Gravity Wall SGW+

Contents

Basic Documentation – Overview

In addition to the individual program manuals, you will find basic explanations on the operation of the programs on our homepage www.frilo.com in the Campus-download-section.

Application options

The program provides the stability and serviceability verifications as well as the verification of the internal stability of a gravity wall made of unreinforced or reinforced concrete.
The gravity wall can have a toe (valley side) and a haunch on the hill or valley side. The base can be inclined.

The ground surface behind the wall can be horizontal or sloped upwards, either continuously or with a polygonal profile. A downwards slope (negative slope) cannot be defined due to the restrictions of the applied calculation method.

The ground can consist of any number of horizontally limited soil layers. An additional soil layer can be defined on the valley side. Stagnant groundwater can be considered as well as different earth pressure situations (e.g. earth pressure due to compaction, increased active earth pressure).

Available standards

You can optionally perform the design in accordance with

▪ DIN EN 1992-1-1:2015

▪ ÖNORM EN 1992-1-1:2011

▪ PN EN 1992-1-1:2010

Geotechnical standards

The geotechnical verifications can optionally be based on:

▪ DIN EN 1997-1:2010 or DIN 1054 in the persistent design situation DS-P

▪ ÖNORM EN 1997-1: 2013 in the design situation DS-1 in combination with any consequence class

▪ PN EN 1997-1:2011

Gravity wall with loads

Loads

▪ Area load, line load and moment acting on the wall crown and the toe

▪ Horizontal force applying at a freely selectable height to the wall and the toe

▪ Area load on the ground surface, optionally applying distant to the wall

▪ Strip load, line load and block load applying at freely selectable positions on the ground surface or inside the soil

Other actions

"Stagnant groundwater" can be taken into account.

Results

- Overview of the decisive load case combinations and the results of the verifications

- Output of the earth pressure distribution on the wall as a graphic and in the form of tables

- Water pressure distribution

- Verification of the overturning stability

- Verifications of the ground failure resistance and the sliding stability or

- Simplified verification in typical cases as per DIN 1054 A 6.10 (not with ÖNORM)

- Embankment failure analysis incl. slip circle representation

- Verification of the gaping joint in the 1st and 2nd core range
  (for verifications as per ÖNORM, this verification replaces the overturning stability verification according to DIN 1054)

- Additional features for verifications in accordance with DIN:
  The software checks whether verifications of the stability against detrimental torsion/displacement are required.
  These verifications are not performed, however.

- Output of settlement and torsion

- Base pressure distribution for the design of the toe for bending and shear force

- Reinforced concrete design in the ULS [1] of the wall at a freely selectable number of points (bending and shear force). Output of the required reinforcement.

- Design of the toe in the ULS at its contact face (bending and shear force). Output of the required reinforcement.

The geotechnical verifications are based on the persistent design situation.

[1] ULS: ultimate limit state

Basis of calculation

SGW+ performs verifications of the internal and external stability as well of the serviceability of a gravity wall in the persistent design situation. Well-drained soil (calculation with the effective shear parameters $\phi = \phi'$, $c = c'$) and stagnant groundwater are assumed.

Earth pressure

Earth pressure is calculated in accordance with DIN 4085 /9/ or EAB /12/ and the 'Grundbautaschenbuch' /13/. The minimum earth pressure is determined in accordance with EAB /12/ ($\phi_{equiv} = 40\,°$, comparison of the resultant forces, earth pressure generated by area loads with a characteristic friction angle).

Where discontinuous slopes are concerned, the earth pressure is considered in accordance with Jenne /1/:
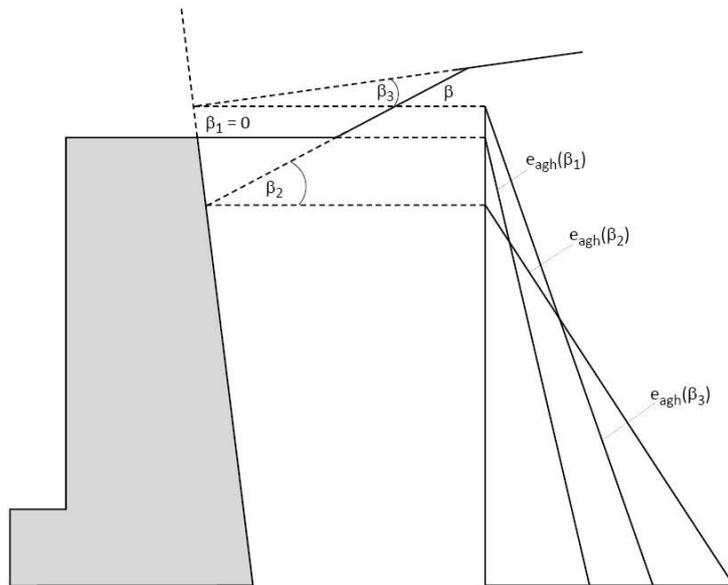
The earth pressure is always applied as a single action that has either a favourable or an unfavourable effect. This means that you cannot consider the vertical component separately from the horizontal one.

The earth pressure is usually calculated with the active earth pressure inclination angle of the gravity wall.

You can distinguish between earth pressure due to compaction, increased active earth pressure and earth pressure at rest in this connection.
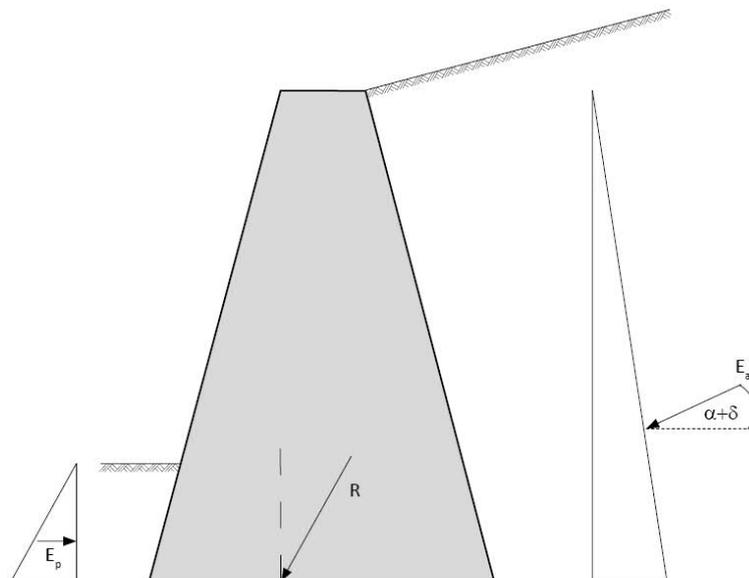
If the inclination of the gravity wall on the hill side is greater than α_{max}, the earth pressure is calculated on a plane of rupture inclined at α_{max}. Then the soil weight of the soil between the plane of rupture and the wall and, if applicable, a load acting on this wedge is considered as an action.

To determine the earth pressure acting on the inclined plane of rupture in combination with multiple soil layers, the inclination angle α_{max} of the plane of rupture is to be determined for each soil layer individually. The result of this method is a plane of rupture with linear sections and kinks at their joints.

$\alpha_{max} = \vartheta_{ag} - \varphi$

with:

ϑ_{ag} for $\alpha = 0°$ and $\delta_a = \beta$
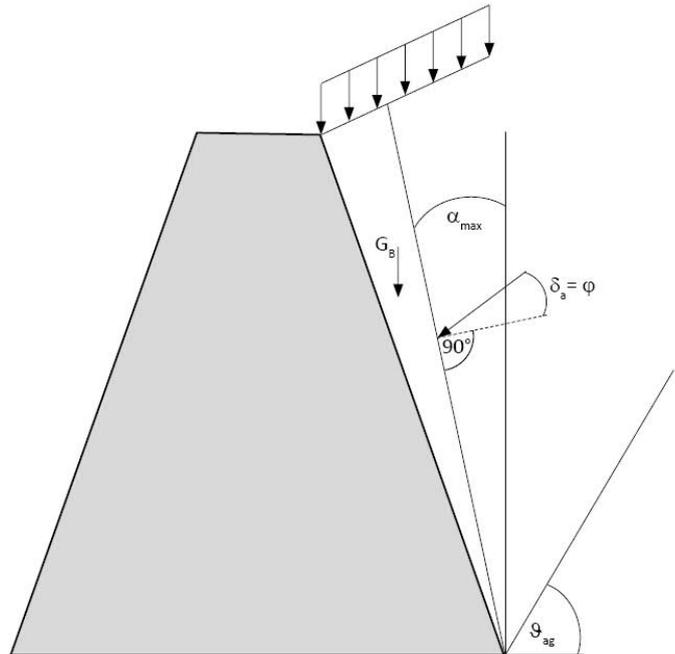
Earth resistance

Basically, you should consider earth resistance only if it will apply throughout the entire service life of the structure. Earth resistance is disabled in the software by default. If you activate the option, you can specify individually which percentage of the earth resistance should be considered in the respective verification. The software displays information about the values recommended in the standard.

If you select DIN EN 1997:2010 for the calculation, the earth resistance can only be calculated with a purely horizontal inclination (i.e. the earth resistance has no vertical component), because DIN 1054 prescribes this approach for the ground failure analysis and recommends it for the sliding stability verification. If the wall has a toe, the earth resistance is calculated separately for the wall and for a vertical equivalent joint.

The earth resistance in the equivalent joint is used in the external stability verifications and in the foundation design; the earth resistance at the wall has only an influence on the wall and foundation design.

If the horizontal loads acting in the direction of the valley are higher than the applying earth resistance, the software automatically adjusts the application factors in such a manner that the earth resistance never exceeds the horizontal loads. In the ground failure analysis, it is made sure in addition that the applied soil reaction force is considered with maximally 50 % of the actual earth resistance if the verification is based on DIN EN 1997:2010.

Other actions

Weight of soil

On the toe, the weight of soil is automatically considered. In the special case that the inclination of the gravity wall on the hill side is greater than α_{max}, the soil between the plane of rupture and the wall is taken into account as the self-weight of the soil. If there is groundwater, the part of the soil that is under water is considered with its buoyant unit weight. The total weight of soil is treated as a single action.

Water pressure

Water pressure is considered as being hydrostatic. It is assumed that no flow or very low flow occurs and that the wall is embedded in a soil layer with low permeability. The water pressure is applied all around the gravity wall in compliance with the pressure level and handled as a permanent action.
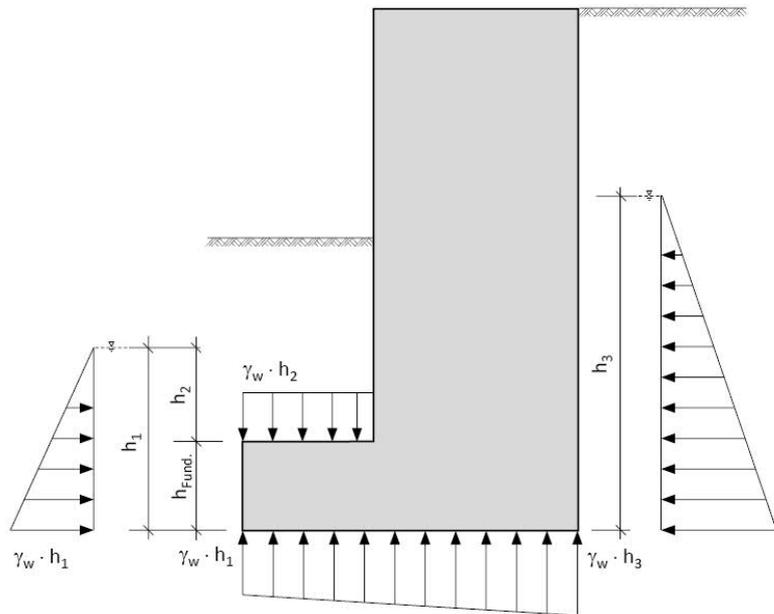
Ground loads

Ground loads generate earth pressure if they apply closely to the wall or to the plane of rupture.

Loads always apply in the way they are defined by the user. This means that loads are always considered fully, not only with their unfavourable portions, in all verifications with exception of the embankment failure analysis. Moreover, area loads below 10 kN/m² are not automatically treated as permanent loads independent of their actual group of action, as the EAB /12/ allow it. The user can define the approach recommended by the EAB without any problems, however.
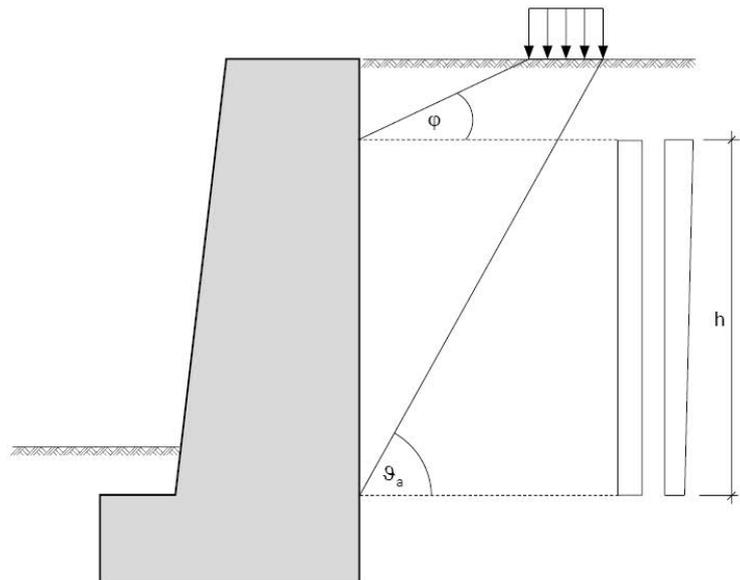
Component loads

Component loads do not generate earth pressure and are only included with their resultant force in the verifications of the external and internal stability.

Component loads can also act horizontally. Please note that horizontal loads in the hill direction (loads oriented to the right in SGW+) that exceed the total horizontal loads in the valley direction are not permissible. The program displays a corresponding error message in this case. Such a horizontal load would push the wall into the soil and contradict the assumptions the calculation is based on (such as overturning about the valley-side edge, ground failure mode in the valley direction and, last but not least, application of earth pressure). If such a great horizontal load applies, you should consider earth pressure in the verifications of the external stability in such way that you can map the low wall displacement due to the horizontal load (increased active, at rest).

Verifications of the external stability

The verifications of the external stability are so-called geotechnical verifications or soil engineering verifications.

Overturning in accordance with DIN 1054

The verification of the overturning stability is based on DIN 1054 /5/ in the EQU ultimate limit state (involving a loss of overall equilibrium). In this verification, destabilising and stabilising design values of the moments about the valley-side edge of the gravity wall are compared.

$$M_{G,k,dst} \cdot \gamma_{G,dst} + M_{Q,rep,dst} \cdot \gamma_{Q,dst} \leq M_{G,k,stb} \cdot \gamma_{G,stb}$$
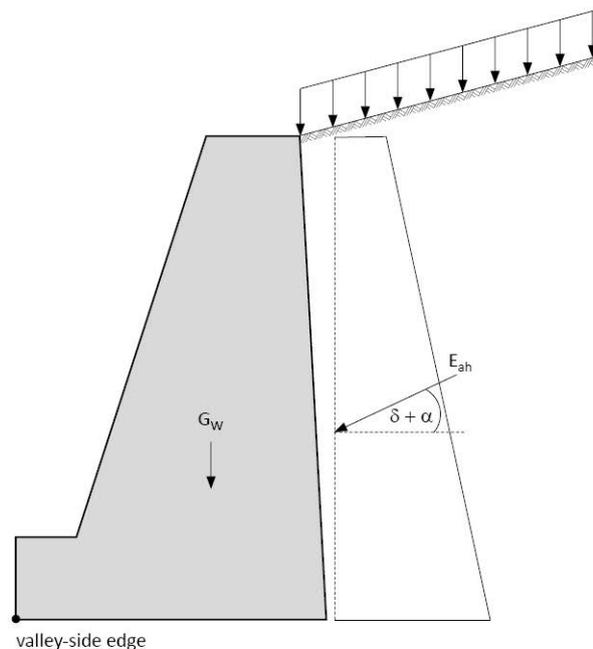
Sliding

The sliding stability verification is performed in the GEO limit state (ultimate limit state involving the failure of structures, components and soil) in accordance with verification method 2 (GEO-2). In this limit state, the partial safety factors are the same for favourable and unfavourable permanent actions as per DIN 1054, i.e. permanent actions are not combined. If the verification is based on ÖNORM, permanent actions are combined with each other.

DIN 1054 specifies that the base friction angle δ_k required for the verification should not exceed 35 ° if it was not calculated specifically. For cast-in-place concrete foundations, it is set equal to the friction angle ϕ' of the soil layer in the base of the foundation (if the inclined base passes through several layers, averaging is based on the length). For foundations of pre-cast components, the base friction angle is set to maximally 2/3 of the friction angle of the soil layer in the base. You cannot take adhesion into account.

The verification is as follows:

$$H_d \leq R_d + R_{p,d}$$

with:

$$R_d = \frac{V_k \cdot \tan\delta_k}{\gamma_{R,h}}$$

$$R_{p,d} = \frac{R_{p,k}}{\gamma_{Ep}}$$

If the base area of the gravity wall is inclined, the verification must be performed in the base (with rotated loads) and, additionally, in a horizontal section (through the subsoil) underneath the base. In this verification, the loads are always rotated automatically to ensure that their direction of action is normal (N) and parallel (T) to the base. The more unfavourable verification becomes decisive. ÖNORM B4435-2 limits the base friction angle to $\phi/3$; compliance with this limit is checked by the software.

equivalent shear joint
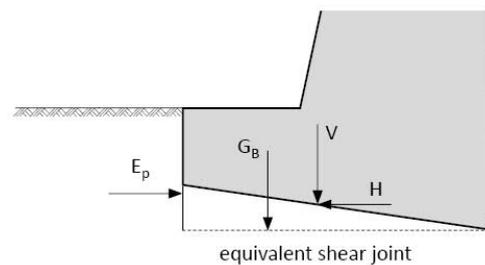
Because the loads are rotated, the horizontally acting earth resistance has a portion, which is perpendicular to the base. In SGW+, this portion is added to the vertical actions V_k and, consequently, influences R_d and not $R_{p,d}$. The portion normal to the base area is considered in the calculation of $R_{p,d}$.

In the verification of the section through the ground, the additional soil wedge and earth resistance in front of the soil wedge are considered by the program. The additional earth resistance is considered with the same factor as the earth resistance in front of the toe. If the earth resistance option is not checked, no additional earth resistance will be considered.

In this case, R_d is determined as follows:

$$R_d = \frac{V_k \cdot \tan\phi_k' + A' \cdot c_k'}{\gamma_{R,h}}$$

A' is the contact area of the equivalent shear joint.

Earth resistance can optionally be considered as additional resistance. If the earth resistance option is activated, you need to check additionally the displacement in the base area as per DIN 1054. If you include earth pressure in the verification of the sliding stability as per DIN 1054, the software checks in addition whether the conditions to provide evidence of the stability against detrimental displacement of the foundations in the base area are satisfied in the limit state of serviceability. The verification is put out in SGW+. If the conditions are not satisfied, however, SGW+ cannot perform the required verification of the stability against detrimental displacement in the base area in the current version.

Ground failure

The detailed ground failure analysis is performed for a strip foundation in the GEO limit state, verification method 2. In this limit state, the partial safety factors are the same for favourable and unfavourable permanent actions as per DIN. If the verification is based on ÖNORM, permanent loads are combined with each other. For the effects of actions in the base area, representative values are determined in accordance with EC7 and are included in the verification to calculate the ground failure resistance (via the eccentricity and the load inclination)-, see EC7, equation (2.7b) in 2.4.7.3. Earth resistance is considered as a soil reaction and included as an action. This soil reaction is included in the verification as per DIN with maximally half of the horizontal resultant force of the actual earth resistance.

If an embedment depth was defined for the gravity wall, the soil in front of the wall is regarded as stabilising (no matter whether earth resistance is considered or not). A structural water load is not included as a

stabilising resistance that counteracts ground failure but only as an action, because water cannot transfer shear forces.

If the verification is performed in accordance with DIN, the vertical portion of the actions is compared to the vertical portion of the ground failure resistance. In verification in accordance with ÖNORM, the total actions are compared to the total resistance.

Simplified verification in typical cases (only with DIN)

The simplified verification in typical cases is performed as per DIN 1054 A, 6.10. It replaces the verifications for the ULS 'ground failure' and 'sliding' as well as the verifications of serviceabilty.

If the simplified method should be used, some prerequisites must be met:

a) The foundation base should be horizontal and the ground surface as well as the layer borders should be almost horizontal.

b) The subsoil should have sufficient strength until below the foundation base, i.e. down to a depth twice as great as the foundation width; the minimum depth should be 2.0 m, see A 6.10.2.1 A (4) for non-cohesive soil or A 6.10.3.1 A (4) for cohesive soil.

c) Dynamic loads should not apply regularly or mainly to the foundation.
No considerable excess pore pressure should occur in cohesive layers.

d) A supporting effect of the soil in front of the foundation should only be considered if it is ensured by constructive or other measures that the soil remains in place.

e) The inclination of the characteristic or representative resultant base pressure force should satisfy the condition:

$$\tan(\delta) = \frac{H_{rep}}{V_{rep}} \leq 0{,}2$$

f) The conditions applying to the permissible eccentricity for characteristic and/or representative effects of actions as per 6.6.5 should be satisfied.

g) The verification of the stability against loss of equilibrium through overturning as per 6.5.4 A (3) should be successful.

The prerequisites a), e), f) and g) are checked by the software. The user is warned in the event of non-compliance. The other conditions cannot be checked automatically, but they are included in the output so that the user can verify them.

After the verification of the criteria, the calculation is performed. To ensure this, the design value of the base pressure loading σ_{Ed} calculated by the software is compared to the design value of the base effects of actions σ_{Rd} entered by the user. The verification is successful if the following is true:

$$\sigma_{Ed} \leq \sigma_{R,d}$$

The design value of the base resistance can be taken either from a soil expertise or from expert literature. DIN 1054 /5/ gives tables for non-cohesive (paragraph A 6.10.2) and cohesive (paragraph A 10.3) soil for this purpose.

The simplified verification always produces more conservative results than the analytical verifications and is intended to help manual calculations in simple cases. We recommend performing analytical verifications as a rule.

The simplified verification in accordance with ÖNORM B4435-1 no longer complies with the state of the art. The standard has not been aligned to the new code concept in any way and therefore, we dispensed completely with this verification in SGW+.

Embankment failure

The embankment failure is a special case among the external stability verifications. Different load assumptions apply in this case. Embankment failure based on the method of slices as per Bishop is implemented with the partial safety concept as per DIN 4084 /8/ or ÖNORM EN 1997:2013. The verification is performed in the GEO ultimate limit state and is based on verification method 3 (GEO-3). It is deemed successful if the following condition is true for the most unfavourable failure mechanism:

$$E_M \leq R_M$$

with:

$$E_M = r \cdot \sum_i \left(\left(G_i + P_{vi} \cdot \sin(\vartheta_i) \right) \right) + \sum M_s$$

and

$$R_M = r \cdot \sum_i \frac{(G_i + P_{vi}) \cdot \tan(\varphi) + c_i \cdot b_i}{\cos \vartheta_i + \mu \cdot \tan \varphi_i \cdot \sin \vartheta_i} + \sum M_R$$

You can select an area that contains the centres of the slip circles that you want to examine. In addition, the radii of these circles are varied; the radii of slip circles, whose perimeters run through the gravity wall, are excluded. At the end of the calculation, the most unfavourable slip circle is put out. You can specify the number of slices.

As a rule, a higher number of slices and a higher number of circle centres and radii allow a more accurate calculation but increase the computing time. To find the most unfavourable failure mechanism, first select a larger area with a coarse grid of circle centres. Typically, the most unfavourable circle centre is situated above the wall on the left and the perimeter of this circle is tangent to the bottom edge of the foundation. If you have calculated the utilization for the coarse grid, perform additional calculations with finer grids at the points where the highest utilization occurred in the previous calculation. When you have found the most unfavourable circle increase the number of slices until the utilization remains unchanged. You should keep in mind that 'higher accuracy' in this context means higher calculation accuracy not more meaningful results. Because the model and the determination of the soil characteristics involve a certain degree of uncertainty, higher calculation accuracy does not necessarily mean that you can predict more precisely the behaviour of the structural system.

If groundwater exists, the weight of the soil is also adjusted automatically here. The influence of groundwater is considered with a hydrostatic approach, which delivers always inaccurate results on the safe side because the decay of the pressure potential in the penetrated soil is not considered. This assumption is justified and sufficiently accurate, because the gravity wall in the slip circle is not permeable. /3/ The resulting moment of the water pressure is added to $\sum M_s$.

Variable actions are only considered in the GEO-3 limit state if they have an unfavourable effect. SGW+ checks for each slice whether the portion of the load on the respective slice has a favourable or unfavourable effect. Therefore, the load is only applied to those slices where it has an unfavourable effect Component loads are treated as external actions and are only considered in the calculation if they have an unfavourable effect and/or if they act permanently. Because they are treated as external actions ($\sum M_s$) they have, unlike the ground loads, no influence on the resistance of the slice.

DIN 4084 and ÖNORM B4433 forbid the calculation of slices whose inclination is greater than that of the earth resistance joint of rupture resulting at an angle of $\delta_P = 0$ °. In such cases, SGW+ includes the earth resistance that results at the last valid slice border with $\phi = \phi_d$, $c = c_d$, $\delta = \beta = 0°$ instead of including the respective slices.

The slope is not considered in this connection because the assumptions are on the safe side if the last valid slice border runs within the slope. The soil layer thickness that is included for the earth resistance is always the difference between the height of the exit point and the depth of the joint of rupture at the last valid slice border.

The earth resistance is considered as a resistance moment in the equation by Bishop as follows:

$$\mu_{R,Ep} = \mu \cdot E_p \cdot r_{E_p}$$

The action resulting from the soil weight in the slice is not considered.

Gaping joint/overturning as per ÖNORM B 4435-2

The verification of the limit of a gaping joint is performed in the serviceability limit state. It is based on EC7 and uses representative actions. The verification checks whether the characteristic resultant base pressure force caused by permanent actions runs inside the first core range and whether the representative resultant soil pressure force of all actions (persistent and variable) runs inside the second core range. You can consider earth resistance here also as an action and limit it with a factor.
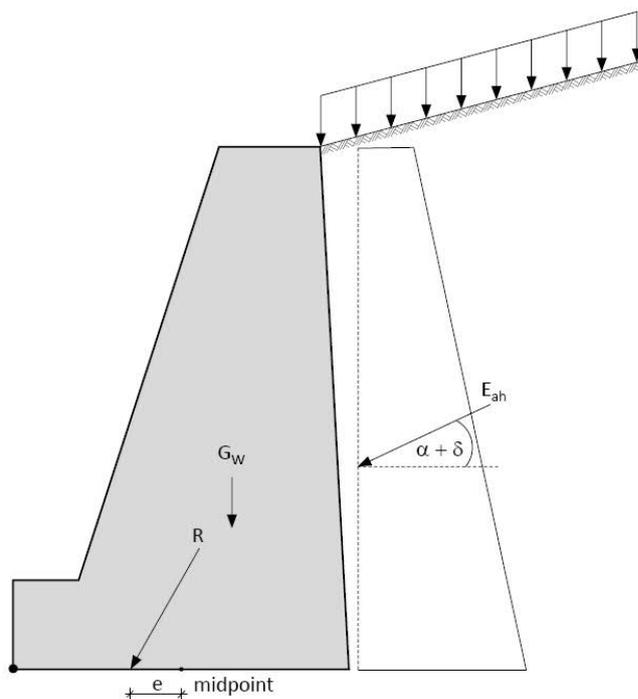
Calculation of the settlement

An indirect settlement calculation is carried out according to the theoretical principles in the Grundbau-Taschenbuch 1990, Volume 1 /13/ at the characteristic point of the foundation (foundation is assumed to be rigid). For this purpose, the program determines the stresses at small distances within the soil layers and at layer boundaries and integrates them numerically. The software calculates both mean settlements and torsion.

In the settlement calculation, a preload can be taken into account which reduces the uniform normal base stress relevant for the settlement. The preload cannot be greater than the uniform base load.

The limiting depth up to which the settlements are to be considered can either be specified or determined by the software as the depth at which the effective soil stress underneath the structure corresponds to 20 % of the superposition stress.

The stiffness modulus, which is taken into account when determining the settlements, is the calculation modulus E* according to DIN 4019. Any correction coefficient must already be included in this calculation modulus if it should be taken into account.

$$E^* = \frac{E}{1-v^2}$$

und

$$E_s = \frac{1-v}{1-v-2v^2} \cdot E$$

As provided for in DIN 1054, variable loads can be considered by using different combination coefficients.

Verification of the internal stability

For the verification of internal stability, the gravity wall is verified in a reinforced or an unreinforced execution.

If the wall has a toe, reinforcement is required.

The design with unreinforced concrete is carried out in accordance with EC2, chapter 12 /10/.

The design with reinforcement is carried out using the kd method.

Minimum reinforcement (including minimum compression reinforcement) is considered automatically unless you uncheck the corresponding options.

If the cross-section height varies, shear force is automatically increased or decreased in the verification of the load-bearing capacity as per DIN 1045-1 10.3.2 (4), when the respective option is checked.

The calculation is performed in a first-order analysis. The design of unreinforced versions is generally to be performed in a second-order analysis in accordance with the National Annex DIN EN 1992-1-1/NA. Only for compression members made of unreinforced concrete with l_{col} / h < 2.5, a determination of the internal forces in a second-order analysis is not required. If this condition is not met, the SGW+ application displays a notification to insert a reinforcement, since a second-order analysis is not supported by the software.

You can optionally display the required reinforcement schematically and put it out.

Wall design

The program puts out the verification for unreinforced concrete or for a required reinforcement.

You can design the wall at a freely selectable number of points. It is loaded by earth pressure (including earth pressure caused by loads), by its self-weight and, if applicable, by water pressure (including buoyancy) and component loads. For the calculation of the internal forces, the wall is idealized as a cantilever arm, the neutral axis of moments runs on the hillside (on the right) in this case.

Under normal conditions, a positive moment and a negative shear force result at the contact face. Therefore, the bending reinforcement must be installed on the hillside.

If the wall contains reinforcement, a variable effective height reduces the value of the shear force in this case (the wall is always thicker on bottom than on top).

In the verification of unreinforced concrete, the corresponding location of the compression zone is determined on the basis of the resulting strain distribution of the cross-section and then the maximum resisting moment is calculated from the result.

In this calculation, the design value of the resisting longitudinal force N_{Rd} is determined (component resistance).

For this purpose, the compressive stresses are integrated over the length of the compression zone. The tensile strength of the concrete is not considered.

$$N_{Rd} \equiv F_{cd} = \int_{0}^{x} \sigma_{cd} \cdot b \cdot dz$$

The strain state for which N_{Ed} is equal to the maximum resisting longitudinal force N_{Rd} is determined iteratively. From this, the corresponding length x of the compression zone can be determined. The maximum resisting moment without reinforcement can then be determined:

$$M_{Rd} \equiv F_{cd} \cdot e = F_{cd} \cdot \left(\frac{h}{2} - a \right)$$
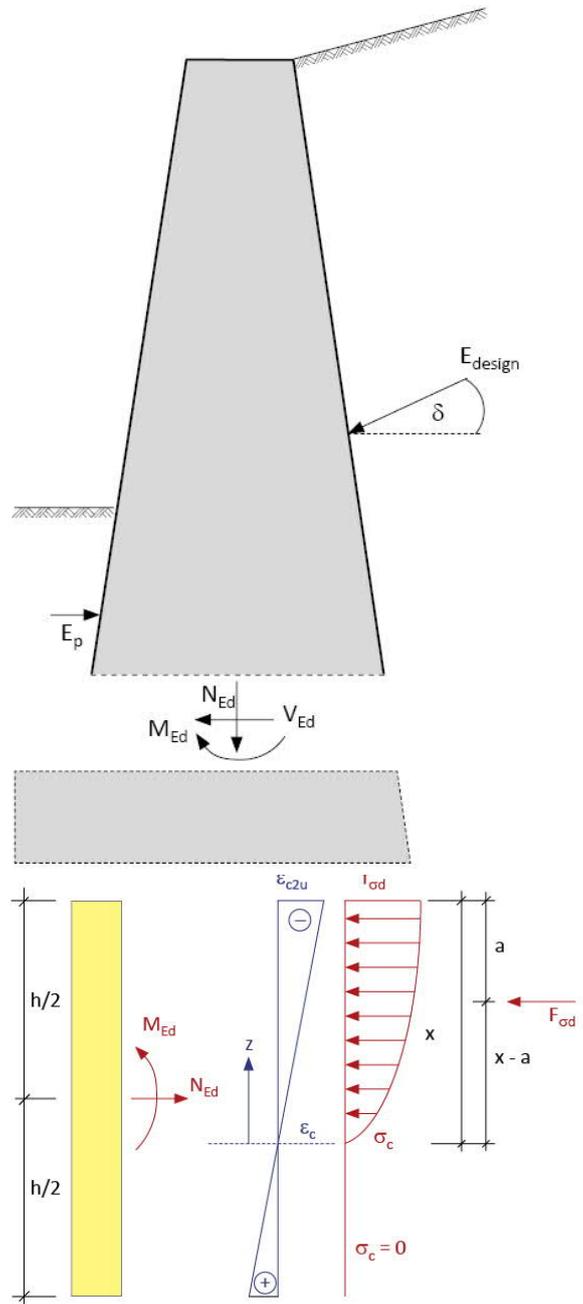
The concrete strengths are reduced as follows due to the lower ductility of unreinforced components compared to reinforced ones:

$$f_{cd,pl} = \frac{\alpha_{cc,pl} \cdot f_{ck}}{\gamma_C}$$

and

$$f_{ctd,pl} = \frac{\alpha_{ct,pl} \cdot f_{ctk;0,05}}{\gamma_C}$$

with $\alpha_{cc,pl}$ = 0.7 and γ_C = 1.5 (for the permanent design situation).

By a comparison of M_{Ed} and M_{Rd}, the utilization of the unreinforced component can then be determined.

The shear force verification of unreinforced components is determined analogously to DIN EN 1992-1-1 [2011-01], 12.6.3.

If a shear force and an axial force act over a compression zone A_{CC}, the design values of the stresses are applied as follows:

$$\sigma_{cp} = \frac{N_{Ed}}{A_{cc}}$$

$$\tau_{cp} = k \cdot \frac{V_{Ed}}{A_{cc}}$$

with k = 1.5

It has to be proven that $\tau_{cp} \leq f_{cvd}$ is.

For the design value of the concrete strength f_{cvd} at shear force and pressure:

if $\sigma_{cp} \leq \sigma_{c,lim}$:

$$f_{cvd} = \sqrt{f_{ctd,pl}^2 + \sigma_{cp} \cdot f_{ctd,pl}}$$

if $\sigma_{cp} > \sigma_{c,lim}$:

$$f_{cvd} = \sqrt{f_{ctd,pl}^2 + \sigma_{cp} \cdot f_{ctl,pl} - \left(\frac{\sigma_{cp} - \sigma_{c,lim}}{2}\right)^2}$$

with $\sigma_{c,lim} = f_{cd,pl} - 2\sqrt{f_{ctd,pl} \cdot (f_{ctd,pl} + f_{cd,pl})}$

A buckling analysis is not performed. This verification can become decisive, however, when high vertical loads apply to the wall crown.

Toe and/or foundation design

If the wall has a toe, the toe and/or the foundation defined by it is always executed with reinforcement. The design is performed at the contact face of the toe. Only the earth pressure on the contact face (earth pressure of the internal stability) is known. Therefore, the toe can only be examined separately for the design in this point. Earth pressure on the wall and earth pressure in the plane of rupture as well as self-weight, soil weight and, if applicable, water pressure (including buoyancy) act on the foundation. In addition to this, the design base pressure that results from the effects of actions on the external system is applied to the foundation. The horizontal component of the design earth pressure in accordance with /2/ is considered in the design to preserve the balance of forces.
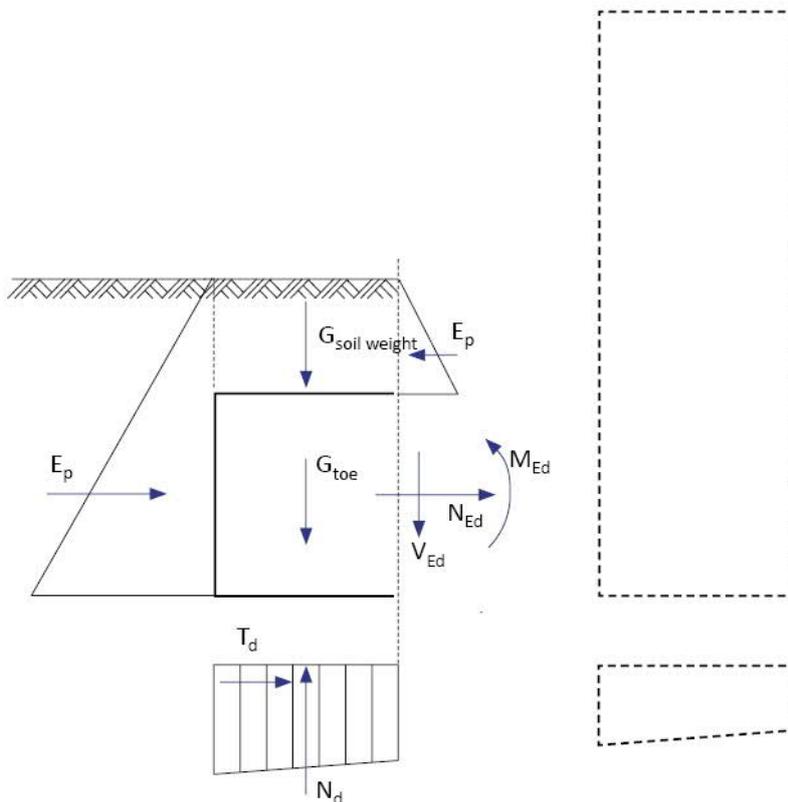
The design base pressure is calculated with the same combination of actions as the design at the contact face. Therefore, another base pressure shape can become decisive for each of both design situations (design for bending, design for shear force). Moreover, it may happen that the verification of the gaping joint in the ULS is successful, but the design base pressure cannot be calculated because a gaping joint exceeds the foundation edge in the design state. WSM+ displays an error message in this case.

The toe is idealised as a cantilever, the neutral axis of moments is on the bottom. Under normal conditions, the base pressure at the toe is high. Therefore, tension acts on the bottom side of the toe and the reinforcement must be installed there. If reinforcement is present, the inclination of the base may reduce the shear force acting on it.
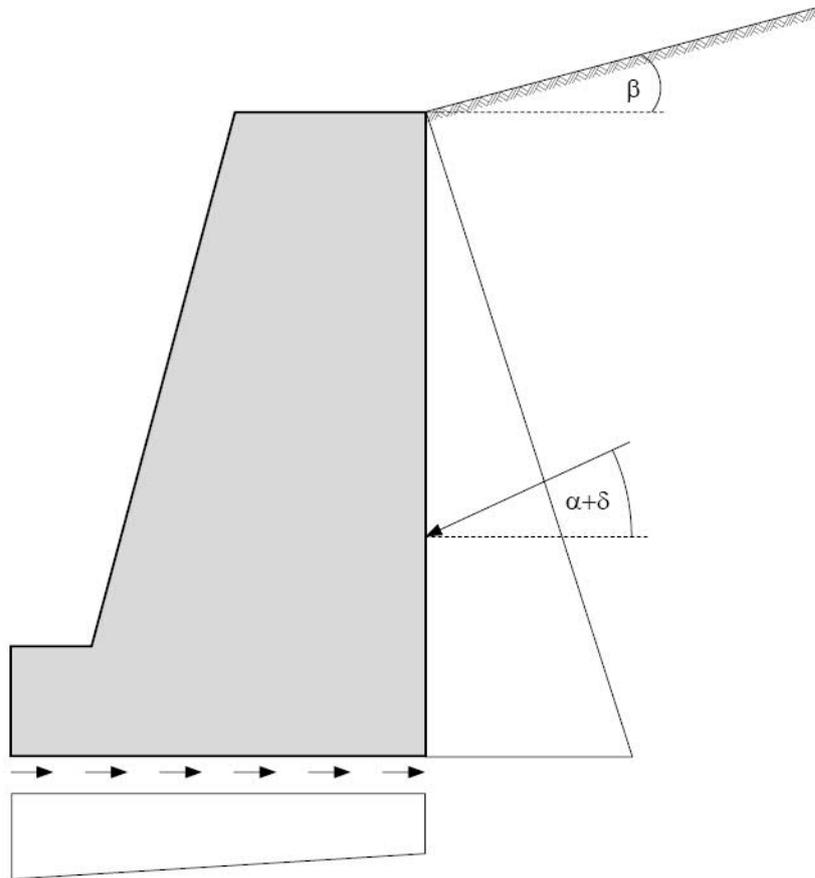
Data entry

You can enter values and define control parameters in the menu on the left screen section.
The effect of a value that you enter is immediately shown in the graphical representation on the right screen section.
Before entering any data, you can edit the dimensional units (cm, m ...) via the options File ▸ Program settings.

You should always define the system is such a way that the resistance face on the valley side is on the left and the action face on the hill side is on the right.

resistance face
on the valley side

action face on
the hill side
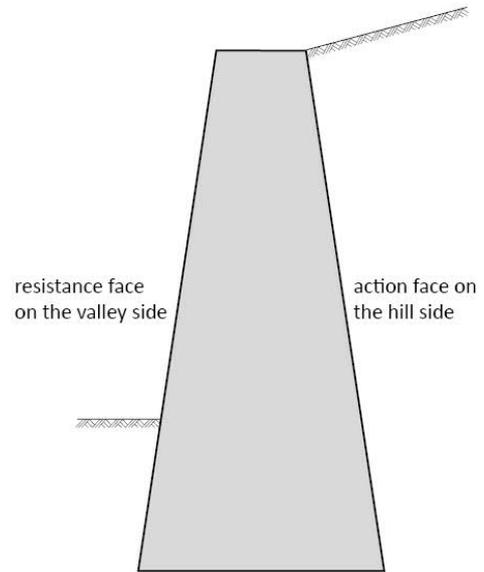
Wizard

The Definition wizard is automatically launched when you start the software. You can disable the wizard in the settings menu.

Input options in the three-dimensional GUI

The data entry via the GUI is described in the document "Basic Operating Instructions - PLUS.
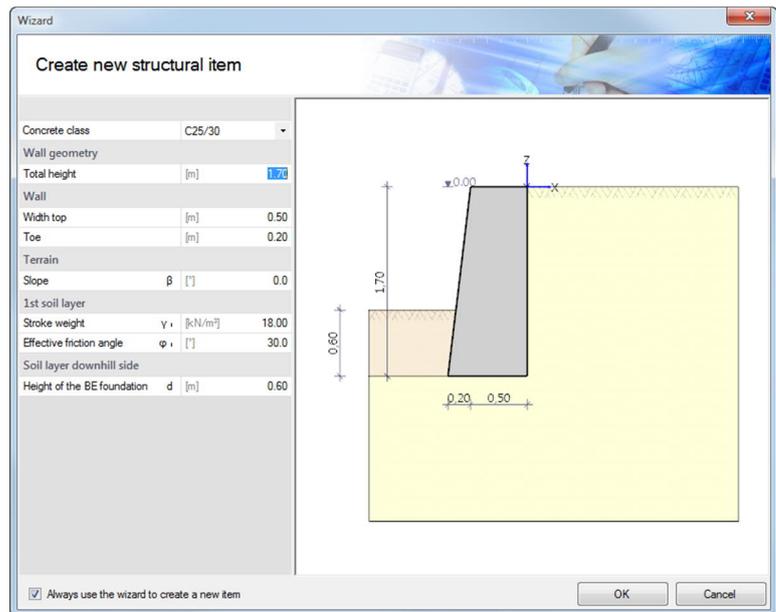
Basic parameters

Available standards

Select the desired reinforced concrete and foundation engineering standards.

Structural system

Remarks

Click on the [✎] button to enter your own comments on the system.

Retaining wall

Enter the dimensions of the wall, the toe, the base inclination and define additional parameters.

The data-entry fields are self-evident in most cases.

When you click into a data-entry field, additional text information is displayed in the information window below the menu on the left.

Base friction angle δ S,k

You can optionally include the base friction angle and set it equal to the friction angle of the soil layer underneath the base, if it was not determined in a separate calculation. The maximum value for this angle is 35°. The base inclination angle of pre-cast parts should be set to 2/3 φ.

Active wall friction angle δ a

Friction angle between the wall and the ground for the calculation of the earth pressure on the acting side (earth pressure at rest, active earth pressure or increased active earth pressure).

Passive wall friction angle δ p

Friction angle between the wall and the soil for the calculation of the earth resistance. You must set this angle to zero for the detailed ground failure analysis as per DIN 4017.

Soil

Define parameters for the soil layers.

Parameters:

Unit weight, unit weight under buoyancy, friction angle, cohesion, thickness of the soil layer, height of the soil in front of the toe, calculation modulus E*.

Explanations on the individual parameters are displayed in the information window.

Defining the layers

Enter the data of the first soil layer either in the corresponding data-entry mask or directly in the table, which

you can display below the graphic by activating the [⊞ Earth layer heel] button.
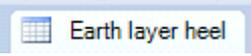
Toolbar: Earth layer heel ◐ 2/2 ◑ ➕ ✖ ⊞ ⊞ ☑
see Data-entry via tables (Basic Operating Instructions).

To add soil layers, always set up a new entry first by activating the [➕] button (an empty data-entry mask is displayed each time).

Ground surface / groundwater

Ground top level (Begin terrain)

Distance of the top edge of the wall to the ground level (z-direction)

Slope

Terrain			
Begin terrain	Δ z	[m]	0.00
Slope		stepped	▾
Slope sections ◀ 1/3 ▶ ➕ ✖ 🔢 🔢 🔢			
Length	bi	[m]	1.00
Inclination	β	[°]	10.0
Ground water			
Ground water			☑
Ground water depth toe	hwl	[m]	0.00
Ground water depth heel	hwg	[m]	0.00

Without	no inclination, i.e. no slope
Continuous	the slope has a continuous inclination
Discontinuous	the slope can be divided into several sections with a different inclination each.
Inclination	enter the inclination angle of a continuous slope

Slope sections

If you have selected a discontinuous slope, you can define the individual sections and their inclination in this dialog.

Fundamentals of the data-entry via tables: see Data-entry via tables (Basic Operating Instructions)

Groundwater

If this option is checked, you can specify the valley-side and hill-side groundwater levels. Only negative values are allowed.

Loads

Fundamentals of the data entry via tables: see Data-entry via tables (Basic Operating Instructions)

Remarks

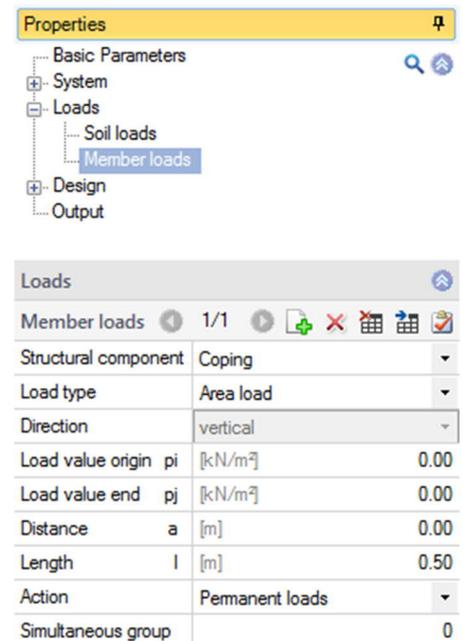Click on the [icon] button to enter your own comments on the loads.

Soil loads

Load type	area load, strip load, block load or line load
Load value pi	load ordinate in kN/m² or kN/m
Distance *a*	distance to the wall crown
Width *b*	width of a line load applying perpendicular to the wall
Length *l*	length of a block load applying parallel to the wall
Application depth *z*	distance of the load to the ground surface in the z-direction. Values above the wall top edge are positive.
Earth pressure distribution	
	if limited live loads apply, you can select between a rectangular distribution and a trapezoidal distribution of the load as per EAB. The ordinates of the trapezoidal distribution result from a linear interpolation that depends on the distance to the wall and the width of the load.
Action	assignment of an action to this load
Simultaneous group	the loads of a concurrency group always apply simultaneously. A concurrency group is defined by the number (0, 1, 2, ...) that is assigned to it.
Alternative group	Loads to which you assign the same alternative group number are mutually exclusive (will be hidden when action=permanent).
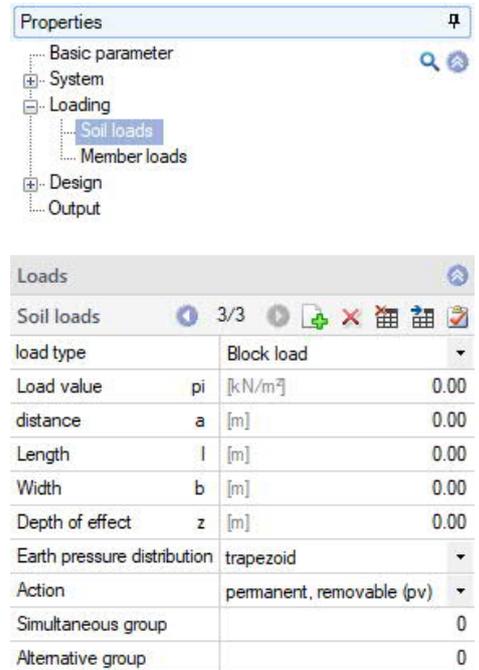
Member loads

Fundamentals of data-entry via tables: see Data-entry via tables
(Basic Operating Instructions)

Component	wall crown, toe, wall, front face of the toe
Load type	depending on the component: area, line, moment load
Load value	for an area load, the load values for the start and end of the load must be entered.
Distance	the best way to understand the effect of this value and to see how it is measured is to enter a value and check the load position in the graphic.

Action and simultaneous group: see description at Soil loads

Design

Remarks

Click on the [icon] button to enter your own comments on the design.

Earth pressure

| Earth pressure type | earth pressure can be calculated either as active earth pressure, earth pressure at rest or as increased active earth pressure, which produces a value between the first two ones. |

Increased active earth pressure

you must check this option if the movement of the wall is insufficient to trigger the limit state of the active earth pressure or to maintain it during the entire service life of the building. When you check the option, the corresponding data-entry field is displayed.

Apply tension from cohesion

calculated tensile stress caused by cohesion must not be considered with unbraced walls or walls with yielding bracing that rotate about their base point or a deeper point (EAB EB4 para. 3).
If the construction pit walls are fitted with low-yielding bracing and a redistribution of the earth pressure is expected, you may include calculated tensile stress caused by cohesion in the verification of whether minimum earth pressure is required (EAB EB4 para. 5). The software calculates the earth pressure for walls that rotate about their base point. Therefore, tensile stresses caused by cohesion should not be included under normal conditions.

Enable minimum earth pressure

if the minimum earth pressure is considered (option ticked), the software checks for each layer of cohesive soil whether the earth pressure resulting from the self-weight of the soil and a shear strength that corresponds to the angle of inner friction $\phi = 40°$ becomes decisive at a cohesion of $c = 0$ kN/m^2. Calculation in accordance with EAB, 5th edition /12/.

Enable compaction earth pressure

when soil is backfilled layer by layer and strongly compacted subsequently, the earth pressure exceeds the earth pressure resulting from the self-weight of the soil.

Settings

allows you to define additional parameters concerning compaction earth

pressure in a separate dialog (click on [icon]):

Approach according to DIN 4085 or according to "Franke":
The compaction earth pressure for strong compaction is calculated as per DIN 4085. For light compaction (vibrating plate with an operating mass of up to 250 kg), the method described by Franke (Franke, D., Verdichtungserddruck bei leichter Verdichtung, BAUTECHNIK 85 (2008) Booklet 3, p. 197 to 198) /14/ should be selected.
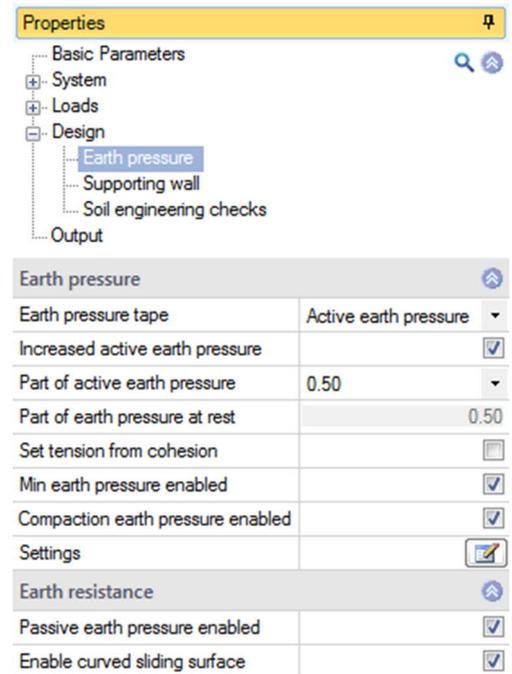
Curved planes of rupture:
The depth 'zp', at which the full compaction earth pressure is considered, is determined by comparing the compaction earth pressure to the passive earth pressure. The associated passive earth pressure coefficient can be determined in combination with linear and curved planes of rupture.

The compaction width and the resilience of the wall are displayed - please observe the tool tips.

ÖNorm B4434: Compaction force. It corresponds to the load per length unit of the roller lining for static compactors. For vibrating rollers, it is composed of the weight and the centrifugal force. If the centrifugal force is not known, you can apply the compaction force approximatively with twice the weight per length unit.

Include earth resistance   you should only apply earth resistance if it is ensured that the earth in front of the toe will not be removed during the entire service life of the gravity wall. You must define in another dialog whether earth pressure is included fully or with a reduction factor ▸ Design ▸ Retaining wall ▸ Reduction factor (see below). (▸ Design ▸ Soil engineering verifications ▸ Earth resistance).

Enable curved planes of rupture
the assumption of linear planes of rupture for the passive earth pressure is no longer appropriate in the following cases: $| α + δ| < β$ and $φ > 35°$. The earth pressure coefficients for curved planes of rupture are determined in accordance with DIN 4085 Annex C. The representation is always linear.

Retaining wall

Reduction factor	the factor can range between 0.0 and 1.0. The greatest value means that the full earth pressure resistance is considered in the design of the wall and the foundation. *(This option is only available if the option „Apply earth resistance:" was checked).*

Design of the wall

Number of design sections	the number you specify for 'n' indicates the number of points at which you wish to determine the internal forces and to design the wall. The sections all have the same distance to each other. If you set n = 1, the design is only performed at the intersection of the wall and the foundation.
Insert reinforcement	you can check whether an unreinforced execution of the retaining wall is possible.
Concrete strength class	selection of the concrete quality
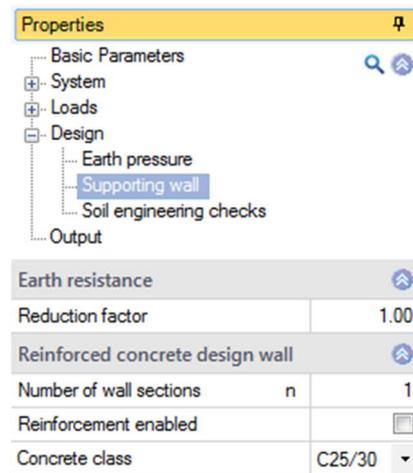
If the "Insert reinforcement" option has been selected:

Durability	See the document "Durability – Creep Factor and Shrinkage Strain"
Reinforcing steel	Selection of reinforcing steel grade.
Reinforcement layer	
	distance of the reinforcement layer (to the valley-side face/to the hill-side face)
Minimum ductile reinforcement	
	when you activate this option, the software checks whether the required reinforcement falls below the minimum ductile reinforcement. The minimum ductile reinforcement will become decisive in this case.
Minimum compressive reinforcement	
	allows you to consider a minimum compressive reinforcement in the bending design.
Minimum shear reinforcement	
	when you activate this option, the software checks whether the required reinforcement falls below the minimum shear reinforcement. The minimum shear reinforcement will become decisive in this case.

Shear force analyses / shear force reduction for haunches

> If the effective height varies, shear force can be reduced or must be increased. You can decide here whether a possible reduction should be applied. The increase is always considered automatically irrespective of your selection.

If a toe is present:

Design of the toe	durability, concrete, reinforcement layer, minimum ductility reinforcement, minimum compression reinforcement and minimum shear reinforcement analogous to "Design of wall".

Soil engineering verifications

Earth resistance

With *active option* *Earth pressure - apply earth resistance*.
Factor for ground failure analysis:
You may include earth resistance as per DIN 1054 with a maximum factor of 0.5. It is considered as an action.

Factor for overturning stability analysis:
The resultant force of the earth resistance can be multiplied with a factor ranging from 0.0 to 1.0, which reduces the actual value. The factor used for the overturning stability verification is also valid for the simplified verification in typical cases and for the verification of the limitation of the gaping joint.

Factor for sliding stability verification:
The resultant force of the earth resistance can be multiplied with a factor ranging from 0.0 to 1.0 to be considered in the sliding stability verification. You may only consider earth resistance in the sliding stability verification if it is ensured that the soil will remain in front of the toe throughout the entire service life of the gravity wall. Moreover, you may only include the entire earth resistance (factor = 1.0) if it is ensured that the wall displaces sufficiently to mobilize the passive earth pressure. If you include earth resistance with the factor 0.5, it is expected that the corresponding earth pressure and the base friction are activated approximately at the same time.

Ground failure

Type of verification analytical/simplified:
You can perform the ground failure analysis either
- as an analytical verification (DIN 1054:2010 6.5.2.2) or
- as a simplified verification (DIN 1054:2012 6.10) based on specified permissible base resistances σ_{RD}, it replaces the ground failure analysis, the sliding stability verification and the setting analyses.

Soil properties

Note: This option is only available if you have selected "Simplified" as the verification type for ground failure.

Base pressure resistance   you can choose whether the design value of the base pressure resistance should be specified directly or whether it should be taken from a user-specified table.

Base pressure resistances according to table
In the table dialog, you can enter or select your own values for base pressure resistance, embedment depth and foundation width.

Embankment failure - Settings

Note: This option is only available if you hold a licence for BBR - Slope Failure!

If the option "Perform embankment failure analysis" is selected, the Embankment failure settings are displayed. The button [icon] allows you to access the corresponding definition dialog.

Slope stability		
Slope stability		⌃
minimal X-value of grid	[m]	-2.50
minimal Z-value of grid	[m]	0.00
Grid width	[m]	2.50
Height of the grid	[m]	1.10
Select searching area		[icon]
Number of grid points in X		6
Number of grid points in Z		6
Number of radii		5
Maximal depth	[m]	5.00
Number of slices		20

Smallest X/Z value	X or Z coordinate of the lower left point of the grid of the slip circle centres.
Width/height grid	width/height in the x- or z-direction of the grid of the slip circle centres.
Select search area	click the [icon] button to interactively select the search area of the slip circle centre with the mouse in the graphical representation.
Number of grid points	number of points in the x- or z-direction at which the slip circle centre is to be located. The centres are distributed evenly.
Number of radii	number of radii to be examined. The radii are evenly distributed between the minimum and maximum radius. The minimum radius results from the condition that the slip circle does not intersect the gravity wall. The maximum radius results from the depth of the defined soil layers.
Maximum depth	depth from the bottom edge of the hillside foundation (measured positively) to the depth to which slip circles are to be checked. This setting automatically controls the maximum width of the terrain to be examined. If the specified soil layers do not extend to the specified depth, the lowest soil layer is assumed internally to extend to the specified depth for the calculation.
Number of slices	the finer the slice sectioning, the more accurate the result. Normally, a fineness of 20 slices is sufficient. The actual number of slices to be used also depends on constraint points, such as layer boundaries or load application points, and therefore, does not have to correspond exactly to the value specified here.

Sliding

Note: This option is disabled if you have selected "Simplified" as the verification type for ground failure.

Perform slide analysis	You can specify whether a sliding stability verification should be performed

Settlements

Affected settlement depth	determines how the affected settlement depth (= limiting depth) is determined. The limiting depth is the depth to which settlements are to be calculated from the load. This depth can either be calculated by the software using the 20 % criterion or entered manually.
Excavation relief	if soil is removed before the loads apply, only that part of the load that exceeds the excavation relief becomes effective for the settling.
Foundation length	a length specification of the gravity wall in y-direction is required for the settlement calculation. This length value only influences the settlement calculation and is otherwise not taken into account.

Consideration of variable loads

Only the portion of the permanent loads effective for the settlement must be considered. Select whether the non-permanent loads are to be taken into account in the settlement calculation, and if so, with which combination coefficient.

Results

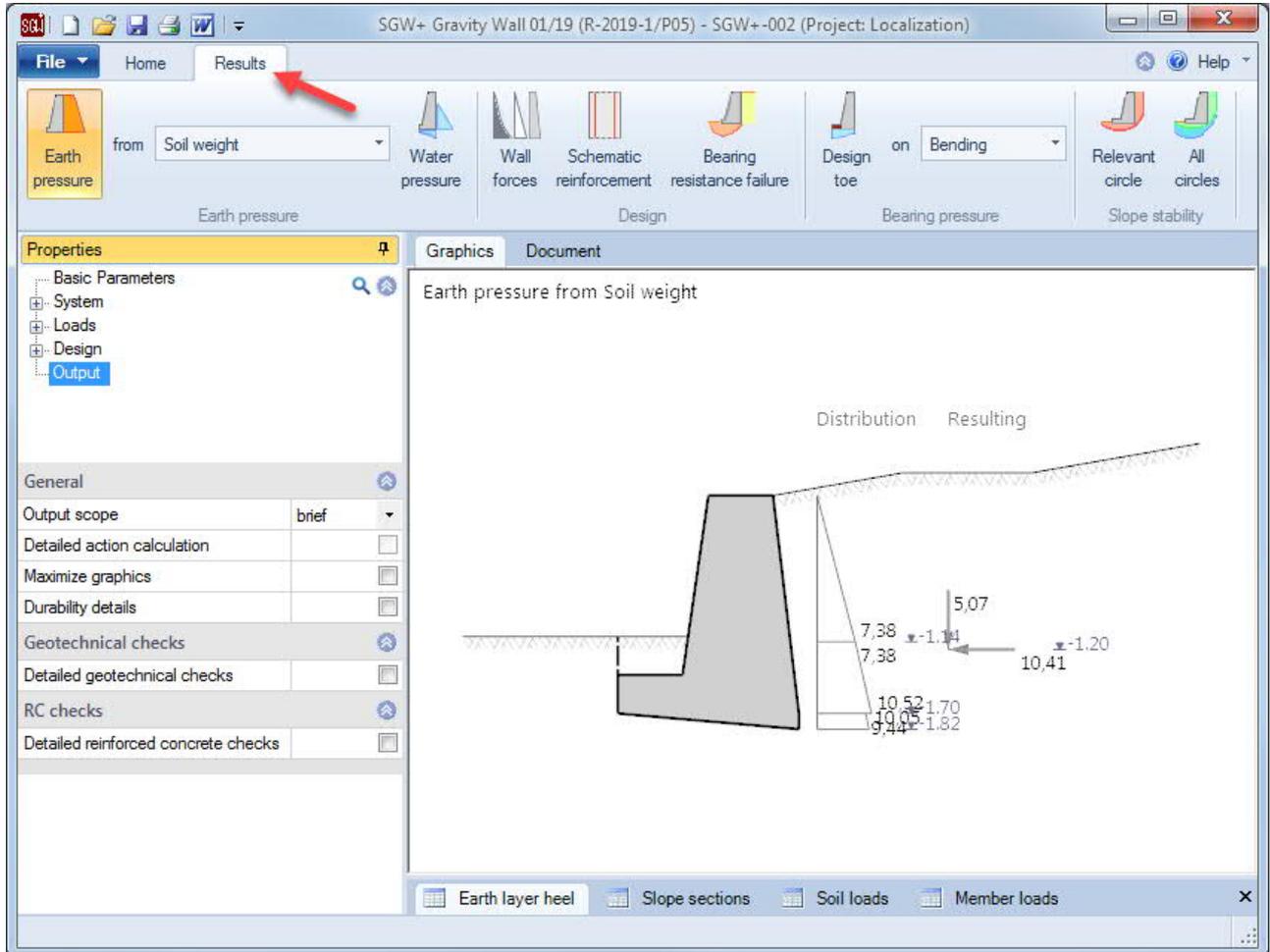The "Results" tab allows you to display various result graphs.

Fig.: Results - Earth pressure

Symbols for the result graphs

Earth pressure

Earth pressure caused by

- Weight of soil
- Cohesion
- Compaction
- Self-weight and cohesion
- Earth pressure and compaction
- Loads

Water pressure

Design

Internal forces in the wall   characteristic internal forces

Schematic reinforcement drawing

Graphical representation of the ground failure

Base pressure for

Design of the toe

with respect to

- Bending
- Shear force

Embankment failure

Relevant circle   decisive slip circles

All circles   all examined slip circles are displayed.

Output

Scope of the output and options

In addition to the default settings "Brief" and "Detailed", you can customize the scope of data to be put out by checking or unchecking the corresponding options.

Output as a PDF file

On the "Document" tab, a PDF document is displayed.

See the document Output and printing for further information.

Reference literature

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/2/   Mesterom, K.-L.: "Beitrag zur Bemessung des erdseitigen Spornes von Winkelstützmauern", in: *Bautechnik 7*, 1985, p. 235 to 237.

/3/   Henner Türke.: "Statik im Erdbau" Ernst & Sohn, 3rd edition

/4/   DIN EN 1997-1 [2010-12] NA

/5/   DIN 1054 [2010-12]

/6/   DIN 4017 [2006-03]

/7/   DIN 4019 [2015-05]

/8/   DIN 4084 [2009-01]

/9/   DIN 4085 [2011-05]

/10/   DIN EN 1992-1-1 [2011-01]

/11/   DIN 1045-1 [2008]

/12/   Empfehlungen des Arbeitskreises Baugruben (EAB), (Recommendations of the Construction Pits Working Group), 5th edition

/13/   Grundbautaschenbuch, 1990, Volume 1

/14/   Franke, D., Verdichtungserddruck bei leichter Verdichtung, BAUTECHNIK 85 (2008) Booklet 3, pages 197 to 198