slip surface segment

U - pore pressure resultant along slip surface segment

φ - angle of internal friction

c - cohesion

d - length of slip surface segment

In case of total stress (entered in the "Soil" dialog window) total parameters are used and pore pressure is considered zero.

2) Pore pressure isolines

Pore pressure isolines must be imported directly from HYDRUS program, it is not possible to input them in the modul Slope stability.

In the area, where u is positive, entered unit weight of saturated soil γsat is considered; in other case unit weight of soil γ is used.

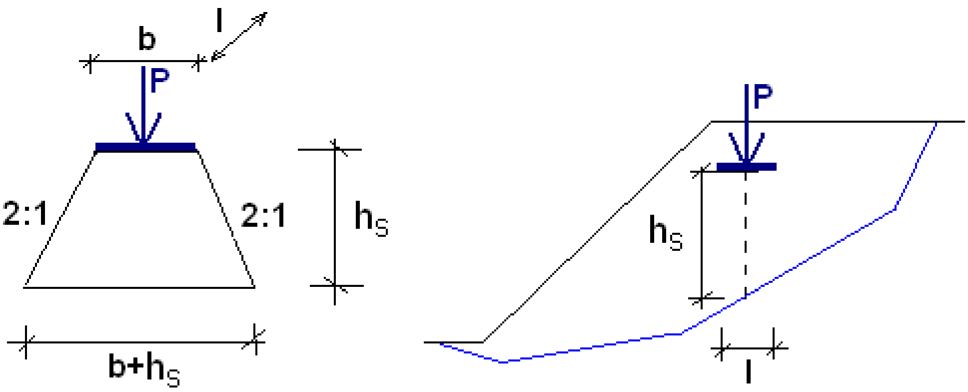
The pore pressure values are introduced with the help of isolines connecting points with the same value of pore pressure. Linear interpolation is assumed to obtain intermediate values. Pore pressure values are then derived from the values of pore pressure obtained in specific points within the slope plane section.

Surcharge

The slope stability analysis takes into account even the surcharge caused by neighboring structures. The surcharge can be introduced either as a concentrated force or distributed load acting either on the ground surface or inside the soil body.

Since it is usually assumed that the surcharge is caused by the weight of objects found on the slope body, the vertical component of surcharge having the direction of weight (material component) is added to the weight of blocks. It means that if the earthquake effects are included this component is also multiplied by the factor of horizontal acceleration or vertical earthquake. Material surcharge component also influences the position of block centroid. The components that do not act in the direction of weight are assumed in equations of equilibrium written for a given block as weightless thus neither contribute to inertia effects of the earthquake nor position of block centroid.

The surcharge is always considered in the analysis with respect to one running meter. Providing the surcharge, essentially acting over the area $b*l$, is introduced as a concentrated force it is transformed before running the analysis into a surface loading spread up to a depth of slip surface along the slope *2:1* as displayed in figure.



Scheme of spreading the concentrated load on the slip surface

The analysis then proceeds with the resultant of surface load p having the value:

$$p = \frac{P}{(b + h_s).l}$$

Anchors

Anchor is specified by two points and a force. The first point is always located on the ground surface; the force always acts in the direction of a soil body. The anchor force when computing equilibrium on a given block (slice) is added to the weightless surcharge of the slope.

Two options are available to account for anchors:

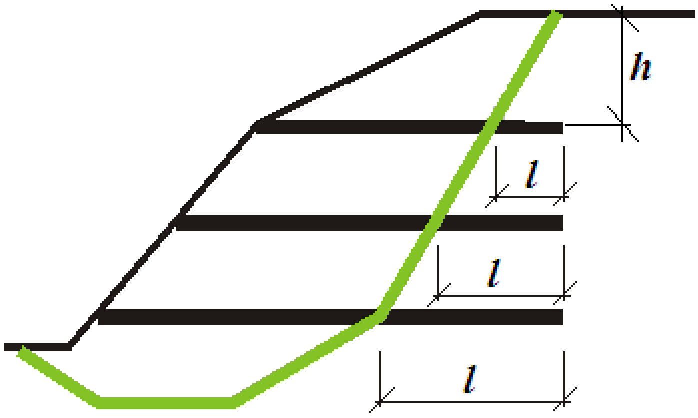
1. **Compute anchor lengths** – analysis assumes infinite lengths of anchors (anchors are always included in the analysis) and computes the required lengths of links anchors (distance between the anchor head and intersection of anchor with the slip surface) subsequently. The anchor root is then placed behind the slip surface. This approach is used whenever we wish the anchor to be always active and thus contribute to increase the slope stability and we need to know its minimum distance.

2. Analysis **with specified lengths of anchors** – the analysis takes into account only those anchors that have their end points (center of roots) behind the slip surface. This approach is used always whenever we wish to evaluate the current state of slope with already existing anchors, since it may happen that some of the anchors may prove to be short to intersect the critical slip surface so that they do not contribute to increase the slope stability.

Reinforcements

Reinforcements are horizontal reinforcing elements, which are placed into the soil to increase the slope stability utilizing their tensile strength. If the reinforcement intersects the slip surface, the force developed in the reinforcement enters the force equation of equilibrium of a given block. In the contrary case, the slope stability is not influenced.

The basic parameter of reinforcement is the **tensile strength** R_t. A design value of this parameter is used - i.e. the strength of reinforcement reduced by coefficients taking into account the effect of durability, creep and installation damage. The force transmitted by reinforcement **can never exceed the assigned tensile strength** R_t.



Scheme of accounting for reinforcement

The second characteristic is the **pull-out strength** T_p. This parameter determines the anchoring length, i.e. the required length of reinforcement in the soil, for which the reinforcement is fully stressed attaining the value R_t. Since the realistic values of the pull-out strength are difficult to determine, the program offers three options for their calculation, respectively for the calculation of the force F transmitted by the reinforcement.

1) Calculate reinforcement bearing capacity

The pull-out force F is given by:

$$F = 2.\sigma.tg\varphi.C.l$$

where:

- σ - normal stress due to self weight at the intersection of reinforcement and slip surface – see Fig.
- φ - angle of internal friction of soil
- C - coefficient of interaction (0,8 by default)
- l - length of reinforcement step joint behind the slip surface into the soil body

2) Input reinforcement anchor length l_k

An anchoring length l_k is specified. This parameter is determined by the shear strength developed between the reinforcement and the soil gradually increasing from zero to its limit value (measured from the end of reinforcement fixed in soil).

$$F = \frac{l}{l_k}.R_t$$

where:

- l - length of reinforcement behind the slip surface into the soil body
- l_k - anchoring length of reinforcement
- R_t - tensile strength

3) Input reinforcement pull-out resistance T_p

The pull-out force F is given by:

$$F = T_p.l$$

where: l - length of reinforcement behind the slip surface into the soil body

Tp - pull-out resistance of reinforcement

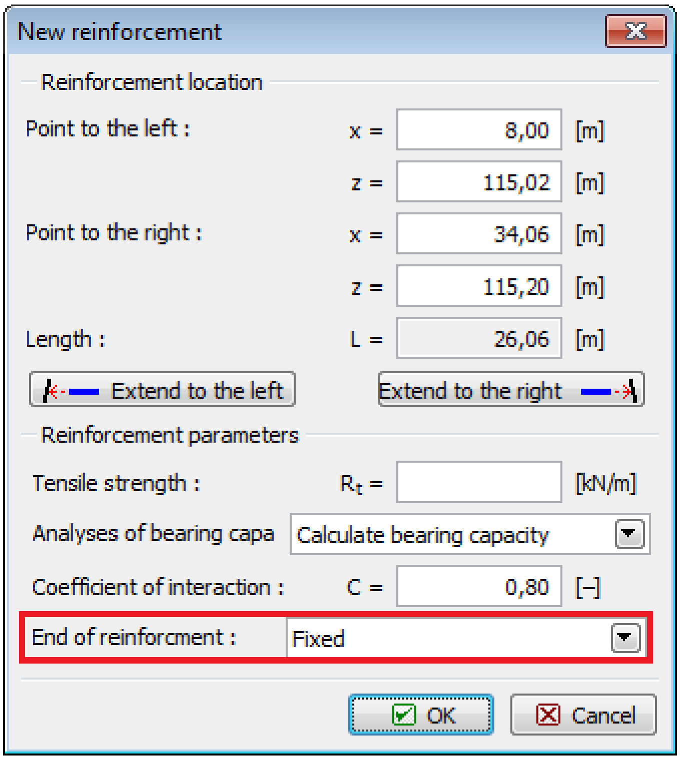
Forces in reinforcements determined on the basis of reinforcement strength may attain relatively large values. Introducing these forces in the analysis yields a higher factor of safety of a given slip surface. In case of rigorous methods (Spencer, Janbu, Morgenstern-Price) the introduction of such forces in the reinforcements may cause the loss of convergence. This appears mainly in cases when these forces are so high that it is not possible to achieve equilibrium of forces acting on blocks while maintaining the principal assumptions of individual methods, e.g. the assumption of zero moment at the end of slip surface. In such a case the forces in reinforcements are reduced as least as possible (to the highest acceptable values) so the method converges and attains acceptable results. The reduced values of forces are then written out as part of the stability analysis results. However, in case of no reduction these forces are not included in the final set of results.

End of reinforcements

The reinforcement mounting is assumed in the program either as **fixed** or **free**.

Should the slope with reinforcement fail the one of the following reinforcement failure shown in the following figures may appear.

If the reinforcement at its starting point in front of the slip surface is fixed (for example fixed into the structure cladding) the 3rd type of failure is prevented – pullout of the reinforcement in front of the slip surface. The failure type 1 and 2 is always checked in the analysis, type of failure 3 is checked only for reinforcements having free end points that allow for such a type of failure.



"New reinforcement" dialogue window - input of end of reinforcement

Breaking of reinforcement – type of failure 1

Pullout of the reinforcement behind the slip surface – type of failure 2

Pullout of the reinforcement in front of the slip surface – type of failure 3

Earthquake effect

The program allows for computing the earthquake effects with the help of two variables – factor of horizontal acceleration K_h or the coefficient of vertical earthquake K_v.

- **Coefficient of vertical earthquake** K_v

The coefficient of vertical earthquake either decreases ($K_v > 0$) or increases ($K_v < 0$) the unit weight of a soil, water in a soil and material surcharge by multiplying the respective values by $1 - K_v$. It is worth to note that the coefficient K_v may receive both positive and negative value and in case of sufficiently large coefficient of horizontal acceleration the slope relieve ($K_v > 0$) is more unfavorable than the surcharge.

- **Factor of horizontal acceleration** K_h

In a general case the computation is carried out assuming a zero value of the factor K_h. This constant, however, can be exploited to simulate the effect of earthquake by setting a non-zero value. This value represents a ratio between horizontal and gravity accelerations. Increasing the factor K_h results in a corresponding decrease of the safety factor SF.

The coefficient of horizontal acceleration introduces into the analysis an additional horizontal force acting in the center of gravity of a respective block with the magnitude K_h*W_i, where W_i is the block overall weight including the material component of the slope surcharge.

The following table lists the values of the factor Kh that correspond to different degrees of earthquake based on M-C-S scale.

M-C-S degree	**Horizontal acceleration**	**Factor of horizontal acceleration**
(MSK-64)	[mm/s^2]	Kh
1	0,0 - 2,5	0,0 - 0.00025
2	2,5 - 5,0	0,00025 - 0.0005
3	5,0 - 10,0	0,0005 - 0.001
4	10,0 - 25,0	0,001 - 0.0025
5	25,0 - 50,0	0,0025 - 0.005
6	50,0 - 100,0	0,005 - 0.01
7	100,0 - 250,0	0,01 - 0.025
8	250,0 - 500,0	0,025 - 0.05
9	500,0 - 1000,0	0,05 - 0.1
10	1000,0 - 2500,0	0,1 - 0.25
11	2500,0 - 5000,0	0,25 - 0.5
12	> 5000,0	> 0.5

Verification of safety

Verification is done according to the **factor of safety**:

$$\frac{M_p}{M_a} > SF_s$$

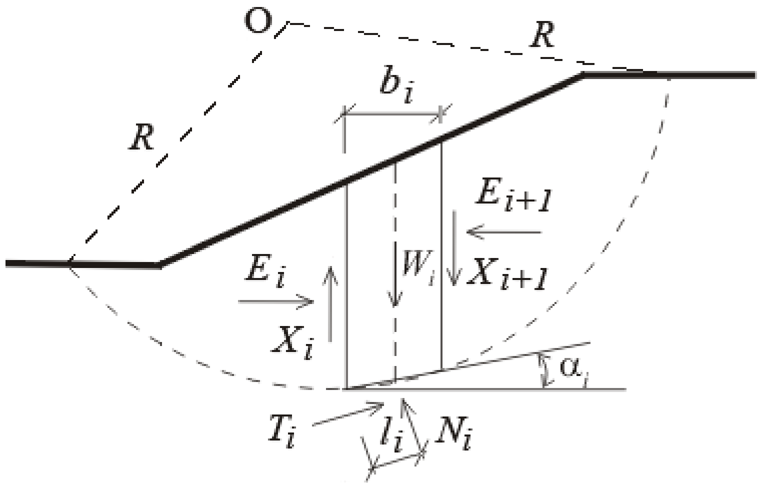
where: Ma - sliding moment

Mp - resisting moment

SF_S - factor of safety imported from main HYDRUS program

Circular slip surface

All methods of limit equilibrium assume that the soil body above the slip surface is subdivided into blocks (dividing planes between blocks are always vertical). Forces acting on individual blocks are displayed in figure.



Static scheme of slice

Here, X_i and E_i are the shear and normal forces acting between individual blocks, T_i and N_i are the shear and normal forces on individual segments of the slip surface, W_i are weights of individual blocks.

Individual methods of slices differ in their assumptions of satisfying the force equations of equilibrium and the moment equation of equilibrium with respect to the center **O**.

The program allows for adopting one of the following methods:

- Fellenius / Petterson
- Bishop
- Spencer
- Morgenstern-Price

Ground water specified within the slope body the analysis in two different ways. First when computing the weight of a soil block and second when determining the shear forces. Note that the effective soil parameters are used to relate the normal and shear forces.

Introducing anchor forces and water above the ground surface into the analysis

Anchor forces are considered as external loading applied to the slope. They are taken with respect to one running meter [*kN/m*]and introduced into the moment equation of equilibrium. These forces should contribute to additional stability, if that cannot be achieved in a different way. There is no limitation to the magnitudes of anchor forces and therefore it is necessary to work with realistic values.

Influence of water above the ground surface is considered as set forces acting perpendicular on the ground surface together with pore pressure along the slip surface, which is derived depending on the depth of slip surface measured from the ground water table. The forces acting on the ground surface enter the moment equation of equilibrium as forces acting on respective arms measured towards the center of the slip surface.

Optimization of circular slip surface searches the most critical surface (the lowest *SF*).

Fellenius / Petterson

The simplest method of slices assumes only the overall moment equation of equilibrium written with respect to the center of the slip surface. The shear and normal forces between blocks X_i and E_i are neglected. The factor of safety *SF* follows directly from the following expression:

$$FS = \frac{1}{\sum_i W_i . sin\,\alpha_i} . \sum_i \left[c_i . l_i + \left(N_i - u_i . l_i \right) . tan\,\varphi_i \right]$$

where: u_i - pore pressure within block

c_i, φ_i	-	effective values of soil parameters
W_i	-	block weight
N_i	-	normal force on the segment of the slip surface
α_i	-	inclination of the segment of the slip surface
l_i	-	length of the segment of the slip surface

Literature:

Petterson KE (1955) The early history of circular sliding surfaces. Geotechnique 5:275–296

Bishop

The simplified Bishop method assumes zero X_i forces between blocks. The method is based on satisfying the moment equation of equilibrium and the vertical force equation of equilibrium.

The factor of safety SF is found through a successive iteration of the following expression:

$$FS = \frac{1}{\sum_i W_i . \sin \alpha_i} . \sum_i \frac{c_i . b_i + (W_i - u_i . b_i) . \tan \varphi_i}{\cos \alpha_i + \frac{\tan \varphi_i . \sin \alpha_i}{FS}}$$

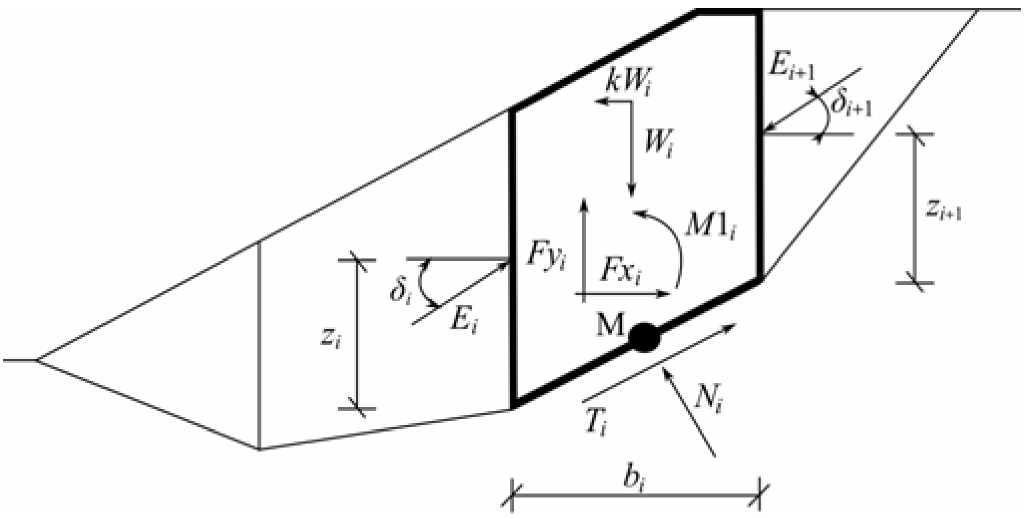
where:	u_i	-	pore pressure within block
	c_i, φ_i	-	effective values of soil parameters
	W_i	-	block weight
	α_i	-	inclination of the segment of the slip surface
	b_i	-	horizontal width of the block

Literature:

Bishop, *A.W. (1955) "The Use of the Slip Circle in the Stability* Analysis *of Slopes", Geotechnique, Great Britain, Vol. 5, No. 1, Mar., pp. 7-17*

Spencer

The Spencer method is a general method of slices developed on the basis of limit equilibrium. It requires satisfying equilibrium of forces and moments acting on individual blocks. The blocks are created by dividing the soil above the slip surface by dividing planes. Forces acting on individual blocks are displayed in the following figure.



Static scheme – Spencer method

Each block is assumed to contribute due to the following forces:

W_i - block weight, including material surcharge having the character of weight including the influence of the coefficient of vertical earthquake K_v

$K_h{*}W_i$ - horizontal inertia force representing the effect of earthquake, K_h is the factor of horizontal acceleration during earthquake

N_i - normal force on the slip surface

T_i - shear force on the slip surface

E_i, E_{i+1} - forces exerted by neighboring blocks, they are inclined from horizontal plane by angle δ

Fx_i, Fy_i - other horizontal and vertical forces acting on block

$M1_i$ - moment of forces Fx_i, Fy_i rotating about point M, which is the center of the i^{th} segment of slip surface

U_i - pore pressure resultant on the i–th segment of slip surface

The following assumptions are introduced in the Spencer method to calculate the limit equilibrium of forces and moment on individual blocks:

- dividing planes between blocks are always vertical
- the line of action of weight of block W_i passes through the center of the i^{th} segment of slip surface represented by point **M**
- the normal force N_i is acting in the center of the i^{th} segment of slip surface, at point **M**
- inclination of forces E_i acting between blocks is constant for all blocks and equals to δ, only at slip surface end points is $\delta = 0$

The solution adopts the following expressions:

$$N_i = N_i' + U_i \tag{1}$$

$$T_i = \left(N_i - U_i\right)\tan\varphi_i + \frac{b_i}{\cos\alpha_i} = N_i'.\tan\varphi_i + c_i.\frac{b_i}{\cos\alpha_i} \tag{2}$$

$$N_i' + U_i - W_i.\cos\alpha_i + K_h.W_i.\sin\alpha_i + Fy_i.\cos\alpha_i - Fx_i.\sin\alpha_i + \tag{3}$$

$$E_{i+1}.\sin\left(\alpha_i - \delta_{i+1}\right) - E_i.\sin\left(\alpha_i - \delta_i\right) = 0$$

$$N_i'.\frac{\tan\varphi_i}{FS} + \frac{c_i}{FS}.\frac{b_i}{\cos\alpha_i} - W_i.\sin\alpha_i - K_h.W_i.\cos\alpha_i + Fy_i.\sin\alpha_i + \tag{4}$$

$$Fx_i\cos\alpha_i - E_{i+1}.\cos\left(\alpha_i - \delta_{i+1}\right) + E_i.\cos\left(\alpha_i - \delta_i\right) = 0$$

$$E_{i+1}.\cos\delta_{i+1}\left(z_{i+1}-\frac{b_i}{2}\tan\alpha_i\right)-E_{i+1}.\sin\delta_{i+1}.\frac{b_i}{2}-$$
$$E_i.\cos\delta_i\left(z_i-\frac{b_i}{2}\tan\alpha_i\right)-E_i.\sin\delta_i.\frac{b_i}{2}+$$
$$M1_i-K_h.W_i\left(y_M-y_{gi}\right)=0 \tag{5}$$

Equation (1) represents the relationship between effective and total value of the normal force acting on the slip surface. Equation (2) corresponds to the Mohr-Coulomb condition representing the relation between the normal and shear forces on a given segment of the slip surface. Equation (3) represents the force equation of equilibrium in the direction normal to the i^{th} segment of the slip surface, whereas Equation (4) represents equilibrium along the i^{th} segment of the slip surface. FS is the factor of safety, which is used to reduce the soil parameters. Equation (5) corresponds to the moment equation of equilibrium about point **M**, where ygi is the vertical coordinate of the point of application of the weight of block and yM is the vertical coordinate of point **M**. Modifying equations (3) and (4) provides the following recursive formula:

$$E_{i+1}=\frac{\left[(W_i-Fy_i).\cos\alpha_i-(K_h.W_i-Fx_i).\sin\alpha_i-U_i+E_i.\sin(\alpha_i-\delta_i)\right].\frac{\tan\varphi_i}{FS}+\frac{c_i}{FS}.\frac{b_i}{\cos\alpha_i}-(W_i-Fy_i).\sin\alpha_i-(K_h.W_i-Fx_i).\cos\alpha_i+E_i.\cos(\alpha_i-\delta_i)}{\sin(\alpha_i-\delta_{i+1}).\frac{\tan\varphi_i}{FS}+\cos(\alpha_i-\delta_{i+1})}$$

This formula allows to calculate all forces Ei acting between blocks for given values of δi and FS. This solution assumes that at the slip surface origin the value of E is known and equal to $E1 = 0$.

Additional recursive formula follows from the moment equation of equilibrium (5) as:

$$z_{i+1}=\frac{\frac{b_i}{2}.\left[E_{i+1}(\sin\delta_{i+1}-\cos\delta_{i+1}.\tan\alpha_i)+E_i.(\sin\delta_i-\cos\delta_i.\tan\alpha_i)\right]+E_i.z_i.\cos\delta_i-M1_i+K_h.W_i.(y_M-y_{gi})}{E_{i+1}.\cos\delta_{i+1}}$$

This formula allows us calculating for a given value of δ all arms z of forces acting between blocks, knowing the value on the left at the slip surface origin, where $z1 = 0$.

The factor of safety SF is determined by employing the following iteration process:

1. The initial value of δ is set to zero $\delta = 0$.

2. The factor of safety SF for a given value of δ follows from equation (6), while assuming the value of $En+1 = 0$ at the end of the slip surface.

3. The value of δ is provided by equation (7) using the values of E determined in the previous step with the requirement of having the moment on the last block equal to zero. Equation (7) does not provide the value of $zn+1$ as it is equal to zero. For this value the moment equation of equilibrium (5) must be satisfied.

4. Steps 2 and 3 are then repeated until the value of δ does not change.

For the process of iteration to be stable it is necessary to avoid unstable solutions. Such instabilities occur at points where division by zero in expressions (6) and (7) takes place. In equation (7), division by zero is encountered for $\delta = \pi/2$ or $\delta = -\pi/2$. Therefore, the value of angle δ must be found in the interval ($-\pi/2$; $\pi/2$).

Division by zero in expression (6) appears when:

$$FS = \tan\varphi_i . \tan\left(\delta_{i+1} - \alpha_i\right)$$

Another check preventing numerical unstability is verification of parameter m_α - following condition must be satisfied:

$$m_\alpha = \cos\alpha_i + \frac{\sin\alpha_i . \tan\varphi_i}{FS} > 0{,}2$$

Therefore before iteration run it is required to find the highest of critical values SF_{min} satisfying above mentioned conditions. Values below this critical value SF_{min} are in area of unstable solution, therefore iteration begins by setting SF to a value "just" above SF_{min} and all result values of SF from iteration runs are higher than SF_{min}.

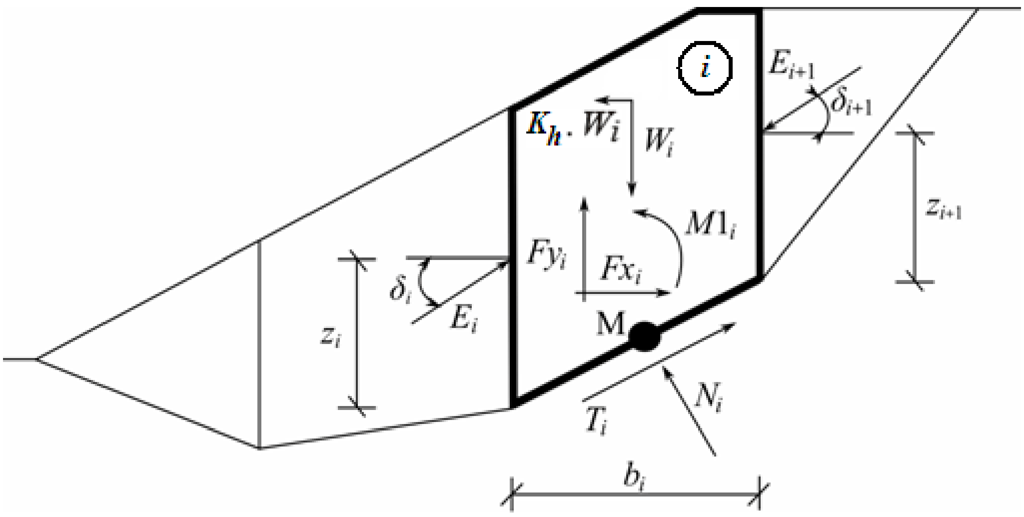
Generally rigorous methods converge worse than the simpler methods (Bishop, Fellenius). Examples with convergence problems include too steep sections of slip surface, complex geometry, a significant jump in surcharge etc. If no result is obtained, we recommend slight change of inputted data, e.g. less steep slip surface, input more points into the slip surface etc. or using of some of the simpler methods.

Literature:

Spencer, E. 1967. A method of analysis of the stability of embankments assuming parallel interslice forces. Géotechnique, 17(1): 11–26.

Morgenstern-Price

Morgenstern-Price is a general method of slices developed on the basis of limit equilibrium. It requires satisfying equilibrium of forces and moments acting on individual blocks. The blocks are created by dividing the soil above the slip surface by dividing planes. Forces acting on individual blocks are displayed in the following figure:



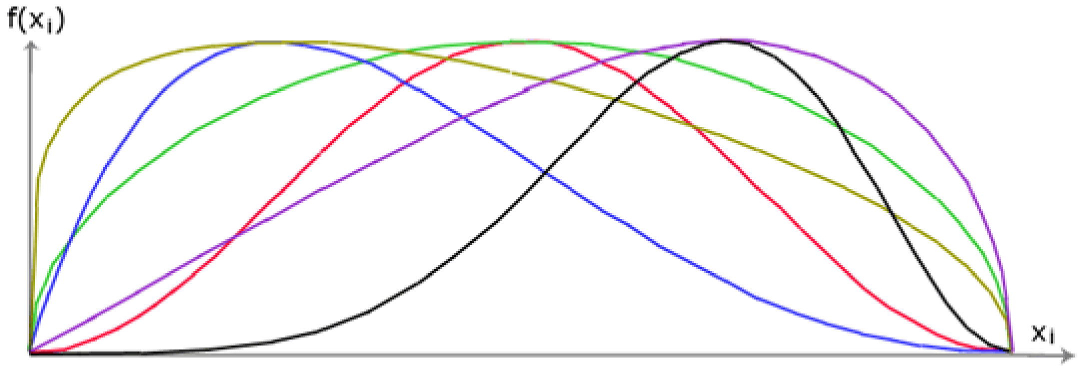
Static scheme – Morgenstern-Price method

Each block is assumed to contribute due to the same forces as in Spencer method. The following assumptions are introduced in the Morgenstern-Price method to calculate the limit equilibrium of forces and moment on individual blocks:

- dividing planes between blocks are always vertical
- the line of action of weight of block W_i passes through the center of the i^{th} segment of slip surface represented by point **M**

- the normal force N_i is acting in the center of the i^{th} segment of slip surface, at point **M**
- inclination of forces E_i acting between blocks is different on each block (δ_i) at slip surface end points is $\delta = 0$

The only difference between Spencer and Morgenstern-Price method is shown in the above list of assumptions. Choice of inclination angles δ_i of forces E_i acting between the blocks is realized with the help of Half-sine function – one of the functions in the following figure is automatically chosen. This choice of the shape of function has a minor influence on final results, but suitable choice can improve the convergency of method. Functional value of Half-sine function $f(x_i)$ at boundary point x_i multiplied by parameter λ results the value of inclination angle δ_i.



Half-sine function

The solution adopts the expressions (1) – (5), shown in Spencer method, i.e.:

$$N_i = N_i' + U_i \tag{1}$$

$$T_i = (N_i - U_i)\tan\varphi_i + \frac{b_i}{\cos\alpha_i} = N_i'.\tan\varphi_i + c_i.\frac{b_i}{\cos\alpha_i} \tag{2}$$

$$N_i' + U_i - W_i.\cos\alpha_i + K_h.W_i.\sin\alpha_i + Fy_i.\cos\alpha_i - Fx_i.\sin\alpha_i + \\ E_{i+1}.\sin(\alpha_i - \delta_{i+1}) - E_i.\sin(\alpha_i - \delta_i) = 0 \tag{3}$$

$$N_i'.\frac{\tan\varphi_i}{FS} + \frac{c_i}{FS}.\frac{b_i}{\cos\alpha_i} - W_i.\sin\alpha_i - K_h.W_i.\cos\alpha_i + Fy_i.\sin\alpha_i + \\ Fx_i\cos\alpha_i - E_{i+1}.\cos(\alpha_i - \delta_{i+1}) + E_i.\cos(\alpha_i - \delta_i) = 0 \tag{4}$$

$$E_{i+1}.\cos\delta_{i+1}\left(z_{i+1} - \frac{b_i}{2}\tan\alpha_i\right) - E_{i+1}.\sin\delta_{i+1}.\frac{b_i}{2} - \\ E_i.\cos\delta_i\left(z_i - \frac{b_i}{2}\tan\alpha_i\right) - E_i.\sin\delta_i.\frac{b_i}{2} + \\ M1_i - K_h W_i\left(y_M - y_{gi}\right) = 0 \tag{5}$$

- (1) relationship between effective and total value of the normal force acting on the slip surface
- (2) Mohr-Coulomb condition representing the relation between the normal and shear

forces on a given segment of the slip surface (N_i a T_i)

- (3) force equation of equilibrium in the direction normal to the i^{th} segment of the slip surface
- (4) force equation of equilibrium along the i^{th} segment of the slip surface
- (5) moment equation of equilibrium about point **M**

Modifying force equations (3) and (4) provides the following recursive formula (6):

$$E_{i+1} = \frac{\left[(W_i - Fy_i).\cos\alpha_i - (K_h.W_i - Fx_i).\sin\alpha_i - U_i + E_i.\sin(\alpha_i - \delta_i)\right].\frac{\tan\varphi_i}{FS} + \frac{c_i}{FS}.\frac{b_i}{\cos\alpha_i} - (W_i - Fy_i).\sin\alpha_i - (K_h.W_i - Fx_i).\cos\alpha_i + E_i.\cos(\alpha_i - \delta_i)}{\sin(\alpha_i - \delta_{i+1}).\frac{\tan\varphi_i}{FS} + \cos(\alpha_i - \delta_{i+1})}$$

This formula allows calculating all forces E_i acting between blocks for given values of δ_i and SF. This solution assumes that at the slip surface origin the value of E is known and equal to E_1 = 0.

Additional recursive formula (7) follows from the moment equation of equilibrium (5) as:

$$z_{i+1} = \frac{\frac{b_i}{2}.\left[E_{i+1}(\sin\delta_{i+1} - \cos\delta_{i+1}.\tan\alpha_i) + E_i.(\sin\delta_i - \cos\delta_i.\tan\alpha_i)\right] + E_i.z_i.\cos\delta_i - M1_i + K_h.W_i.(y_M - y_{gi})}{E_{i+1}.\cos\delta_{i+1}}$$

This formula allows to calculate all arms z_i of forces acting between blocks for a given values of δ_i, knowing the value on the left at the slip surface origin, where $z_1 = 0$.

The factor of safety SF is determined by employing the following iteration process:

1. The initial value of angles δ_i is set according to Half-sine function ($\delta_i = \lambda * f(x_i)$).
2. The factor of safety SF for a given value of δ_i follows from equation (6), while assuming the value of E_{n+1} = 0 at the end of the slip surface.
3. The value of δ_i is provided by equation (7) using the values of E_i determined in the previous step with the requirement of having the moment on the last block equal to zero. Functional values $f(x_i)$ are same all the time during the iteration, only parameter λ is iterated. Equation (7) does not provide the value of z_{n+1} as it is equal to zero. For this value the moment equation of equilibrium (5) must be satisfied.
4. Steps 2 and 3 are then repeated until the value of δ_i (resp. parameter λ) does not change.

It is necessary to avoid unstable solutions for successful iteration process. Such instabilities occur at points where division by zero in expressions (6) and (7) takes place. In equation (7), division by zero is encountered for $\delta_i = \pi/2$ or $\delta_i = -\pi/2$. Therefore, the value of angle δ_i must be found in the interval ($-\pi/2$; $\pi/2$).

Division by zero in expression (6) appears when:

$$FS = \tan\varphi_i.\tan(\delta_{i+1} - \alpha_i)$$

Another check preventing numerical unstability is verification of parameter m_α - following condition must be satisfied:

$$m_\alpha = \cos\alpha_i + \frac{\sin\alpha_i . \tan\varphi_i}{FS} > 0{,}2$$

Therefore before iteration run it is required to find the highest of critical values SF_{min} satisfying above mentioned conditions. Values below this critical value SF_{min} are in area of unstable solution, therefore iteration begins by setting SF to a value "just" above SF_{min} and all result values of SF from iteration runs are higher than SF_{in}.

Generally rigorous methods converge worse than the simpler methods (Bishop, Fellenius). Examples with convergence problems include too steep sections of slip surface, complex geometry, a significant jump in surcharge etc. If no result is obtained, we recommend slight change of inputted data, e.g. less steep slip surface, input more points into the slip surface etc. or using of some of the simpler methods.

Literature:

Morgenstern, N.R., and Price, V.E. 1965. The analysis of the stability of general slip surfaces. Géotechnique, 15(1): 79–93.

Morgenstern, N.R., and Price, V.E. 1967. A numerical method for solving the equations of stability of general slip surfaces. Computer Journal, 9: 388–393.

Zhu, D.Y., Lee, C.F., Qian, Q.H., and Chen, G.R. 2005. A concise algorithm for computing the factor of safety using the Morgenstern–Price method. Canadian Geotechnical Journal, 42(1): 272–278.

Optimization of circular slip surface

The goal of the optimization process is to locate a slip surface with the smallest factor of slope stability SF. The circular slip surface is specified in terms of 3 points: two points on the ground surface and one inside the soil body. Each point on the surface has one degree of freedom while the internal point has two degrees of freedom. The slip surface is defined in terms of four independent parameters. Searching for such a set of parameters that yields the most critical results requires sensitivity analysis resulting in a matrix of changes of parameters that allows for fast and reliable optimization procedure. The slip surface that gives the smallest factor of slope stability is taken as the critical one. Parameters of individual slip surfaces and results from optimization runs can be displayed in output document.

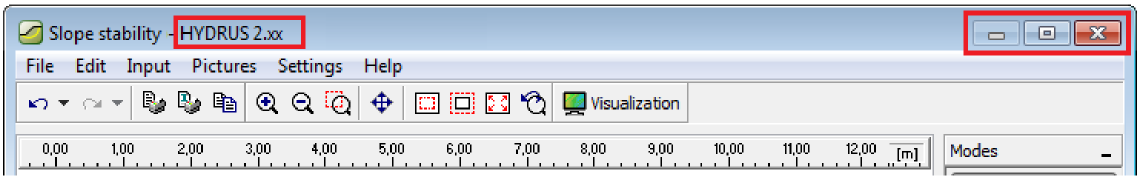
This approach usually succeeds in finding the critical slip surface without encountering the problem of falling into a local minimum during iteration. It therefore appears as a suitable starting point when optimizing general slip surfaces such as the polygonal slip surface.

Graphical User Interface

The programs are standard windows applications. Managing the application environment (application window, dialog windows, control menu, tables, frames, tool bars) applies to standard properties of the Windows environment.

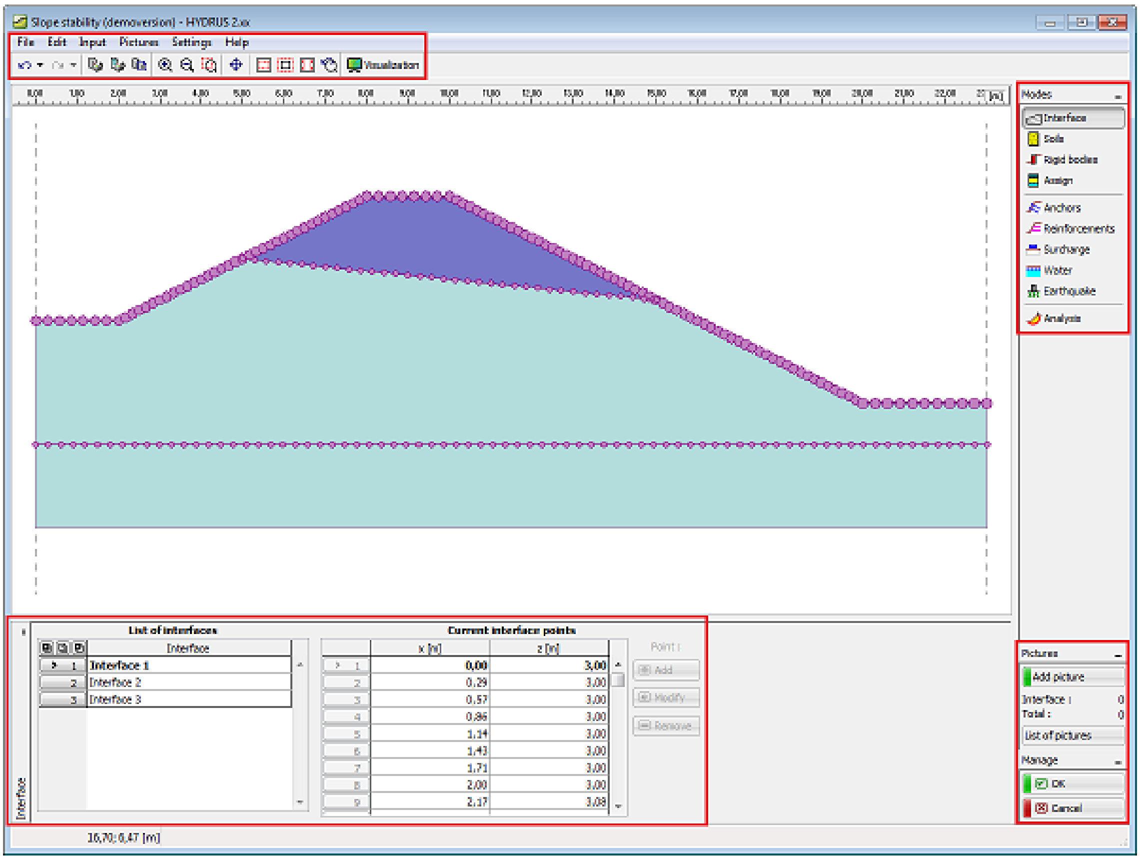
Window for application

The program is launched in standard dialog window containing all managing tools typical for the Windows environment (minimizing, maximizing and closing the application window…). The window header displays information on currently executed task (file name and location) – see figure:



Managing tools of window for application

The desktop constitutes the window of application. It includes the control menu, horizontal tool bars, space for graphic visualization of the executed task and vertical tool bars to select individual inputting modes to specify the task. The bottom part of the desktop displays frames that allows the user to introduce various input parameters into the task. Location of the individual elements on the desktop is evident from the following figure:



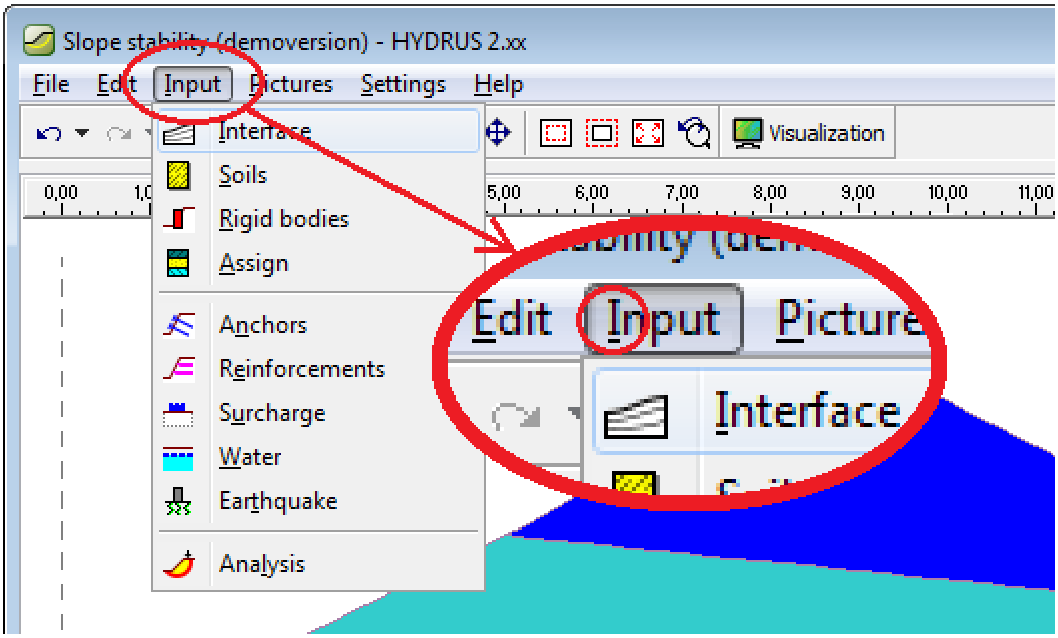
Managing tools of window for application

Control menu

Selecting an item from the menu is performed by clicking the **left mouse button**, or alternatively using the keyboard by pressing **ALT + underlined letter** in the selected menu item.

As typical for the WINDOWS environment, some of the options in the menu can be replaced with the buttons on individual tool bars, or with abbreviated commands entered through the keyboard (providing it exists it is displayed next to the command in the menu – e.g., **Save file – CTRL+S**).

Some of the options in the program can be set only with the help of the menu – e.g., program "Options".



Control menu of program

Horizontal tool bars

The program contains the following tool bars:

- Tool bar "Undo+Print"
- Tool bar "Scale and shift"
- Tool bar "Plot setting"

Tool bar Undo and Print

The tool bar contains the following buttons:

Tool bar "Undo and Print"

Individual buttons function as follows:

Undo

- returns the last performed step (the function is available only in programs with 2D environment and must be allowed in dialog window "Options")

Redo

- restores one returned step (the function is available only in programs with 2D environment and must be allowed in dialog window "Options")

Print and export document

- opens the dialog window to create, edit and print output documents

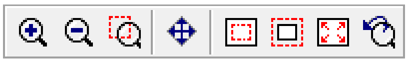
Print and export picture

- opens the dialog window to create, edit and print the current drawing displayed on the desktop

Copy • copies the current picture displayed on the desktop or the inputted soil profile into clipboard

Tool bar Scale and shift

The tool bar buttons serve to manage all plots displayed on the desktop (zoom in/out, move...). The following figure shows locations of individual buttons:



Tool bar "Scale and shift"

Scale up • scales up desktop view while keeping location of the point under the axis cross unchanged – this action is repeated using the left mouse button, the right button leaves the zooming mode

Scale down • scales down the desktop view while keeping location of the point under the axis cross unchanged – this action is repeated using the left mouse button, the right mouse button leaves the zooming mode

Shows marked region • shows and scales up the marked region - the region is selected using the left mouse button

Move displayed region • moves the current view in an arbitrary direction – to proceed move mouse in the desired location while keeping the left mouse button pressed

Scale up • scales up the displayed region while keeping the region centered

Scale down • scales down the displayed region while keeping the region centered

Modify scale • scales the view such that all objects are visible

Use previous scale • modifies view scale - returns the original view scale prior to the last applied scale action

Tool bar Plot setting

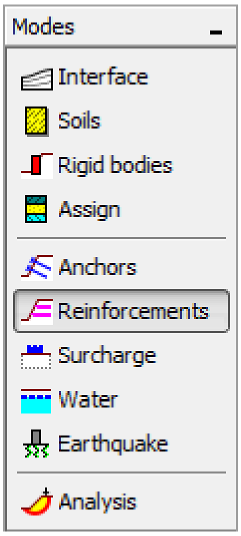
The button on a tool bar serves to set the visualization style settings on the desktop (colors, thickness and style of lines, background...).

Tool bar "Plot setting"

Plot setting • The button opens the "Visualization style settings" dialog window that allows for setting all parameters of the picture displayed on the desktop.

Vertical tool bars

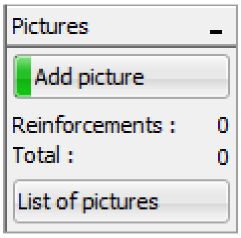
The vertical tool bars serve to select the desired mode (regime) of inputting data (project, geometry, profile....) including analysis type and verification. Selecting the mode from this bar displays in the bottom part of the desktop the corresponding frame for data input.



Tool bar for switching between input data regimes

The standalone vertical tool bar serves to manage pictures.

The "**Add picture**" button opens the "New picture" dialog window. The next line in the bar provides the number of stored pictures in a given regime of data input. The "**Total**" line shows the total number of stored pictures. The "**Picture list**" button opens the list of pictures.



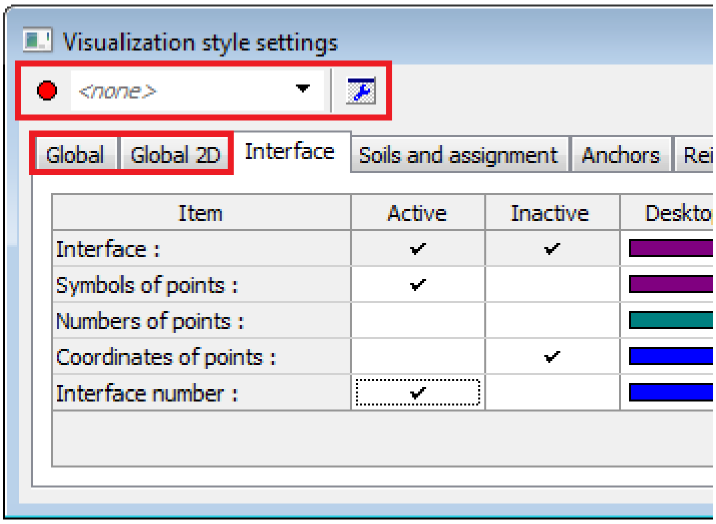
Tool bar for controlling view manager editor

Visualization style settings

The "Visualization style settings" dialog window serves to set the plot style (line type and color) for visualization on the desktop or for printout, respectively. It contains a group of tab sheets that correspond to individual data input regimes. The tab sheets serve to set the style for drawing objects, which are specified in the related input regime.

The "**Global**" tab sheet defines the settings common to all input regimes (background color, color of elements to be deleted or modification and style of drawing of inactive elements).

The program implicitly contains two standard settings of styles and colors, particularly for black or white background. The setting can be modified in the combo list on the tool bar. User settings can be defined, i.e. a user can specify a style of drawing and store that style with the help of the button on the tool bar into the "Style manager".



Dialog window "Visualization style settings" – global setting

The following picture shows an example of a tab sheet for setting the plot in the regime "Water". Individual columns of the table contain (moving from the left):

Item • list of items plotted in a given input regime (here, e.g., water tables, dimensions, gradient, water pressure….)

Active • shows / hides a given item in the **active regime** "Water". In case the option cannot be turned off (the field has a gray background – in this case items "Tables" and "Water **pressure**") the visualization on the desktop is mandatory!

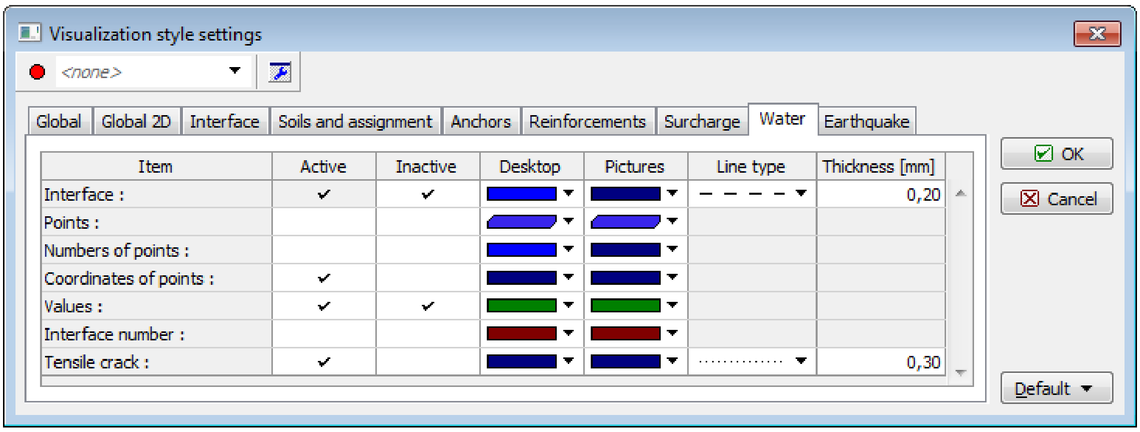
Inactive • shows / hides a given item in **other input data regimes**. Visualization color depends on the assumed setting in the tab sheet "**Global**"

Desktop • determines the item color displayed on the desktop

Pictures • determines the item color displayed in the "Picture list" or on printout ("Print and export picture", "Print and export document")

Line type • determines the line style

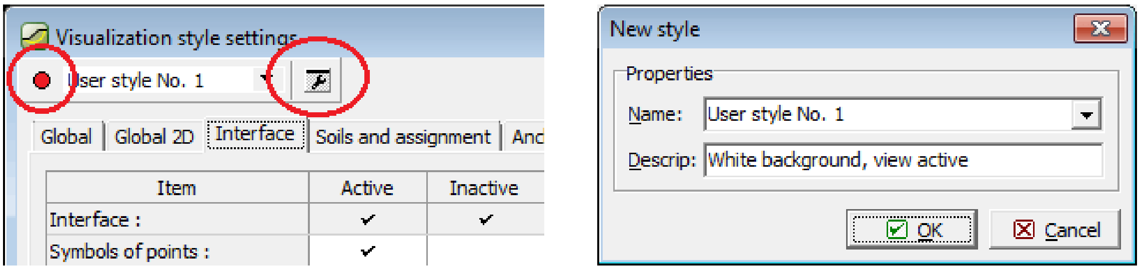
Thickness • determines the line thickness



Dialog window "Visualization style settings" – setting for the input regime "Water"

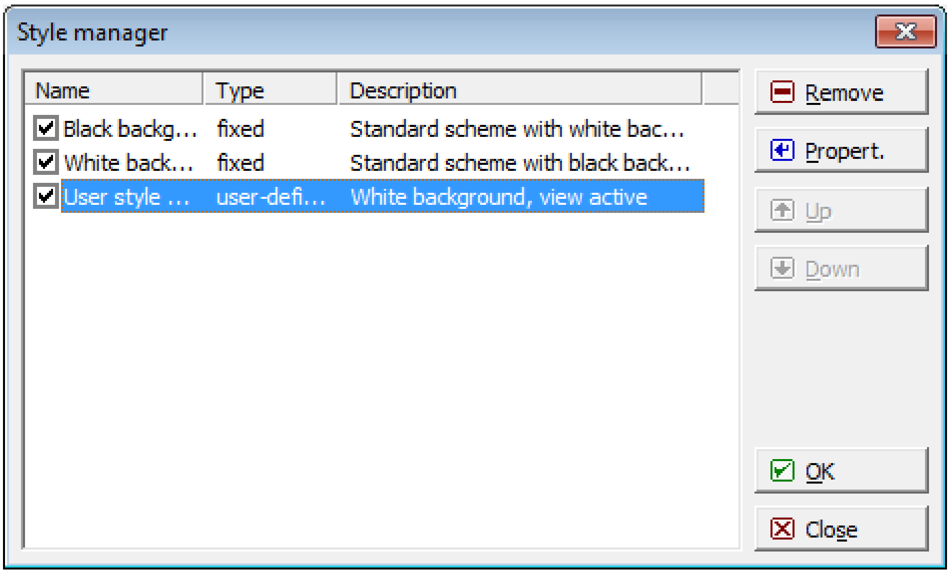
Style manager

The red button on a tool bar of the "Visualization style settings" dialog window opens the "**New style**" dialog window. The window allows for setting the style name and its description. The "**OK**" button saves the selected style.



Saving the user profile of visualization style

In such a way an arbitrary number of user profiles of visualization styles can be defined. The list of such profiles can be accessed from a combo list already containing implicitly predefined profiles (black and white background), or a view manager (can be opened by pressing the button on a tool bar) that allows for editing the profile. The buttons "**Up**" and "**Down**" serve to move within a list of the user defined profiles.

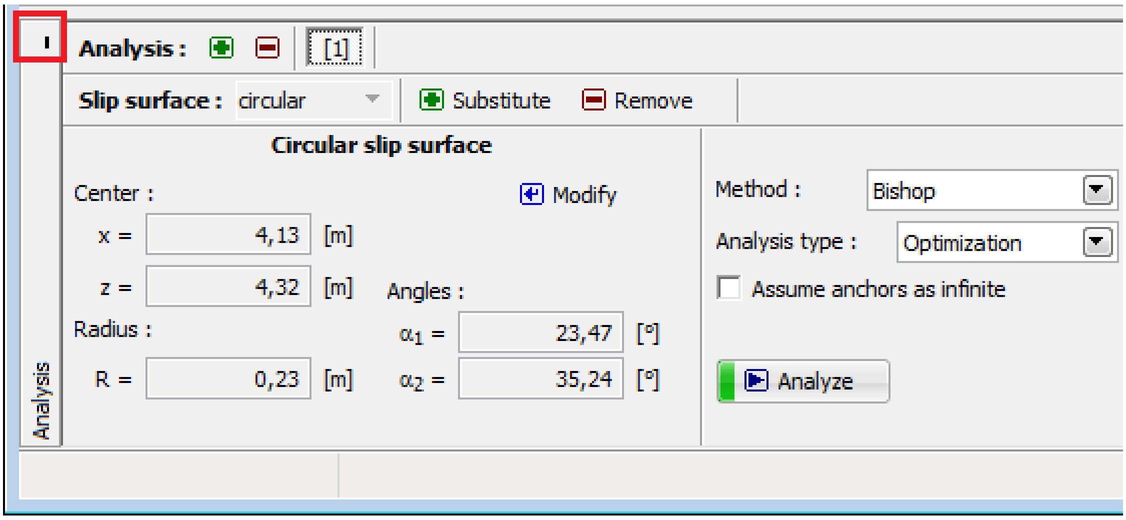


Dialog window "Style manager"

Frames

The frame is a permanently opened window in the bottom part of the application window. Frames are changed depending on the input data regime of a given task selected from the vertical control bar. The frame may contain the following items: table, combo list, fields for inputting data ($h1$, $h2$....) and command buttons.

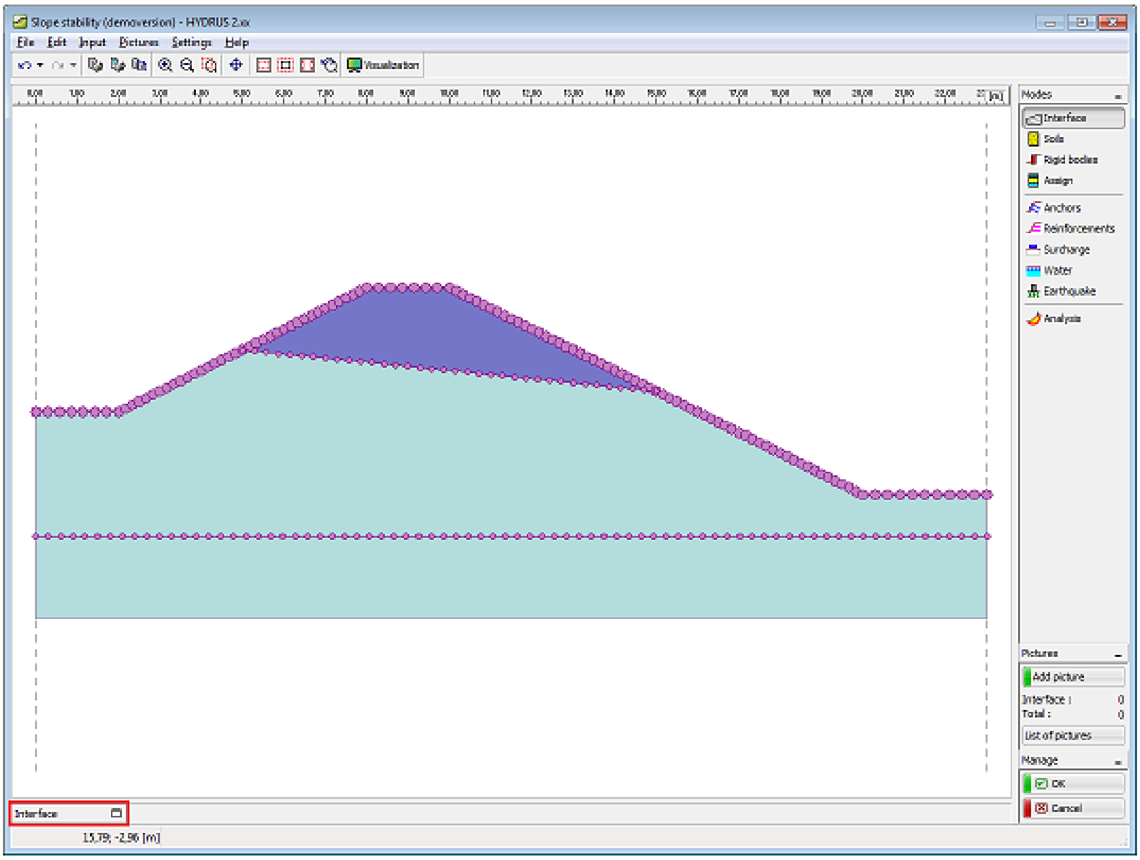
The function key "**Tab**" together with cursor arrows for moving within the selected element (e.g., combo list) and in case of command buttons the corresponding underlined letter ("**Add**" – "**A**") are employed when selecting the data using the keyboard.



Frame control elements

The frame can be minimized using the button in the left upper corner. In this case the frame space is taken by the drawing space. In some cases it is more advantageous to exploit the frame space for increasing the drawing space, which is possible owing to the fact that the program uses the system of active dimensions and active objects so that the frame does not have to be displayed all the time.

Returning the frame to its original face is performed by pressing the button in the left bottom corner of the desktop showing the frame name. Providing the frame is minimized, e.g. in the regime "Water" it remains hidden even when switching to other input data regime.



Frame control elements

Tables

The table is a list of inputted data (for example a list of surcharges, soils, profile interfaces...). The table header contains a list of items (surcharge, name, width, size...) and in the upper left corner control elements to manage the table rows:

- **selects all table rows**
- **cancels selection**
- **inverts selection**

The assumed selection can be also changed by pressing the desired row number. Buttons with numbers are "**pressed**".

The "**Add**" button opens the corresponding dialog window for inserting the table data. If the list of data in the table is empty then all input fields in the dialog window are empty. If the table contains some already inputted elements then the input fields are filled with values taken from the current table row (an "**arrow**" is positioned next to the row number). Elements (rows) are inserted in the table by pressing the "**Add**" button in the dialog window. New data are placed at the end of the table.

Individual rows are edited with the help of the "**Edit**" button. Only the row marked with an **arrow** (see figure) will be edited regardless of other selected rows in the table. Some of the dialog windows allows for editing a group of selected items using the "**Edit selected**" button. It is therefore possible to modify values in more rows all at once. Always the selected rows are edited.

The "**Remove**" button deletes all selected ("**pressed**") rows. More than one row can be removed at the same time. If no item is selected the program deletes the current row (marked with an "**arrow**").

It there is among rows selected for deletion a row, which cannot be deleted (e.g. starting point of a structure), the program stops the deletion process!

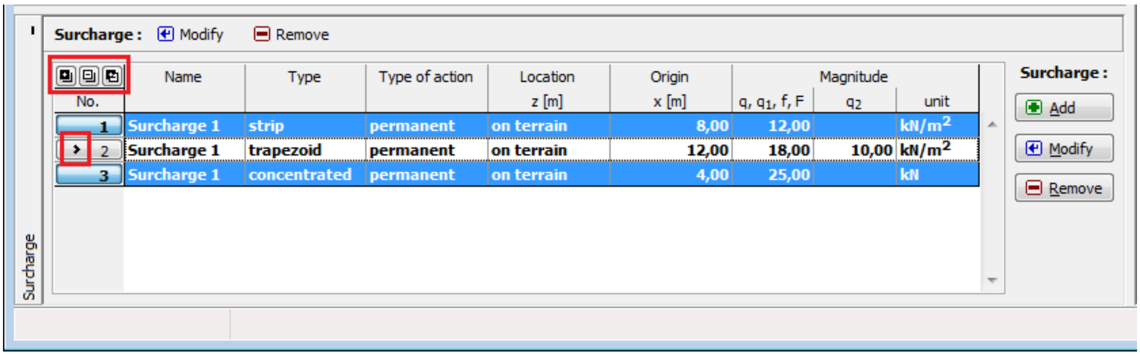
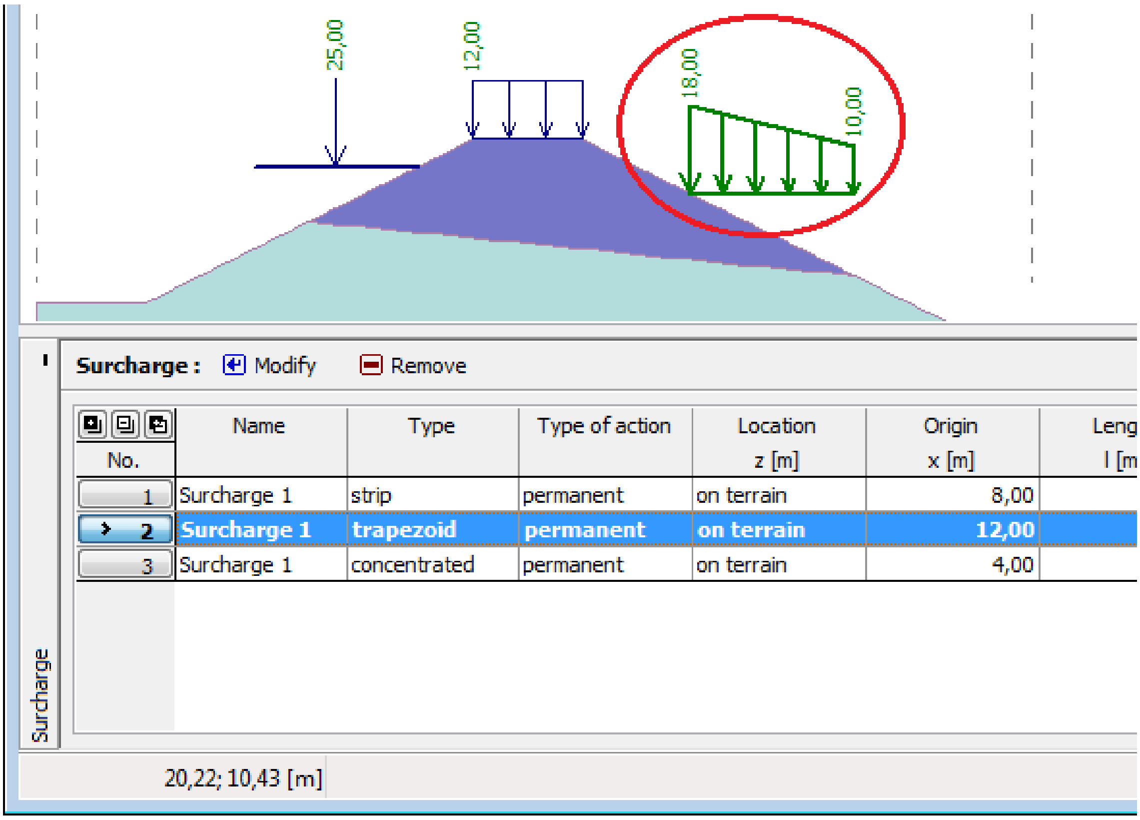


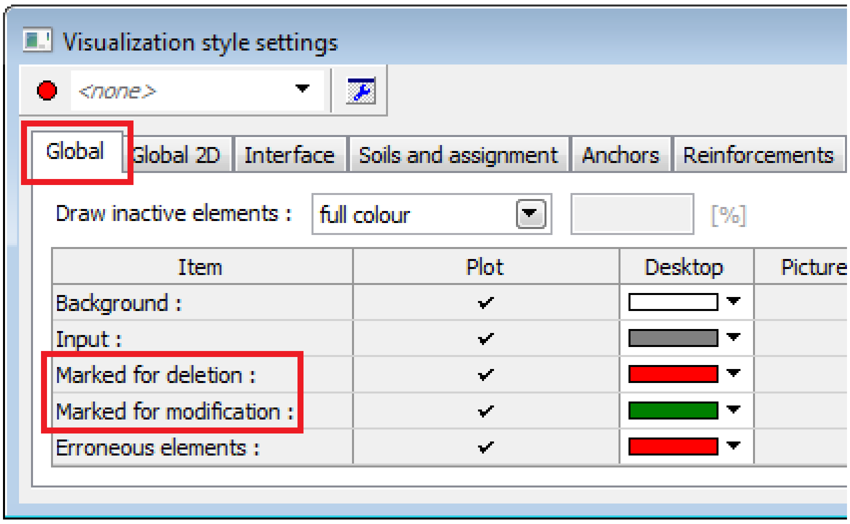
Table example

Selection state of individual table rows corresponds to visualization state of objects on the desktop. An object on the desktop that corresponds to the current row in the table (an "**arrow**" is positioned next to the row number) is implicitly displayed **extra bold**. If the row is selected ("**pressed**") the corresponding object is displayed in **green**. Pressing the "**Remove**" button colors all objects selected for deletion **red**.



Visualization of selected objects

Marking objects using these colors is implicitly set. This setting, however, can be modified in the "Visualization style Settings" - tab sheet "**Global**".



Setting color for selecting objects

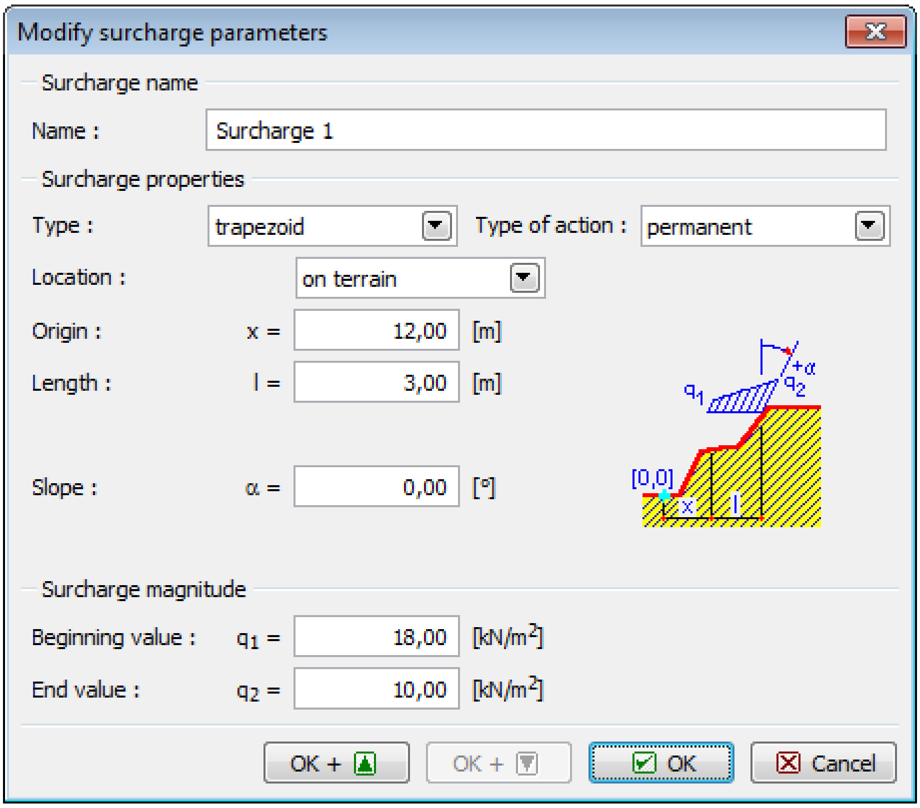
Dialog windows

A dialog window is one of the elements that allows for inputting data into the program. In all programs the dialog windows apply to conventional windows management typical for the WINDOWS environment. A left mouse button is used when selecting objects in the window or alternatively the function key "**Tab**" when using the keyboard. The cursor arrows, "**ENTER**" key or in case of command buttons the corresponding underlined letter ("**Cancel**" - "**C**", "**OK**" – "**O**") are employed when moving within an object.

A dialog window can contain the following items: table, combo list, fields for inputting data (number, text) and command buttons. The "**OK**" command button confirms the selection, while the "**Cancel**" button leaves the input mode.

Providing the window contains a certain non-typical control element (or this element has some other than typical effect) its function is described in the corresponding data input regime.

As an example consider the following picture showing the "**Edit surcharge**" dialog window that contains the "**OK +** " and "**OK +** " buttons. These buttons allow the user to move within the list of inputted surcharges and at the same time to confirm changes made in the window. Pressing this button results in the same action as if closing the window with the "**OK**" button and opening it again for the next element in the list.



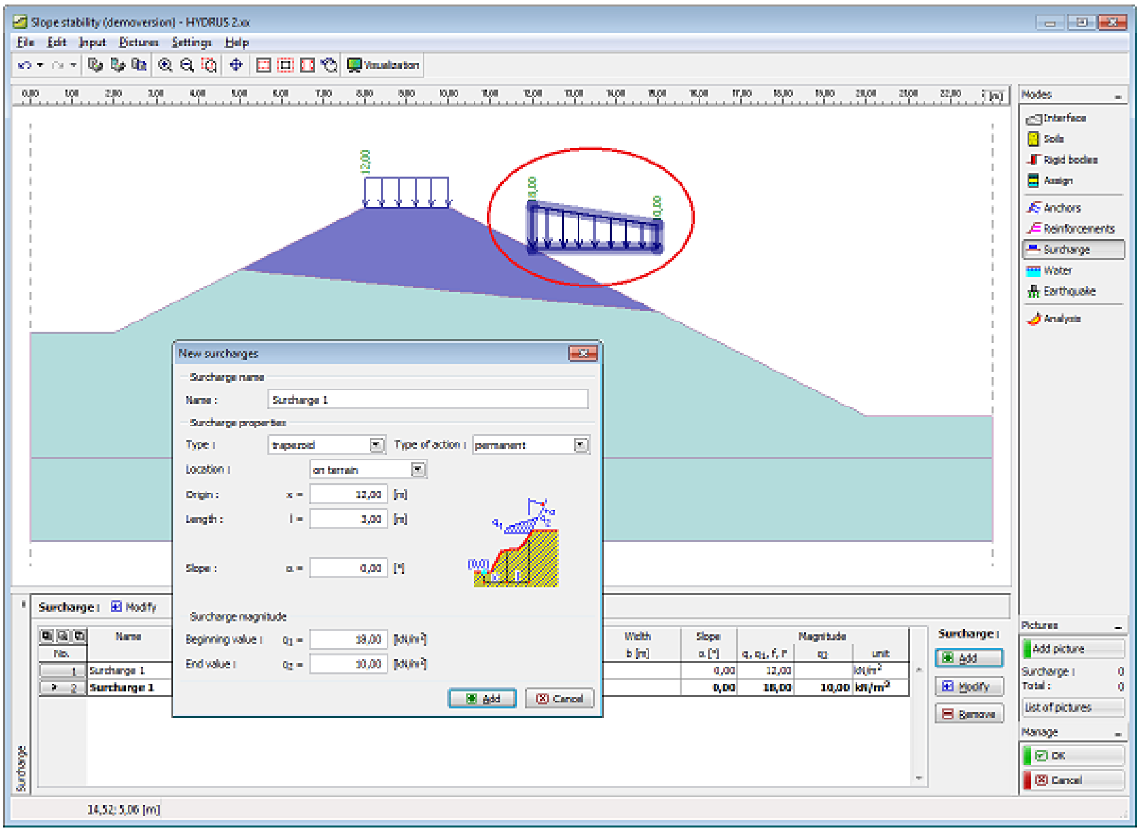
Dialog window example

Active dimensions and objects

The system of active dimensions and objects allows for faster editing of the inputted data.

- **Active dimension** is a dimension that can be edited directly on the desktop. The value of active dimension is labeled by frame (dashed line). Positioning the mouse cursor and the frame changes its mask into a "**hand**". Clicking the value than changes the frame view (is plotted in a solid line), the cursor starts to blink and the dimension can be edited. The "**Enter**" button closes the editing mode. The change is immediately displayed on the desktop.

- **Active object** functions in a similar way. Changing the cursor mask into a "**hand**" and clicking the object (double click) than activates the editing mode. In this case, however, the values are not edited directly on the desktop, but rather in the dialog window originally used to create the object. The picture shows an example of an active object (trapezoidal surcharge), when clicking on the desktop opens the "**Edit surcharge**" dialog window.



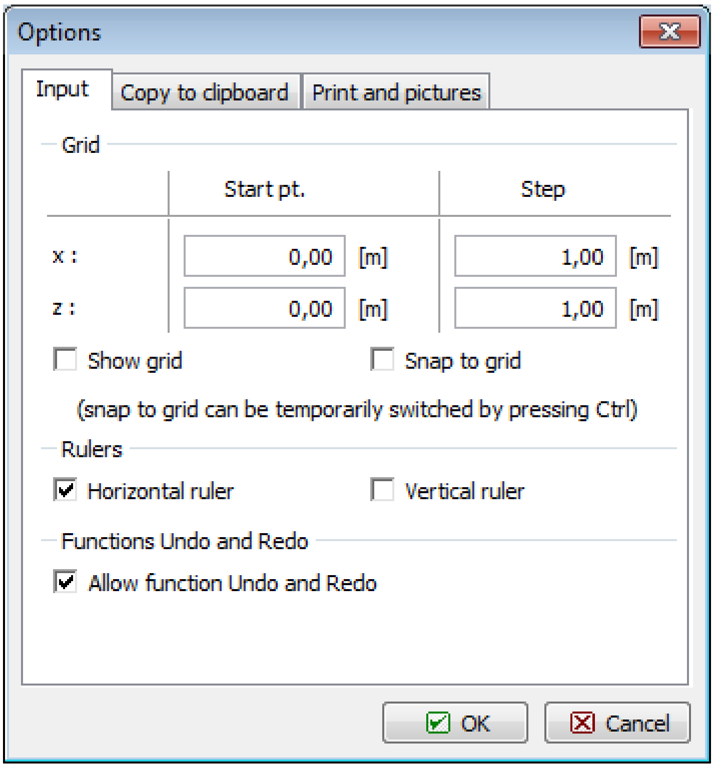
Example of using active objects

Options

The "Options" dialog window serves to set some of the special program functions (copy to clipboard, print view, grid and step, etc.).

This dialog window is opened from a control menu (items "**Setting**", "Options").

The window contains individual tab sheets (number and content may vary depending on individual programs) that allow for specifying corresponding settings.



Dialog window "Options"

Options – copy to clipboard

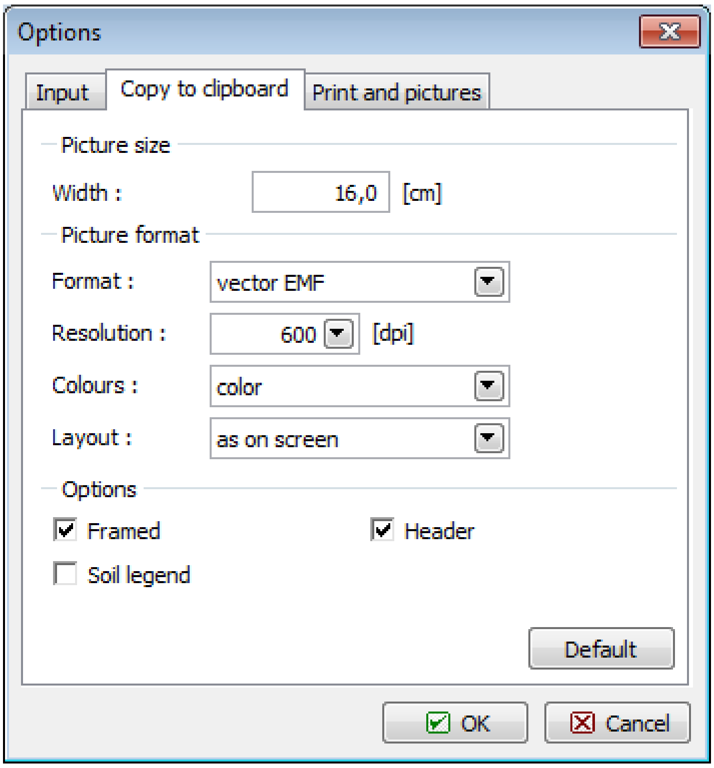
The "**Copy to clipboard**" tab sheet allows for setting the controlling parameters:

Picture size
- The setting defines the picture size. Enter the picture width, the height is calculated according to the picture contents automatically.

Picture format
- The setting defines the picture format (*.EMF, *.WMF, *.BMP), its resolution, color and orientation. Recommended setting is displayed in the figure (format: *.EMF, resolution: 600 dpi, color).

Options
- The setting defines the picture frame and header. If both options are checked, the picture contains both the frame and header.
- Option "Soils legend" adds legend of used soils into picture.

The "**Default**" button in the window sets original implicit values.



Dialog window "Options" – tab sheet "Copy to clipboard"

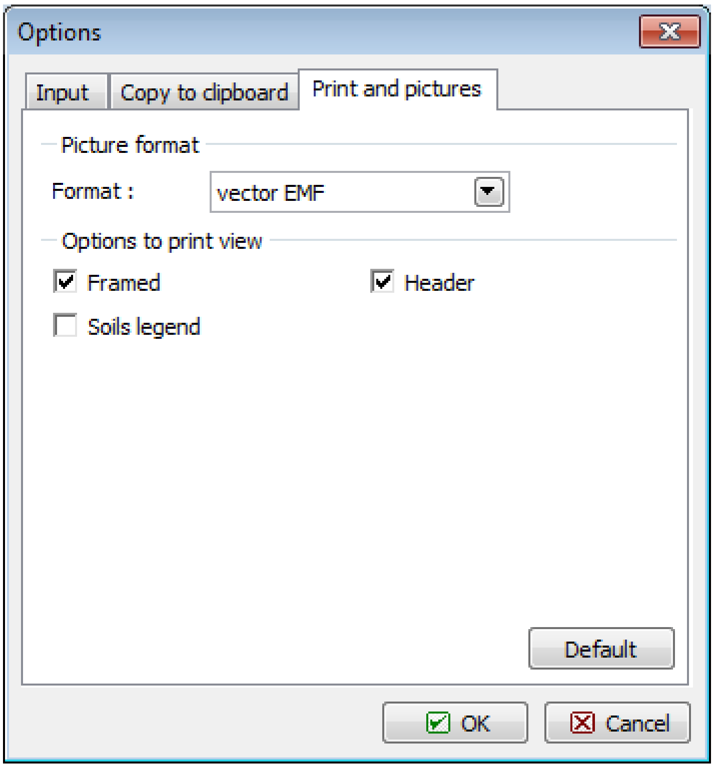
Options – print and pictures

This dialog window is opened from the control menu (items "**Setting**", "Options"). The "**Print and pictures**" tab sheet allows for setting the picture parameters assumed for "Print and export picture" and "Print and export document" dialog window.

Picture format
- The setting defines the picture format (*.EMF, *.WMF, *.BMP).

Options
- The setting defines the picture frame and header. If both options are checked, the picture contains both the frame and header.
- Option "Soils legend" adds legend of used soils into picture. This is valid only for "Print and export picture".

The "**Default**" button in the window sets original implicit values.



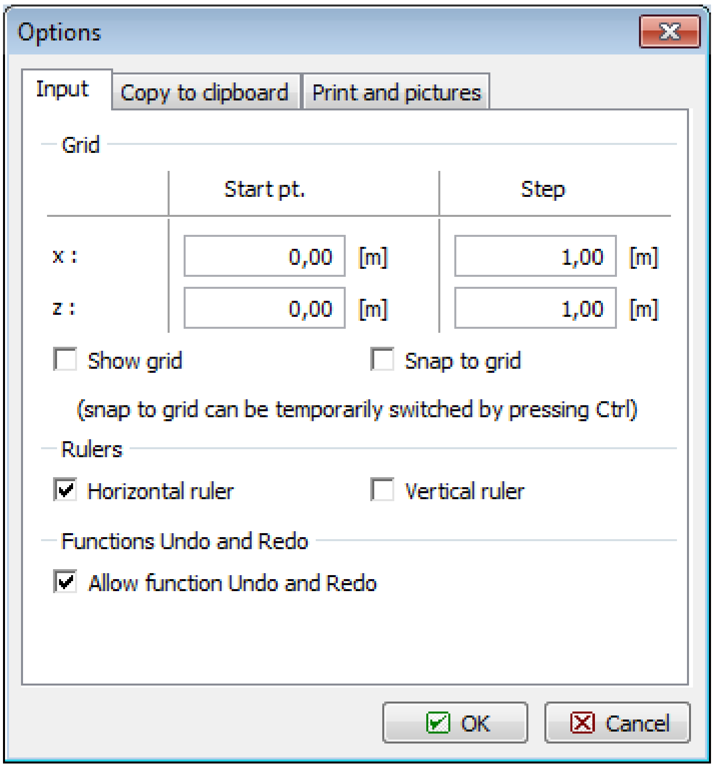
Dialog window "Options" – tab sheet "Print and pictures"

Options - input

The "Options" dialogue window, tab sheet "**Input**" allows for setting the "**Grid**" parameters and parameters of functions "**Undo**" and "**Redo**".

This tab sheet is implemented **only in 2D programs** (Slope stability, Settlement, Beam, etc.).

Grid	• sets the grid origin and step in the X and Z directions
Show grid	• shows / hides grid on the desktop
Snap to grid	• turns on / off the snap to grid option using the mouse (when shifting the mouse the cursor jumps over the defined grid – a point off the grid can be specified by holding the "**CTRL**" key)
Horizontal rule	• shows / hides horizontal rule with a scale of distances on the desktop
Vertical rule	• shows / hides vertical rule with a scale of distances on the desktop
Functions "Undo and Redo"	• turns on / off the possibility of using these functions in the program (on horizontal tool bar these buttons are "**foggy**"



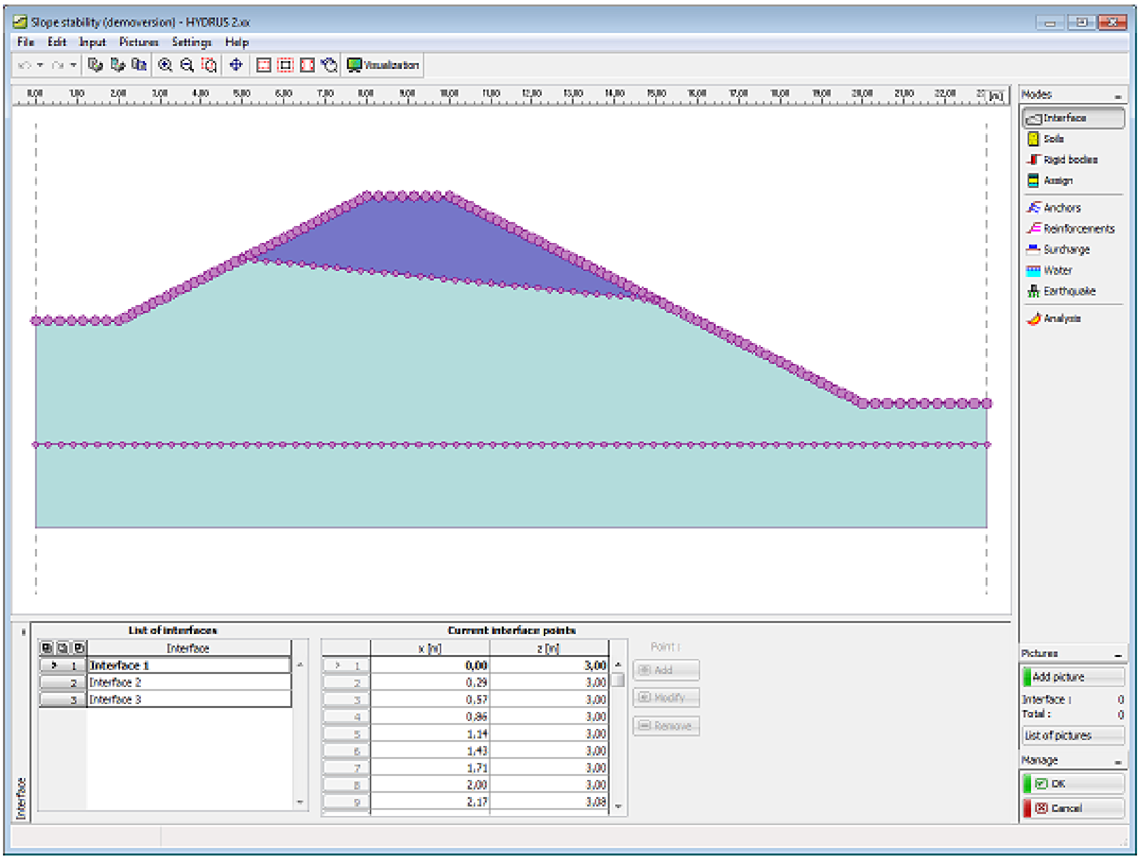
Dialog window "Options" - tab sheet "Input"

Input regimes and analysis

This capture contains basic description of individual regimes of inputting data into the program:

Interface

The "Interface" frame serves just for visualizastion of data, that was imported from main HYDRUS program. It cannot be changed in Slope stability modul.

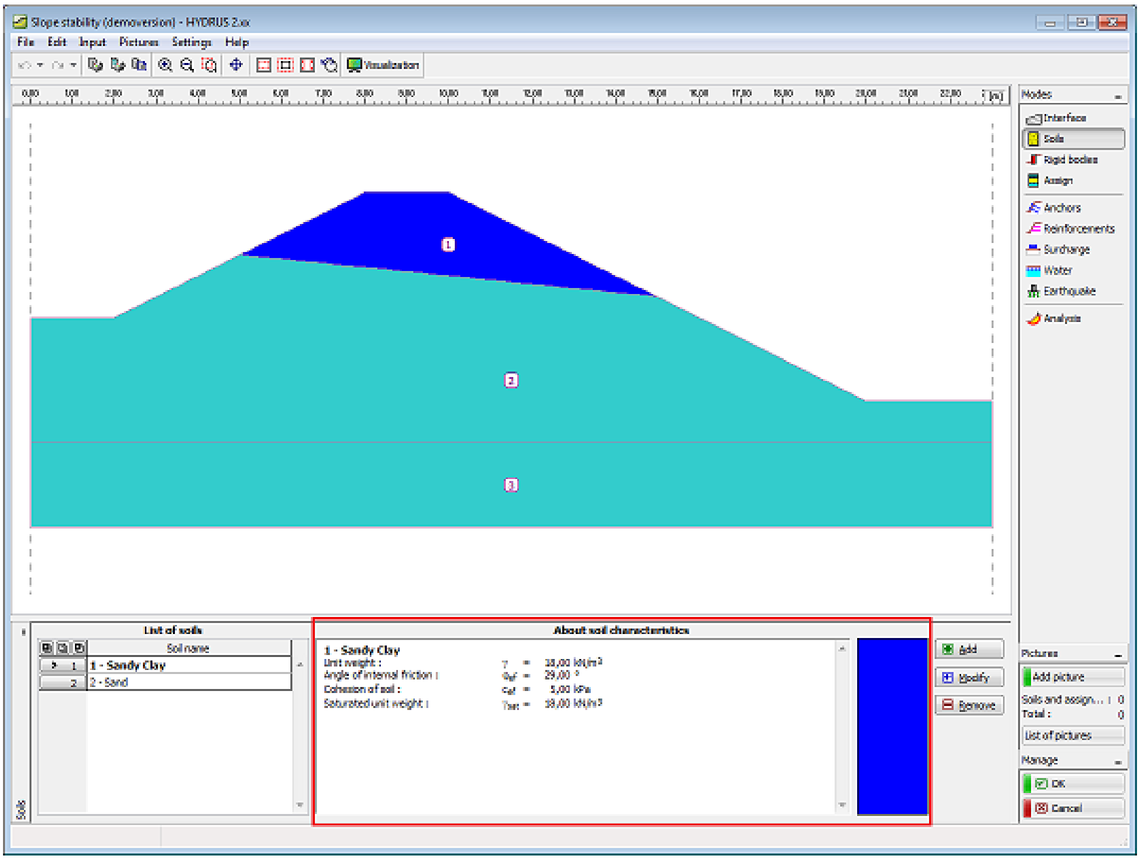


Frame "Interface"

Soils

The "Soils" frame contains a table with a list of inputted soils. The table also provides information about currently selected soil displayed in the right part of the frame.

The soil characteristics needed in the program are further specified in the chapter "Basic data". These properties are usually imported from the main HYDRUS program. Imported properties cannot be changed, but it is possible to enter new soils in this frame.



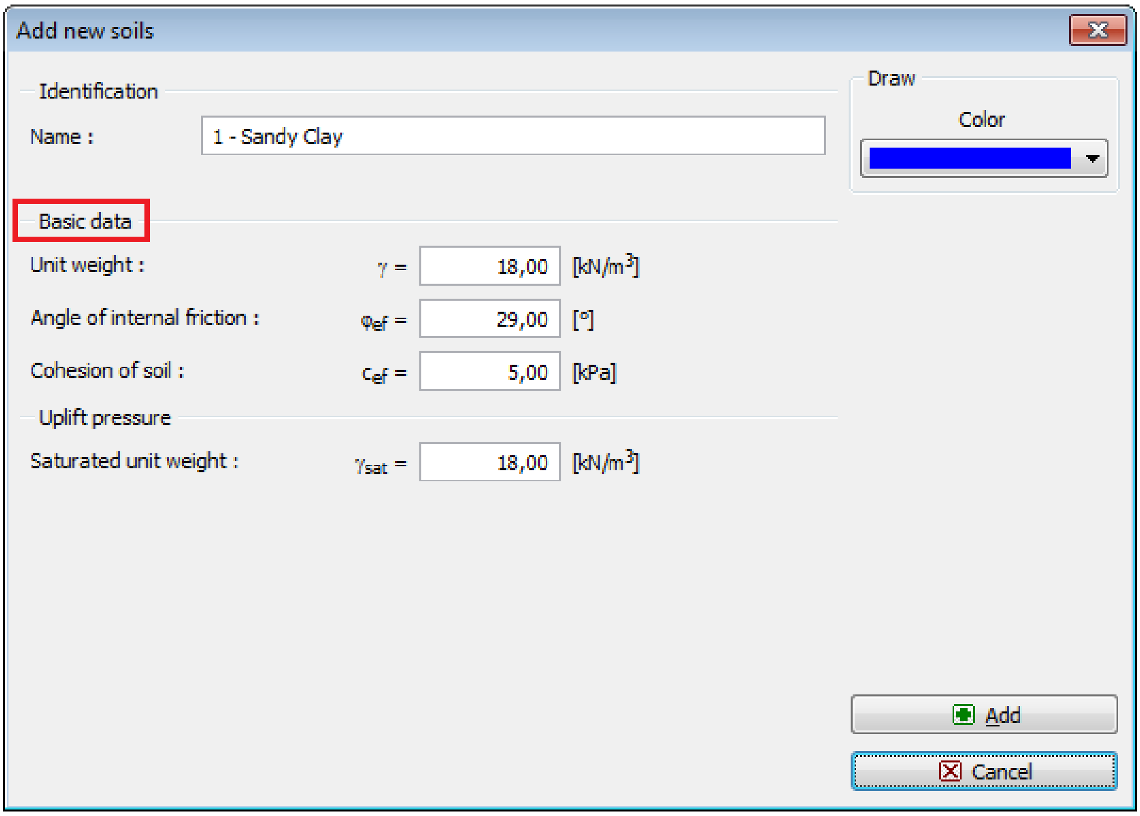
Frame "Soils"

Basic data

This part of the window serves to introduce basic parameters of soils – **unit weight, angle of internal friction** and **cohesion**. The last parameter is saturated unit weight, that is used for computation of soil weight under GWT.

These properties are usually imported from the main HYDRUS program. Imported properties cannot be changed, but it is possible to enter new soils in this frame. The particular values should be obtained from geotechnical survey or from laboratory experiments

The associated theory is described in detail in chapter "Slope stability analysis".



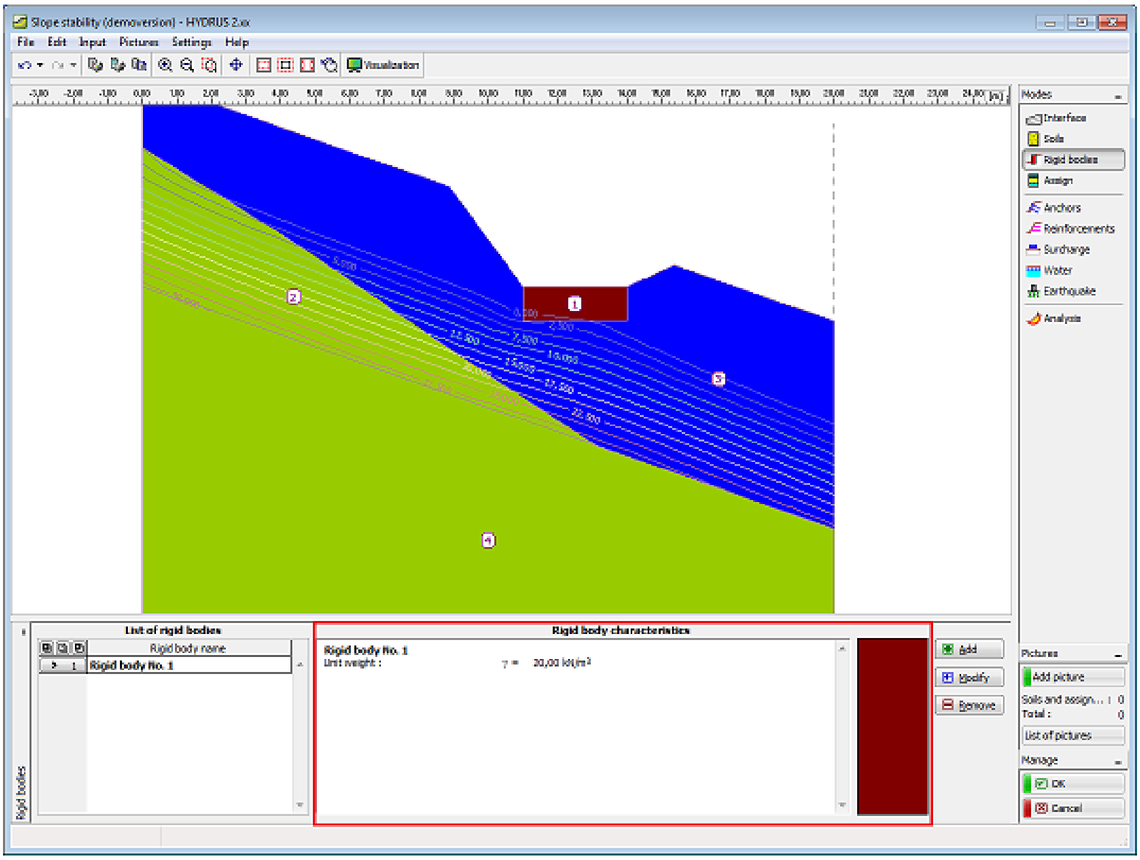
Dialog window "Add new soils" - "Basic data"

Rigid bodies

The "Rigid bodies" frame contains a table with a list of inputted rigid bodies. The rigid bodies serve to model regions with a high stiffness – e.g., **sheeting structures** or **rock subgrade**. This table also provides information about the currently selected rigid body displayed in the right part of the frame.

Adding (editing) rigid bodies is performed in the "**Add new rigid body**" dialog window. This window serves to input the unit weight of the rigid body material and to select color. The rigid bodies are in the frame "Assign" ordered after inputted soils.

Rigid bodies are introduced in the program as regions with high strength so they are **not intersected by a potential slip surface**. Providing we wish the slip surface to cross a rigid body (e.g., pile wall) it is recommended to model the rigid body as a soil with a cohesion corresponding to pile bearing capacity against slip.

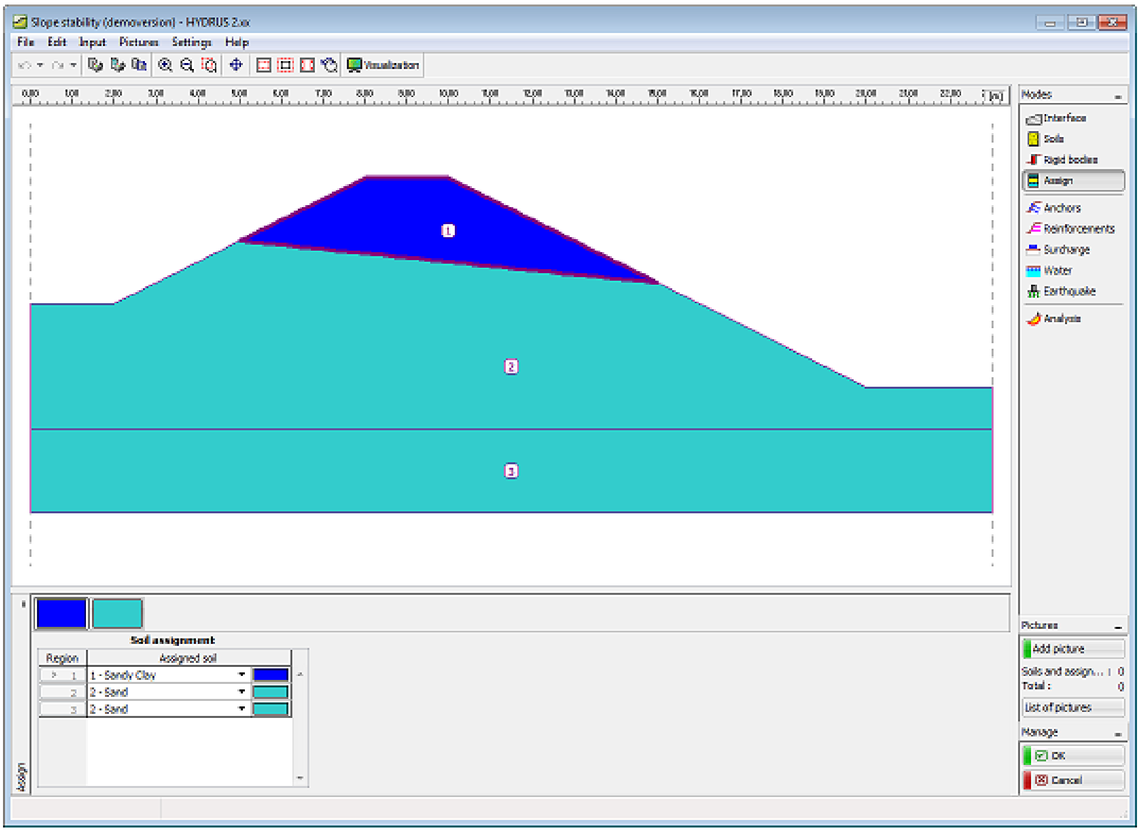


Frame "Rigid bodies"

Assign

The "Assign" frame contains a list of layers of profile and associated soils. The list of soils is graphically represented using buttons in the bar above the table, or is accessible from a combo list for each layer of the profile.

The procedure to assign soil into a layer is described in detail herein.

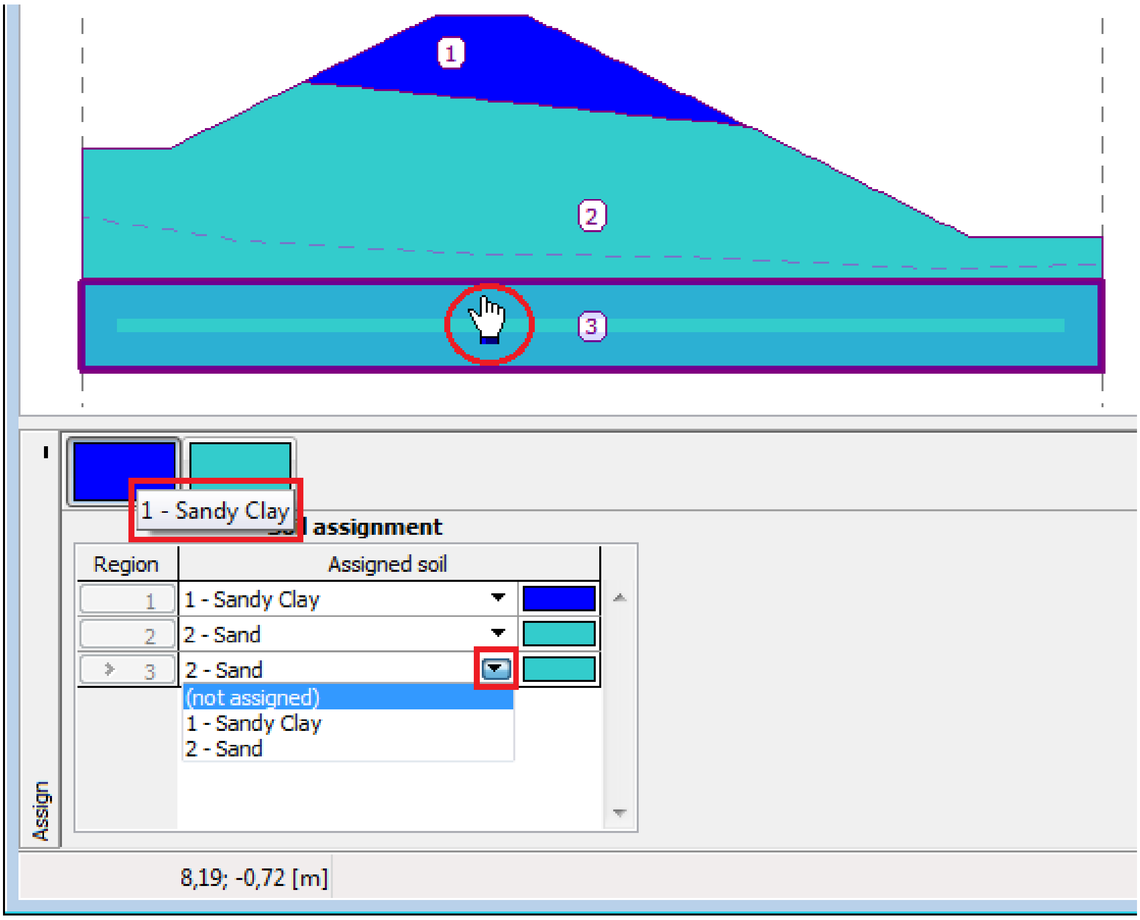


Frame "Assign"

Assigning soils

Two options are available to assign soils into individual profile layers. Clicking the left mouse button on the tool bar button above the table selects the desired soil (positioning the mouse cursors in the bar above the soil button displays a bubble hint with the soil name). The soil is inserted by moving the mouse cursor (the cursor mask changes into a "**hand**") first into a specific layer and then by pressing the left mouse button.

The second option requires opening a combo list of a specific interface and then selecting the desired soil to be assigned. All changes in the soil assignment are automatically displayed on the desktop.



Frame "Assign"

Anchors

The "Anchors" frame contains a table with a list of inputted anchors. Adding (editing) anchors is performed in the "**New anchor (Modify anchor parameters)**" dialog window. The inputted anchors can be edited on the desktop with the help of active objects.

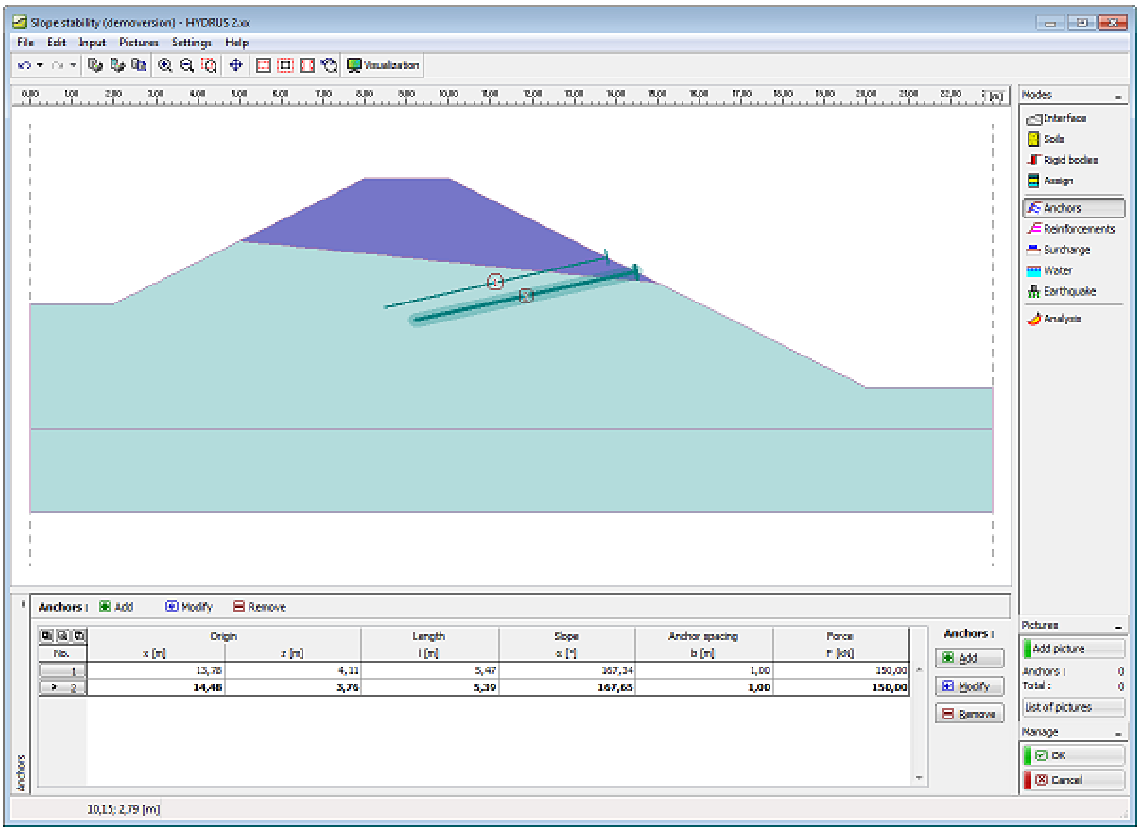
You are asked to input the anchor location (starting point), its length and inclination, anchor spacing and pre-stress force. The anchor starting point is always **attached to the terrain**.

Anchors can also be introduced with help of a **mouse click**. Mouse input mode is determined by pressing buttons on the horizontal bar "**Anchor**". The following modes are available:

- **Add** — clicking the left mouse button allows for specifying the starting and end point of an anchor. The grid function can be exploited in the input mode. The starting point is always "attached" to the terrain. The coordinates of inputted points are automatically round up to two digits – both input modes (manual, mouse) are therefore identical
- **Modify** — clicking the left mouse button on already existing anchor opens the "**Modify anchor property**" dialog window, where the selected anchor can be modified
- **Remove** — clicking the left mouse button on an anchor opens the dialog window to confirm the **reinforcement removal** – confirming this action then removes the anchor

Effect of anchors on the analysis is described in more detail in the theoretical part of the hint.

Note: The program does not check the anchor bearing capacity against breakage.



Frame "Anchors"

Reinforcements

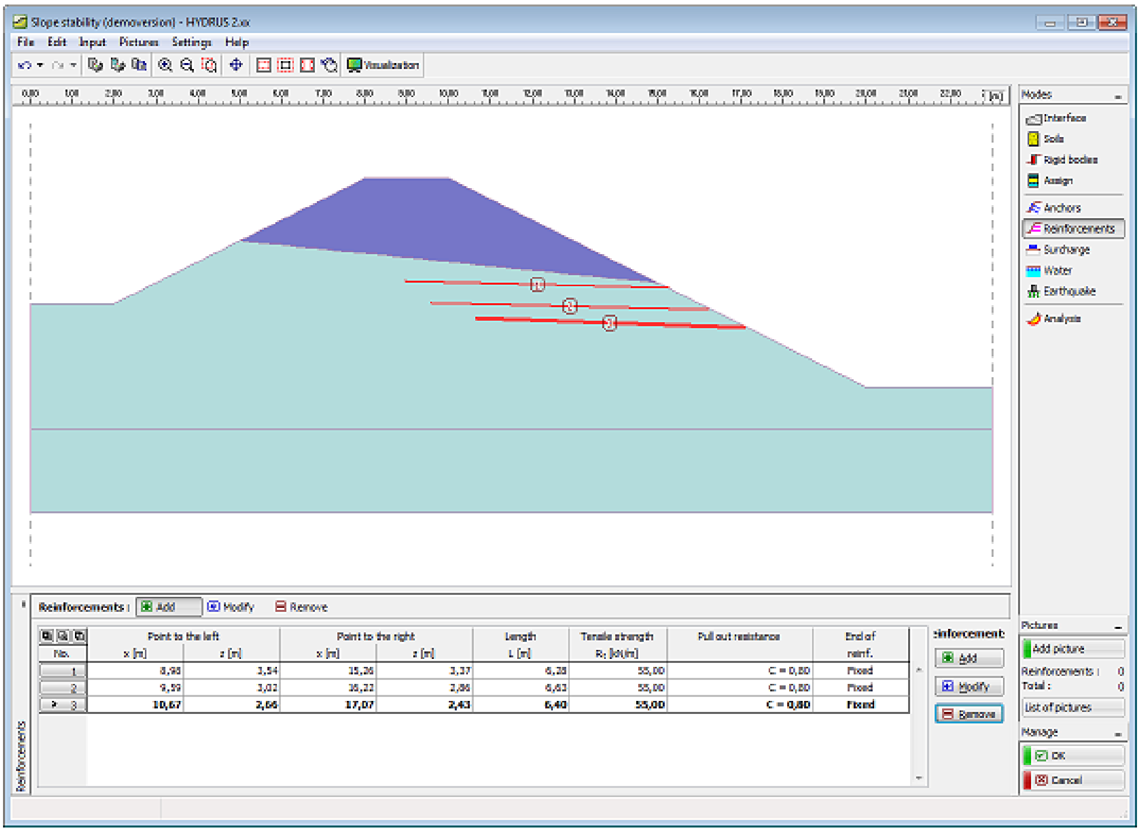
The "Reinforcements" frame contains a table with a list of inputted reinforcements. Adding (editing) reinforcement is performed in the "**New reinforcement (Modify interface properties)**" dialog window. The inputted reinforcements can be edited on the desktop with the help of active objects.

Properties like reinforcement location, anchorage length from both left and right end, tensile strength of reinforcement R_t and end of reinforcement (fixed or free) must be specified.

Reinforcements can also be introduced with help of a **mouse click**. Mouse input mode is determined by pressing buttons on the horizontal bar "**Reinforcement**". The following modes are available:

- **Add** — clicking the left mouse button allows for specifying the starting and end point of a reinforcement. A predefined grid can be used in the input mode. The starting point is always "attached" to the terrain. The coordinates of inputted points are automatically round up to two digits – both input modes (manual, mouse) are therefore identical
- **Modify** — clicking the left mouse button on already existing reinforcement opens the "**Modify reinforcement property**" dialog window, where the selected reinforcement can be modified
- **Remove** — clicking the left mouse button on reinforcement opens the dialog window to confirm the **reinforcement removal** – confirming this action then removes the reinforcement

Including reinforcements in the analysis is described in more detail in the theoretical part of the help.

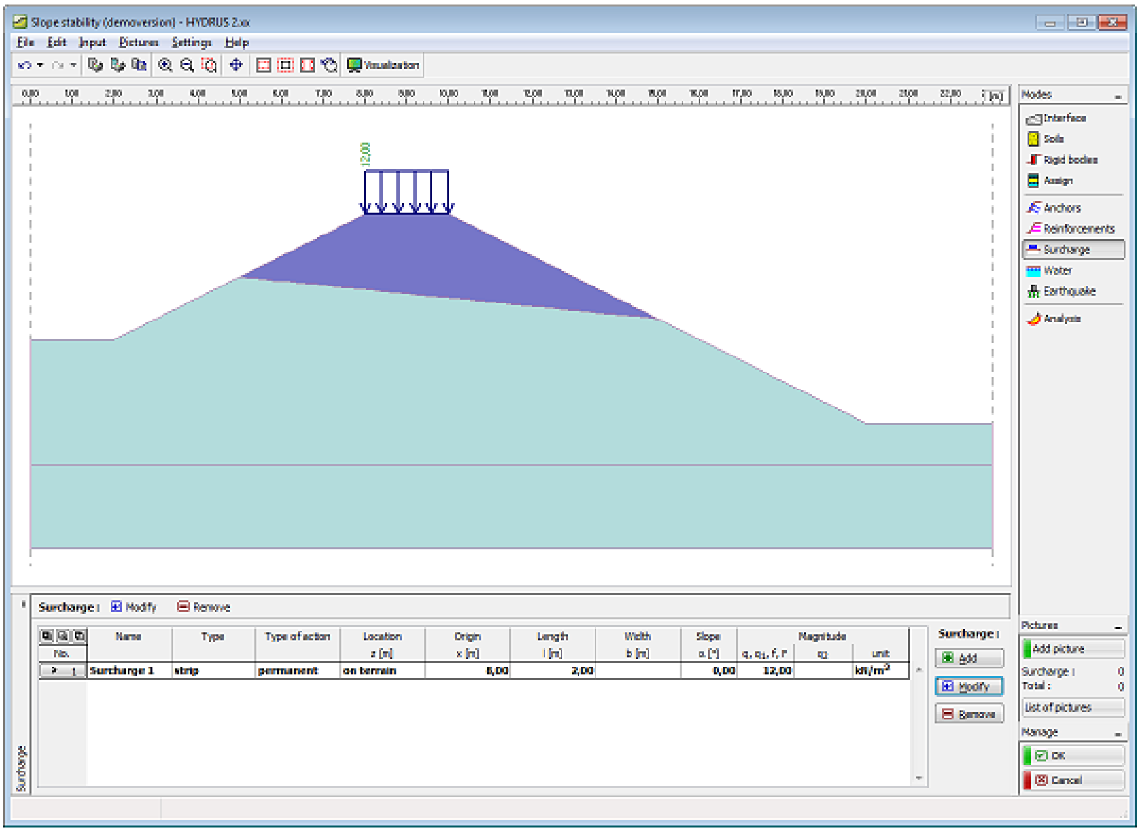


Frame "Reinforcements"

Surcharge

The "Surcharge" frame contains a table with a list of inputted surcharges. Adding (editing) surcharge is performed in the "**New (edit) surcharge**" dialog window. The inputted surcharges can be edited on the desktop with the help of active objects.

Influence of surcharge on stability analysis of slopes is described in the theoretical part of the hint.



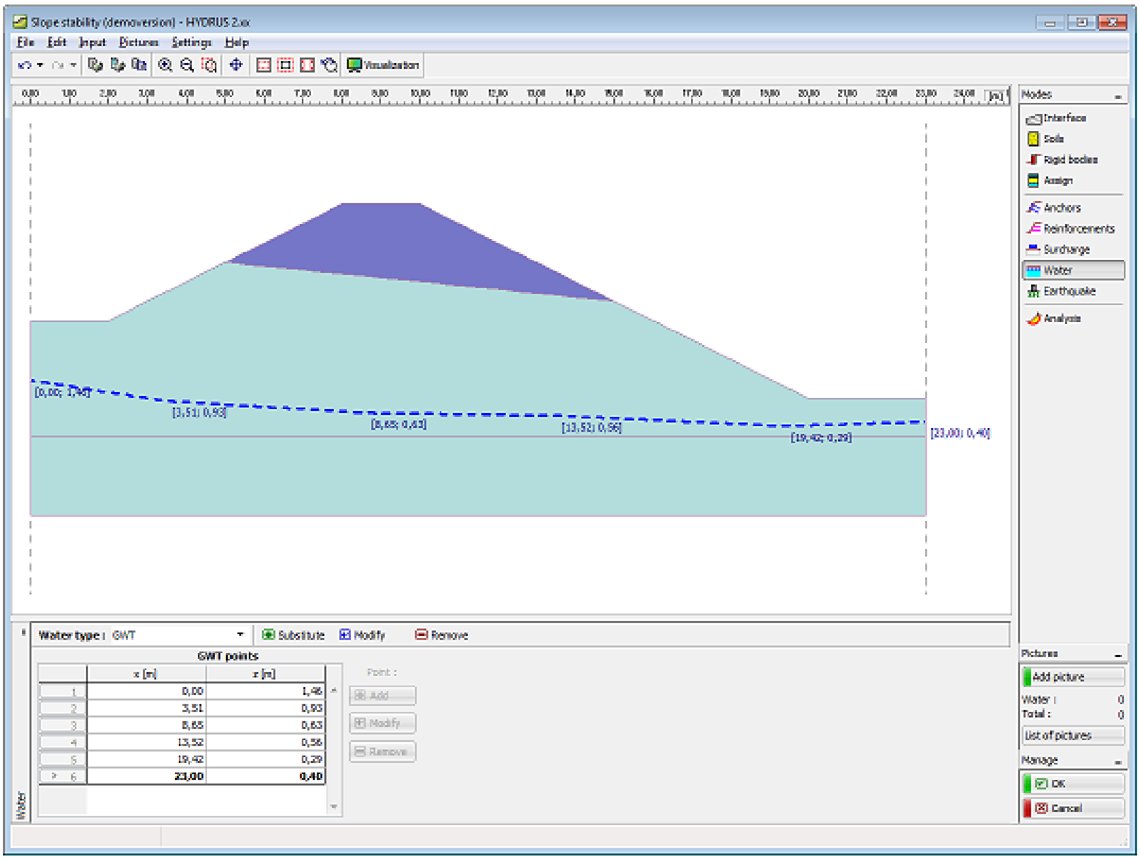
Frame "Surcharge"

Water

The "Water" frame serves to set the type of ground water table. Three options to specify the type of water are available from the combo list.

The **isolines of pore pressure** are imported from main Hydrus program and cannot be changed.

There is possibility to input GWT (Ground Water Table) in the modul "**Slope stability**" and check other influence of water..



Frame "Water"

Input of the GWT

A tool bar in the top part of the desktop contains control buttons to manage GWT.

Tool bar "GWT input"

Input • turns on the regime for inputting a new interface – individual interfaces can be added in an arbitrary order. Each interface is automatically stored in the list of interface when leaving the input mode

Modify • turns on the regime for editing an interface – this regime is also activated by clicking the desired interface on the desktop

Remove • upon pressing the "**Remove**" button the program marks the selected interface with a red color and opens the dialog window to confirm this action

Every change made to a given interface can be put back using the "UNDO and REDO" buttons on the horizontal tool bar.

The "**Add**" button starts the regime for inputting points of a new interface. Other buttons on the same tool bar assumed for inputting and editing interface points become active. The "**OK**" button (tinged green) closes the input regime and stores the inputted points. The "**Cancel**" button (tinged red) closes the input regime without accounting for changes.

Two options are available to specify coordinates of individual interface points:

Using table: interface points are introduced in the "**New interface points**" table. The "**Add**" button opens the "**New point**" dialog window that allows for specifying coordinates of a new point. The "**Add**" button then inserts the point into the table. The "**Cancel**" button is serves to close the input mode when all interface points are introduced. The "**Edit**" and "**Remove**" buttons allow for either editing or deleting the inputted points. Each change in interface geometry immediately appears on the desktop.

Using mouse: individual buttons on the vertical tool drive this inputting mode. The following modes are available:

Add point	• the point is inserted by clicking the left mouse button on the desktop - the grid option can be exploited when inserting the point - the inputted point is automatically rounded to two decimal digits – both mouse and keyboard input modes are therefore identical
Edit point using mouse	• pressing the existing interface point using the left mouse button allows for selecting this point and then moving it to a new position
Edit point in dialog point	• clicking the existing interface point opens the dialog window that allows for modifying the point coordinates
Remove point	• pressing the existing interface point using the left mouse button opens the "**Remove point**" dialog window – when confirming this action the point is deleted

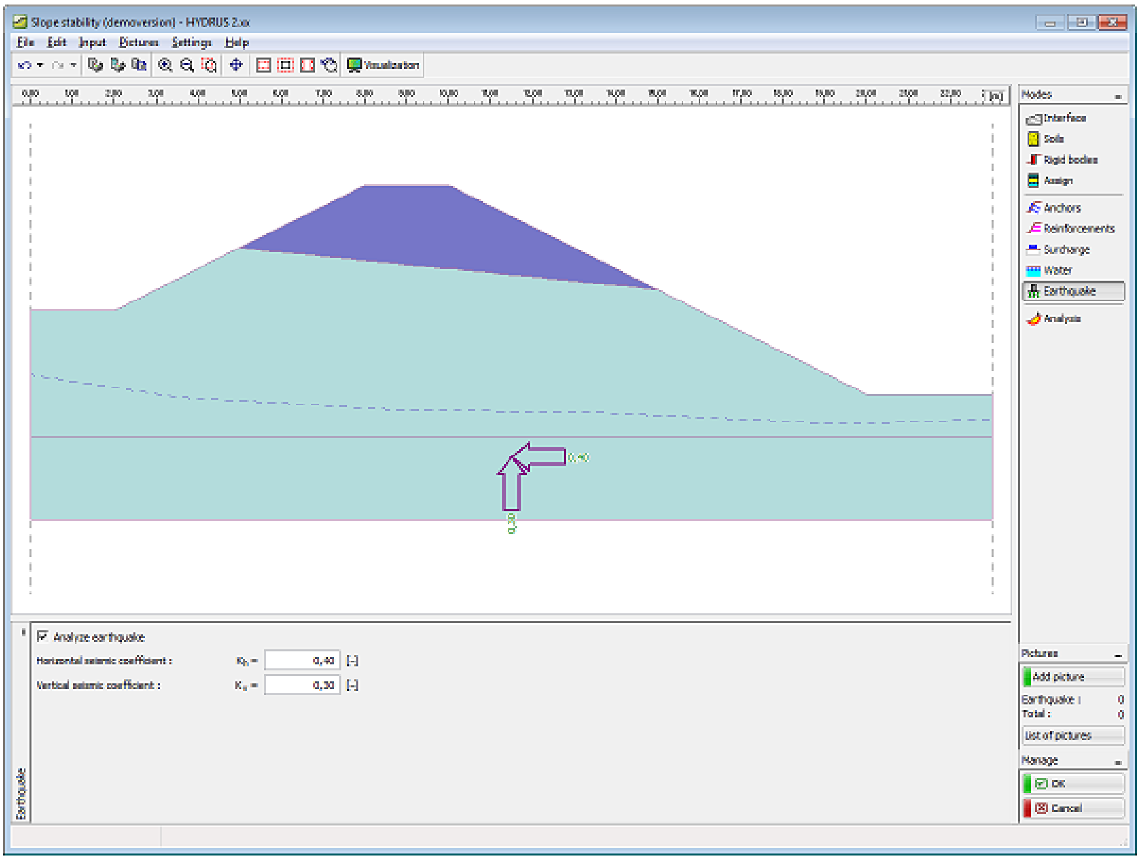
The program allows also for introducing vertical interfaces – in such a case the program requests to insert the point either to the **left** or to the **right**. The buttons that serve to confirm the action are colored – the same color is also used to visualize both input variants on the desktop.

The "**OK**" button (tinged green) is used to store the inputted interface when all interface points are introduced.

Earthquake

The "Earthquake" frame serves to input earthquake parameters. Directions of inputted earthquake effects are displayed on the desktop.

Slope stability analysis while accounting for earthquake is described in the theoretical part of the hint in chapter "Influence of earthquake".



Frame "Earthquake"

Analysis

The "Analysis" frame displays the analysis results. Several analyses can be performed for a single task.

The starting point in the slope stability analysis is the selection of the slip surface. The analysis is started using the "**Analyze**" button. The analysis results appear in the right part of the frame.

The type of analysis is selected in the mid section of the frame – four methods are available:

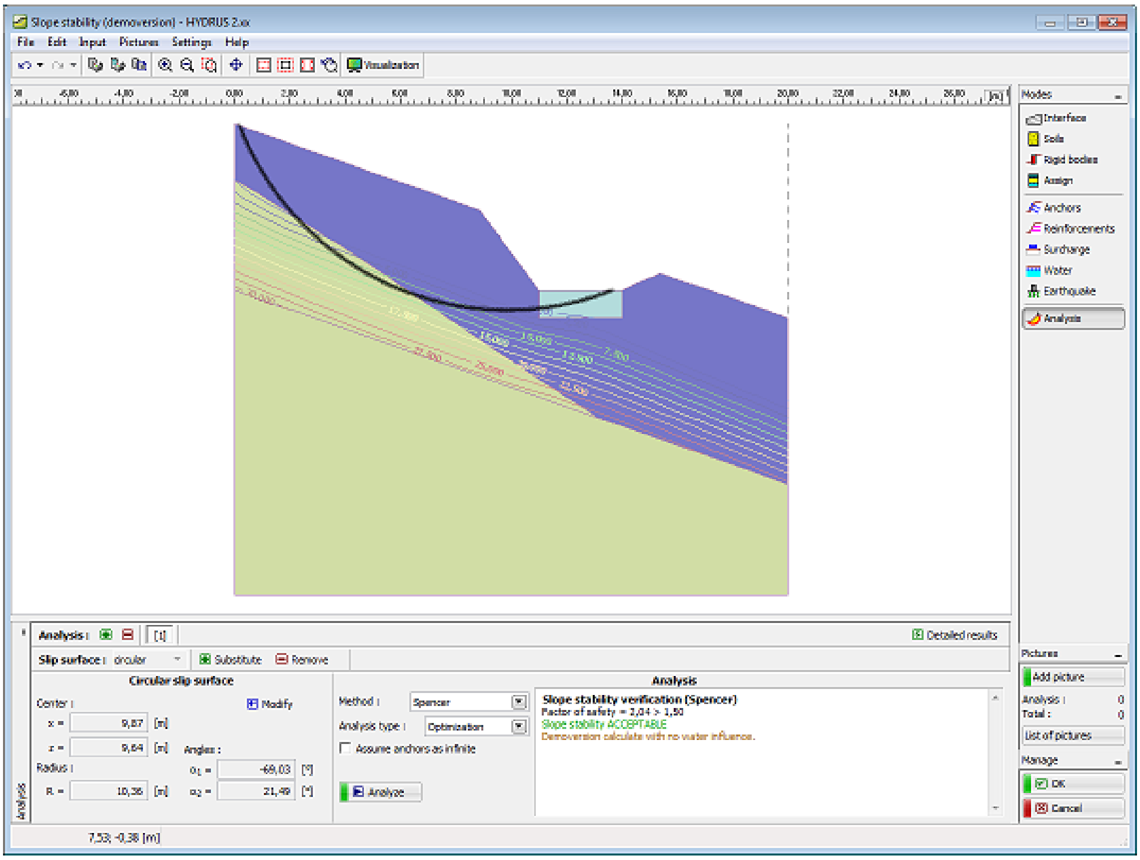
- Fellenius/Petterson
- Bishop
- Spencer
- Morgenstern-Price

It is also possible to specify how to deal with anchors in the analysis (box "**Assume anchors as infinite**").

The slip surface, even the optimized one, must be introduced in the frame – several possibilities are available:

> **using mouse** – press the "**Input**" button to active the input regime and then by clicking the left mouse button enter three points to define a circular slip surface (the introduced slip surface can be further modified using the "**Modify**" button or specified again with the help of the "**Replace**" button
>
> **using the dialog window** – pressing the "**Input**" button in the "Circular slip surface" frame opens the "Circular slip surface" dialog window that allows for specifying the radius and coordinates of center

The analysis results appear in the left part of the frame and the optimized slip surface on the desktop. Visualization of results can be adjusted in the "Visualization style settings" dialog window.



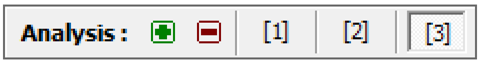
Frame "Analysis"

Running more verifications

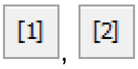
Several analyses can be carried out on this frame. It is usefiull for example fo

- Analysis of various slip surfaces
- Verification according to different theories

The bar in the top part of the frame serves to manage individual analyses.



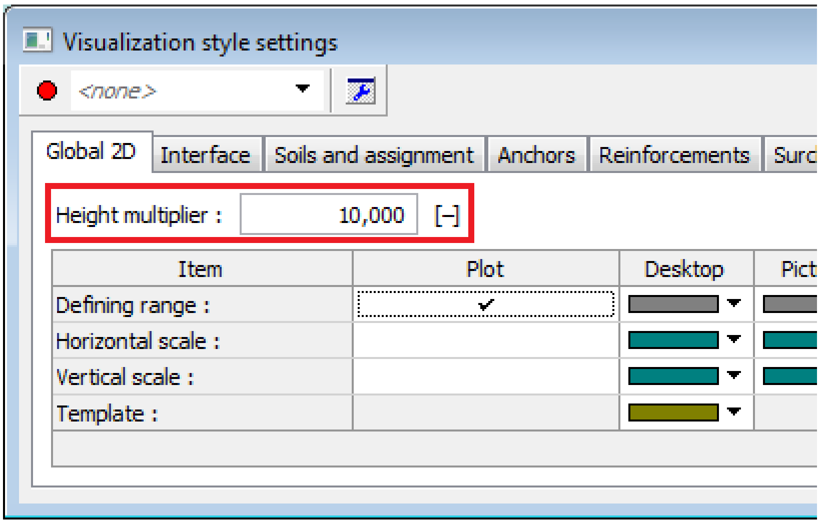
Frame "Analysis" – tool bar "Running more analyses / verification"

	**Add**	•	adds additional analysis on the bar
	**Remove**	•	removes the **currently selected** analysis
	Analysis **1,2,.**	•	switches between individual analyses

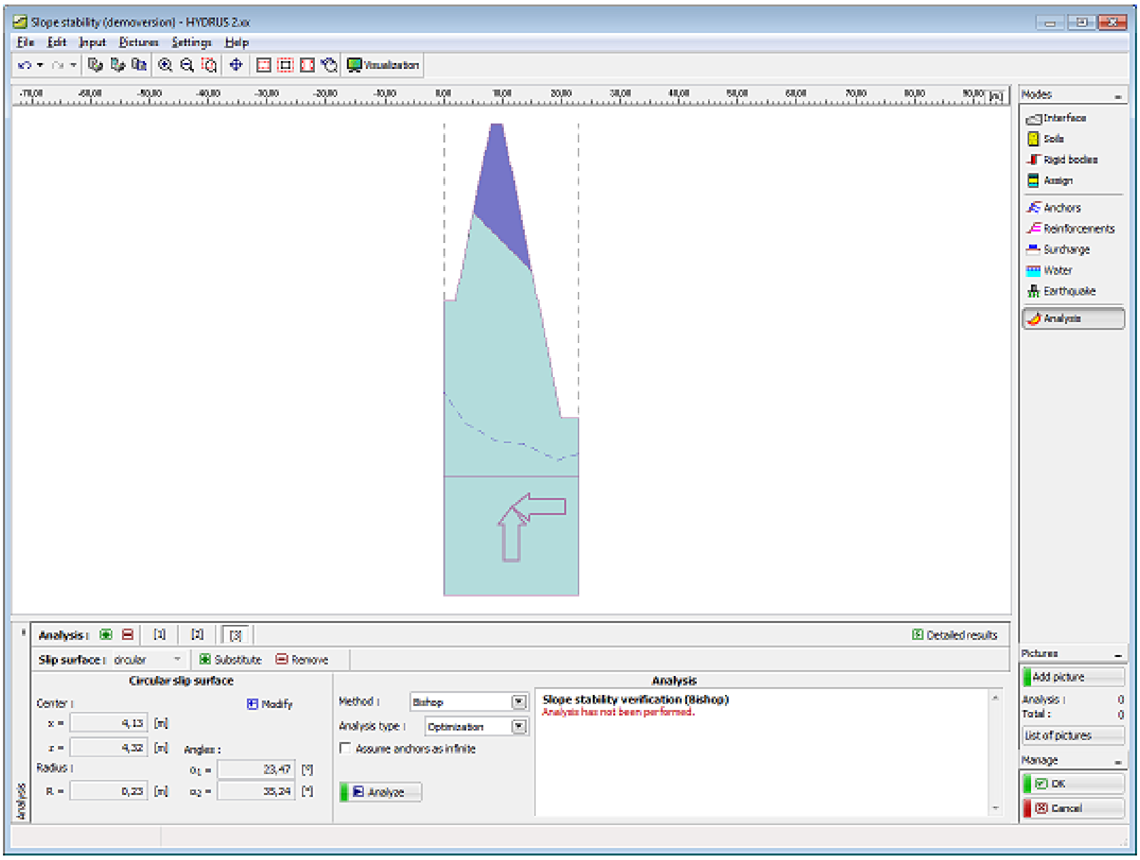
Height multiplier

Providing the analyzed slope is too long or has small height the plotted slip surface might not be sufficiently visible. This problem can be solved by selected courser scale in the vertical direction with the help of height multiplier. The value of this multiplier is set in the "Visualization style settings" dialog window, tab sheet "**Global 2D**". Using standard setting ("Height multiplier" equal to one) plots undistorted structure proportional to its dimensions.

Only polygonal slip surface can be inputted graphically when exploiting the height multiplier option. The circular slip surface must be in such a case inputted manually in the "Circular slip surface" dialog window using the "**Input**" button.



Setting height multiplier



Visualization of the resulting slip surface when using height multiplier

Outputs

The program contains three basic output options:

- Print and export document
- Print and export picture
- Copy to clipboard

Adding picture

The program allows for storing the current picture irrespectively of the program regime. To that end, press the "**Add picture**" button on the vertical tool bar. The button opens the "**New picture**" dialog window and inserts the current view on the desktop view in the window.

The picture is always linked to a certain input regime or analysis. (The current regime is displayed next to the picture name). When printing a document the picture is automatically added to a specific regime in the tree.

The program allows for defining the picture either for a specific stage of construction (or for the current analysis) or adjusting the setting such that the picture is added to the document in all stages of construction (or all analyses). The latter option is assumed when selecting "**all**" in the "**Stages**" combo list (or "Analysis" list).

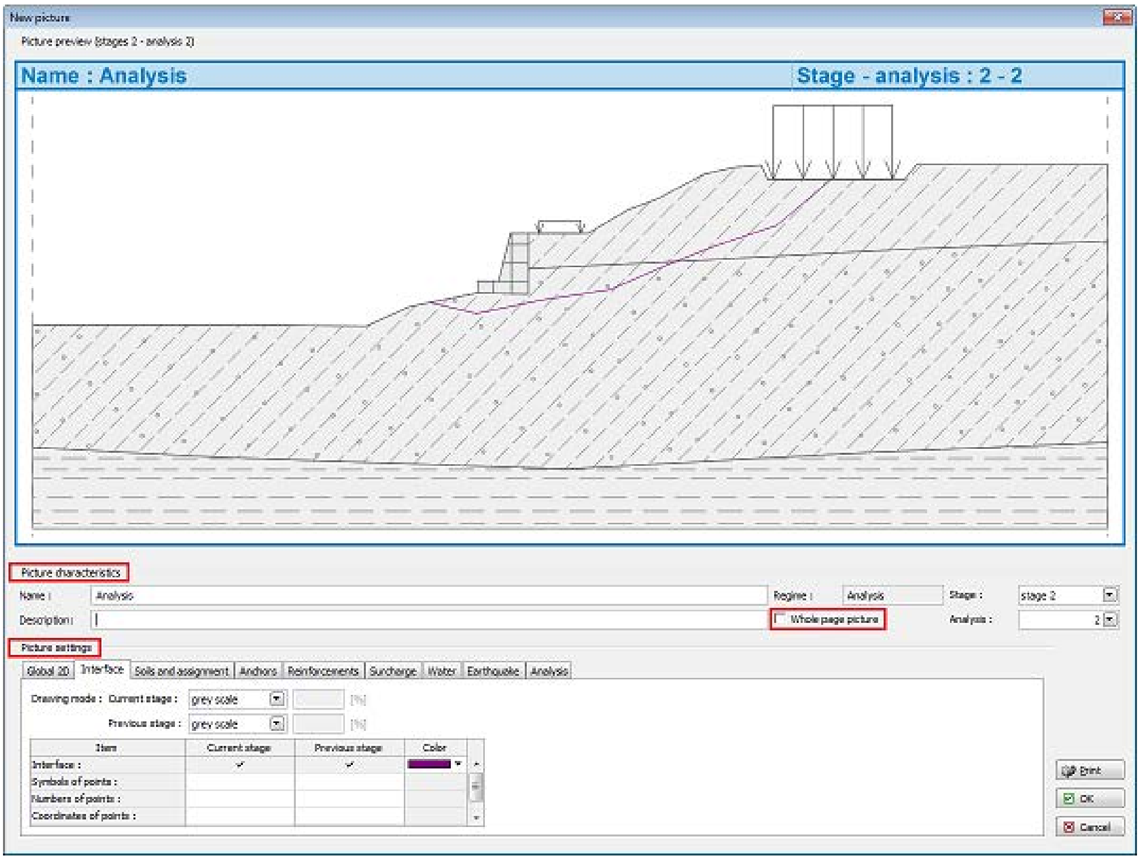
Checkbox "**Whole page picture**" allows to use whole page picture in document.

Warning: All inputted pictures are automatically regenerated whenever modifying data.

The "**Picture settings**" frame in bottom part of the dialog window further allows for adjusting colors and style of line (object) drawing – see "Visualization style settings".

The "**OK**" button stores the picture into the "Picture list". It can be then opened and modified at any time.

The picture can be also printed out from this window – pressing the "**Print**" button opens the dialog window for printing and exporting pictures. If the picture is active over all stages (or all analyses), then all possible combinations of pictures are printed all at once.



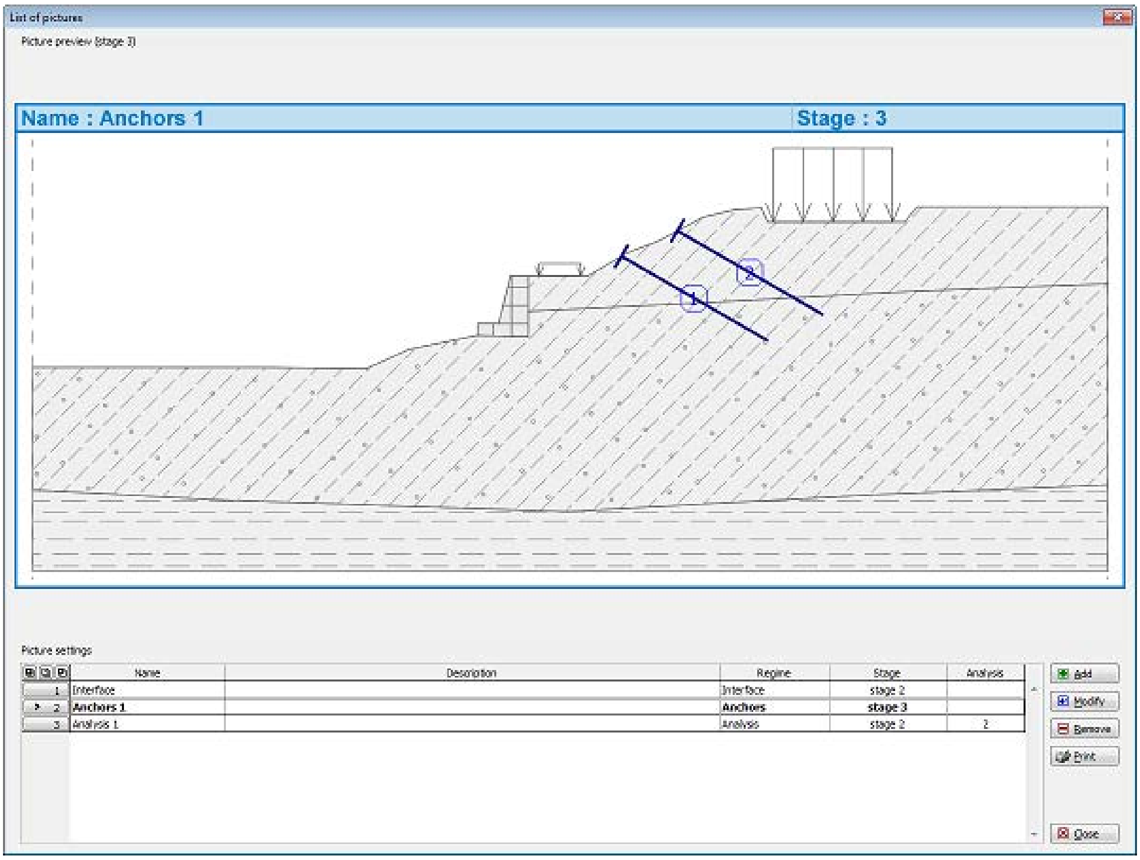
Dialog window "New picture"

List of pictures

Pictures stored with the help of the "New picture" dialog window are ordered in the table in "List of pictures". The "List of pictures" dialog window is opened using the button on the vertical tool bar. The table of list of pictures contains the picture name and description, the regime in which it was created and stage of construction or the analysis number.

Individual pictures can be edited using the "**Modify**" button, which opens the "**Edit picture**" dialog window (this window corresponds to the "New picture" dialog window both in the way it looks and in the way it functions).

These pictures can be printed out from the window by pressing the "**Print**" button that opens the dialog window for printing and exporting the picture. Providing the picture is active over all stages of construction (over all analyses, respectively) then the program prints all possible combinations of the picture. Providing more pictures are selected then all selected pictures are printed out.



Dialog window "List of pictures"

Print and export document

The "Print and export document" dialog window can be opened either from the control menu (items "**Files**", "**Print document**") or using the "Files" button on the horizontal tool bar. The page print preview with a generated text appears in the window.

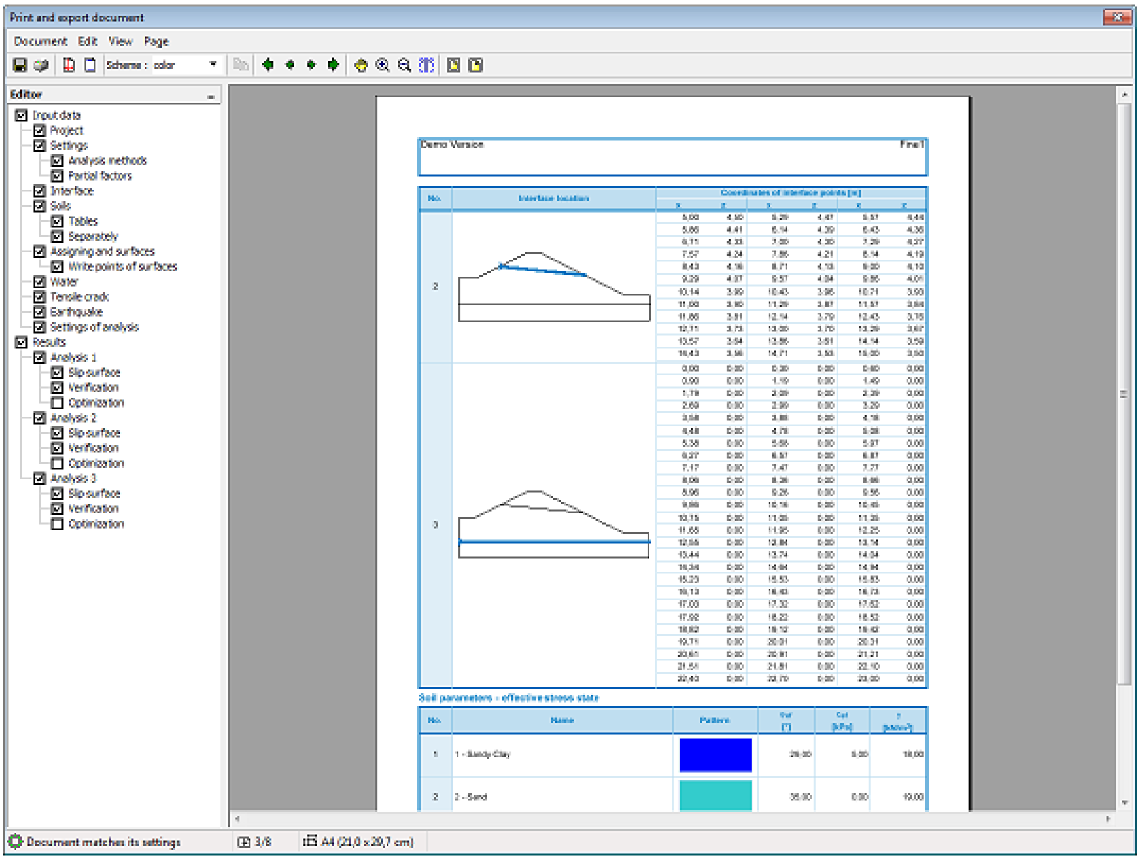
This window generates output document including pictures stored in the "Picture list". This window allows either for printing the created protocol or exporting it for further use. The **document is always up to date** – the program creates the document again based on inputted data (even with regenerated pictures) whenever opening this window.

Only specific parts of the document including pictures can be generated by checking the corresponding "**tree**" item in the left part of the window. Selecting or deselecting an arbitrary item prompts the program to regenerate the document automatically.

The dialog window contains its own "Control menu" and "Tool bar" for finalizing the page face (header and footer definition, page size and edges definition and definition page numbering).

A mouse ball or scroll bar can be also used to view the document.

The button part of the dialog window displays current information (defined page size, current document page and the total number of pages).



Dialog window "Print and export document"

Print and export picture

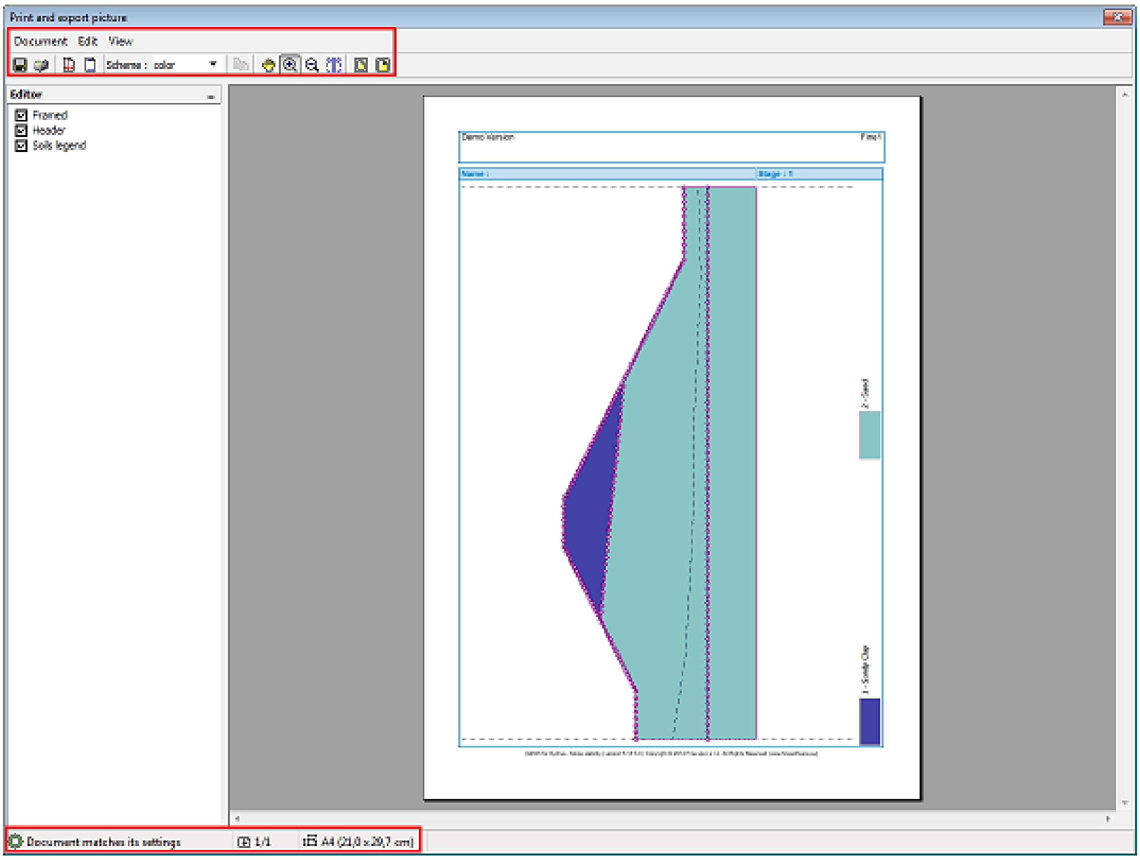
This window serves to print or export one or more pictures. Three options are available to open this window:

- Using the control menu (items "**Files**", "**Print view**") or the "Files" button on the tool bar to print data from the desktop.
- Using the "New picture" dialog window by pressing the "**Print**" button.
- Using the "List of pictures" dialog window by pressing the "**Print**" button.

The window may contain more than one picture at the same time (when printing more construction stages or analyses) when printing more pictures from the list. Each pictured is printed on a separate page. The picture preview can be adjusted using buttons on the tool bar or a mouse ball.

The dialog window contains its own "Control menu" and "Tool bar" for finalizing the page face (header and footer definition, page size and edges definition and definition page numbering).

The button part of the dialog window displays current information (defined page size, current document page and the total number of pages).



Dialog window "Documents" – print and export current picture (view)

Control menu Print and export

The control menu of the "Print and export document" and "Print and export pictures" dialog windows contains the following items:

Document

Save as	• opens the "Save as" dialog window that allows for saving the file in format *.PDF, or *.RTF
Send	• opens the dialog window for mail client an adds the picture as an attachement in format *.PDF
Open and edit	• opens text editor (associated in the Windows system with *.RTF extenison) that allows for editing the page manulally
Page properties	• opens the "Page properties" dialog window that allows for specifying the page style (size, edges, layout)
Header and footer	• opens the "Header and footer" dialog window that allows for inputting the document headers and footers
Print	• opens the system window for "**Print**"
Close	• closes the dialog window

Edit

Copy • copies the selected picture (text) to clipboard – parameters are set in the "Options" dialog window – tab sheet "Copy to clipboard"

Select all • marks all on page (on document) into block

Cancel selection • cancels entire selection (picture, text)

View

Full page • modifies the page size such that the entire page in the dialog window is visible

Page width • fits the page to a maximum width of the document dialog window

Page (this item appers in the menu only if the document has more than one page)

First page • shows the document first page

Previous page • shows the previous page

Following page • shows the following page

Last page • shows the document last page

Tool bar Print and export

The tool bar of the "Print and export document" and "Print and export picture" dialog windows contains the following buttons:

Tool bar "Print and export"

Individual buttons function as follows:

	**Save as**	• opens the "Save as" dialog window that allows for saving the file in format *.PDF, or *.RTF
	**Print**	• opens the system window for "**Print**"
	**Page properties**	• opens the "Page properties" dialog window that allows for specifying the page style (size, edges, orientation)
	**Header and footer**	• opens the "Header and footer" dialog window that allows for inputting the document headers and footers
	**Color style**	• determines the style of picture view (color, gray scale, black & white)
	**Copy**	• copies the selected picture (text) to clipboard – parameters are set in the "Options" dialog window – tab sheet "Copy to clipboard"
	**First page**	• shows the document first page
	**Previous page**	• shows the previous page
	**Next page**	• shows the following page
	**Last page**	• shows the document last page

	Move	• moves the current view in an arbitrary direction – to proceed move mouse in the desired location while keeping the left mouse button pressed
	Zoom in	• scales up the desktop view while keeping location of the point under the axis cross unchanged – this action is repeated using the left mouse button, the right button leaves the zooming mode
	Zoom out	• scales down the desktop view while keeping location of the point under the axis cross unchanged – this action is repeated using the left mouse button, the right mouse button leaves the zooming mode
	Text selection	• allows for selecting the text under the axis cross - to proceed move mouse over the desired text while keeping the left mouse button pressed
	Full page	• modifies the page size such that the entire page in the dialog window is visible
	Page width	• fits the page to maximum width of the document dialog window

Setting header and footer

The dialog window serves to define properties of the document header and footer. The "**print header (footer)**" check box determines whether to print the document header (footer).

Header and footer lines may contain an arbitrary text and inserted objects implicitly defined by the program. These objects receive program information such as:

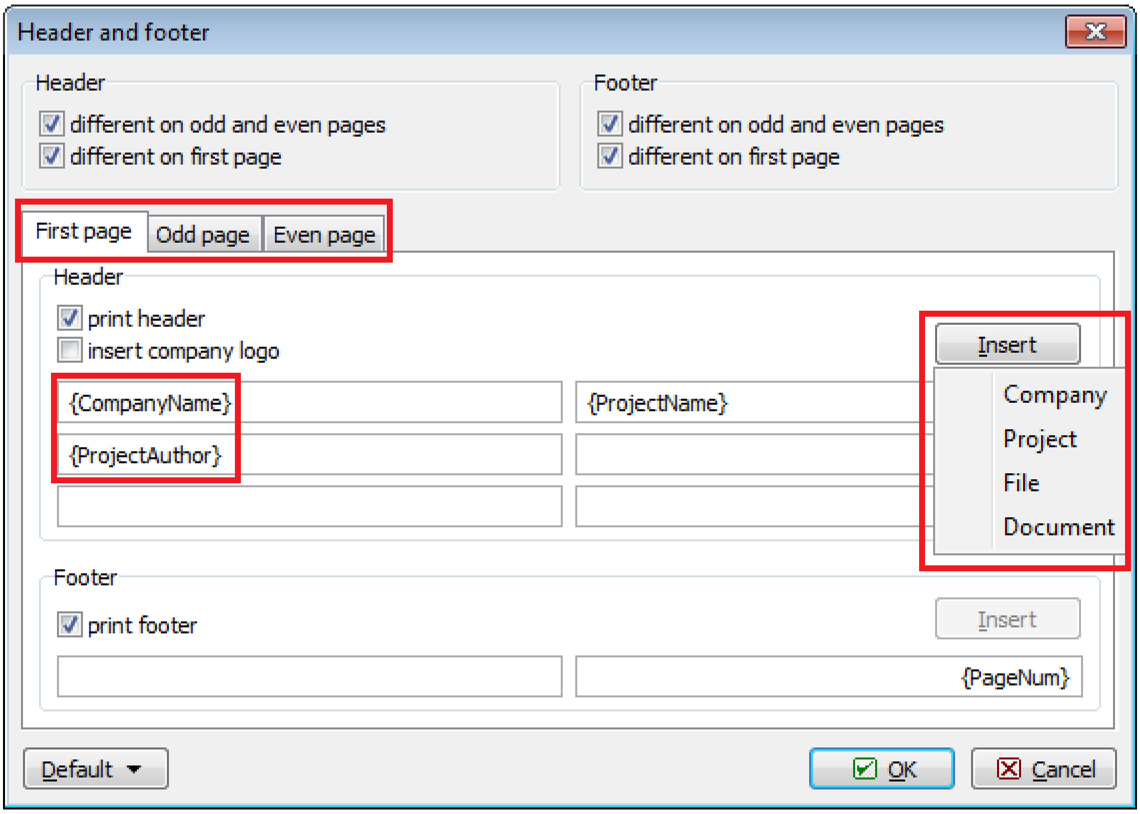
- From the "Company data" dialog window (company name, logo, address)
- From the "**Project**" frame (name and task description, author)
- From the document system data (date, time, page numbering)

Objects can be introduced using the "**Insert**" button (the button opens a list of objects). The button is active only if the cursor is found in one of the line that allows for inserting text (object). Inserted objects are written in an internal format different from other text and placed in curly brackets.

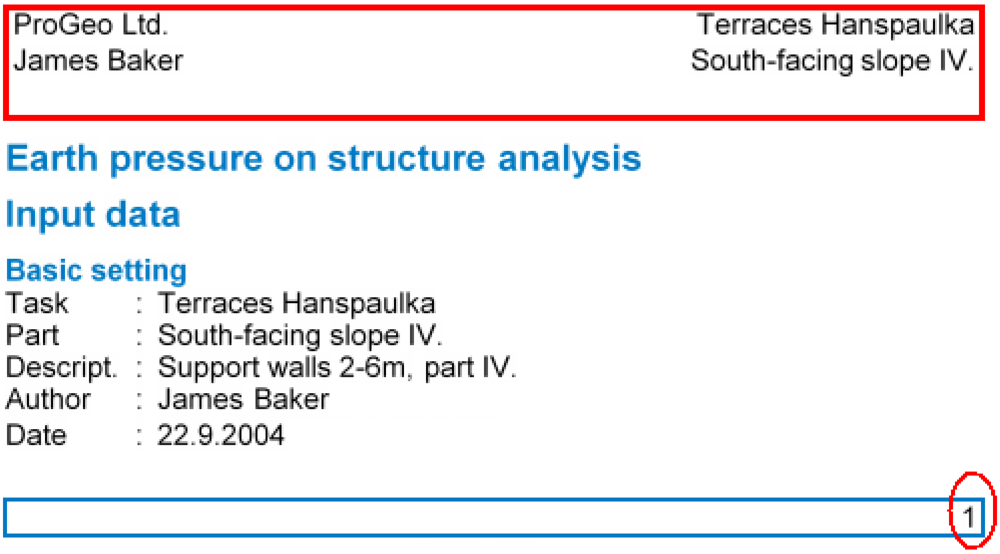
The program allows for defining various headers for the first page or odd and even pages, respectively. Individual headers are in such a case defined in separate tab sheets.

The "**use as default**" option sets the inputted header and footer parameters as default for the newly created data. The assumed default setting is common for all our programs. Different computer users may use different settings.

Writing format and the resulting view are evident from the following pictures.



Dialog window "Header and footer"

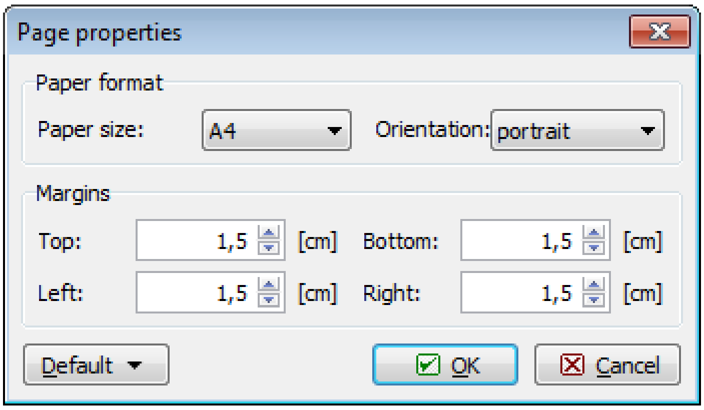


View of document header and footer

Page properties

The dialog window allows for setting the page layout (paper format, print orientation and edges).

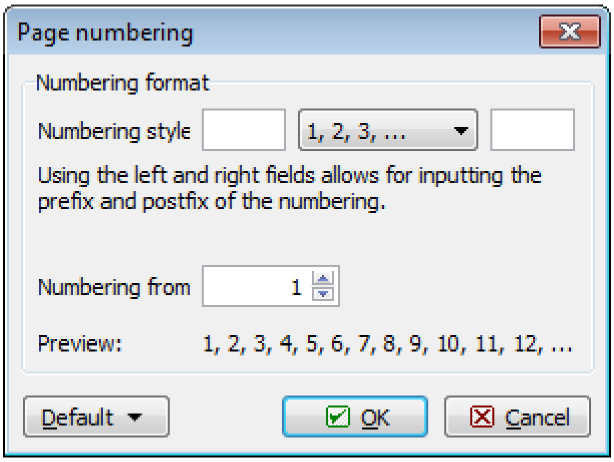
The "**use as default**" option sets the inputted page properties as default for the newly created data. The assumed default setting is common for all our programs. Different computer users may use different settings.



Dialog window "Page properties"

Page numbering

This dialog window allows the user to set page numbering. The combo list serves to define the numbering style (Arabic digits, roman digits, with the help of symbols). A constant text can be placed both in front and behind the page number. The "**Numbering from**" option allows for starting the page numbering from an arbitrary number. The "**use as default**" option sets the inputted page numbering properties as default for the newly created data. The assumed default setting is common for all our programs. Different computer users may use different settings.



Dialog window "Page numbering"

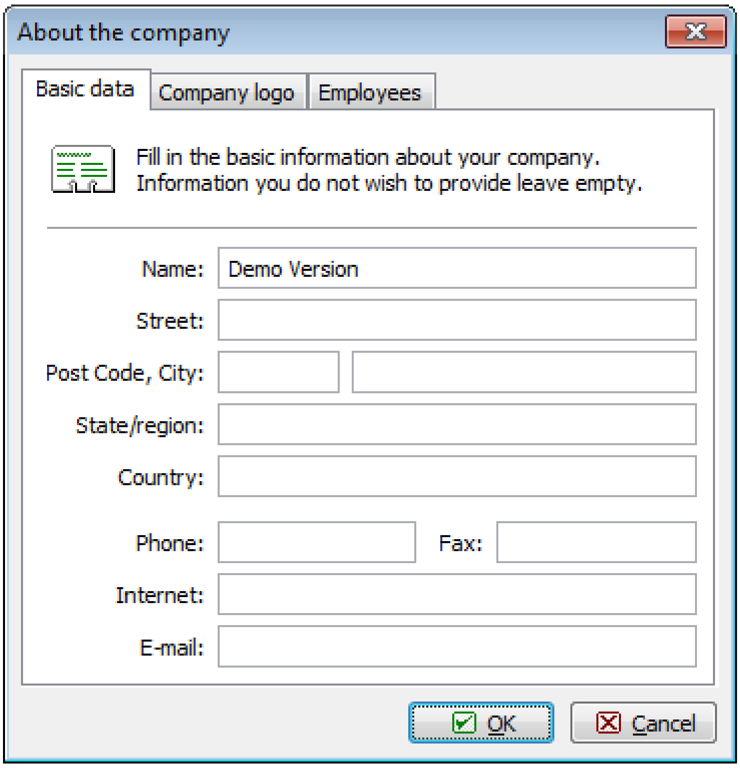
About company

The dialog window is launched from the managing menu (items "**Settings**", "**Company**").

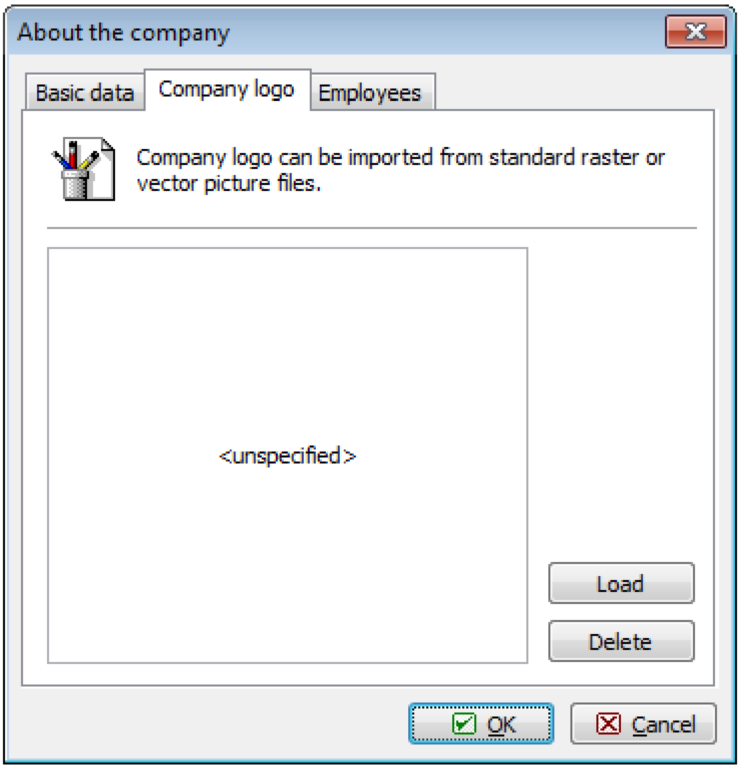
The "Basic data" tab sheet serves to specify the basic information about company. The inputted data are used by the program when printing and exporting documents (pictures), in the document header or footer.

The "**Company logo**" tab sheet allows the user to load the company logo. The "**Load**" button opens the dialog window which allows for opening the picture in various formats (*.JPG, *.JPEG, *.JPE, *.BMP, *.ICO, *.EMF, *.WMF).

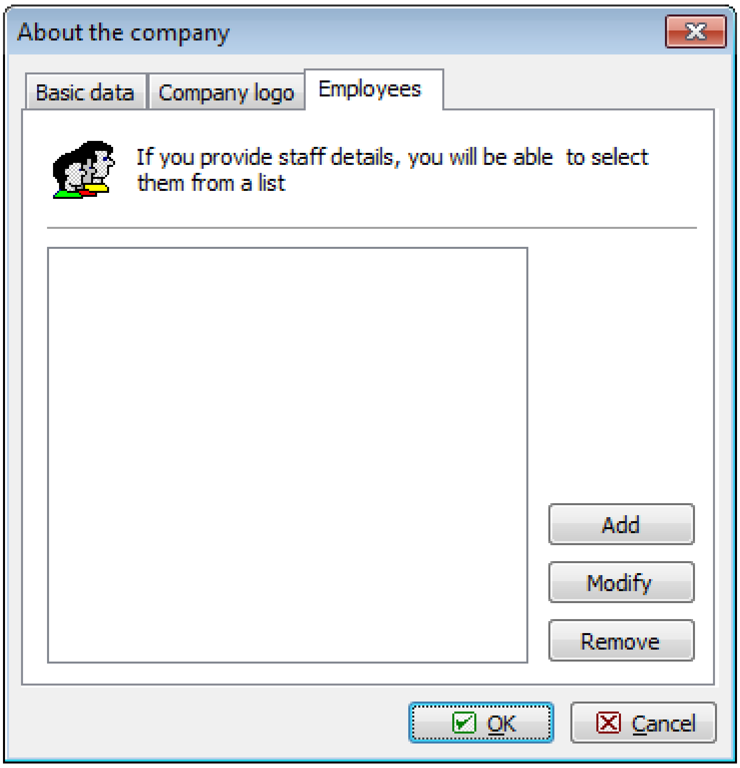
The "**Employees**" tab sheep allows for inputting the list of program users (employees). When filling the name list it is no longer necessary fill the author's name in the frame "Project".



Dialog window "About company" – tab sheet "Basic data"



Dialog window "About company" – tab sheet "Company logo"



Dialog window "About company" – tab sheet "Employees"