



K-REA

C. TECHNICAL MANUAL

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C.1. Calculation principle

K-REA enables to analyse a plane or circular retaining wall, using the model of a beam supported by elastic-plastic springs.

C.2. Summary of the calculation method

The calculation method is based on the construction of a rigidity matrix containing:

- beam elements that represent the wall
- springs that simulate the soil in an elastic phase
- external links

In the elastic phase, the elements representing the soil react linearly (depending on displacements) until they reach either an inferior level or a superior level, beyond which the value of the earth pressure is a constant.

C.3. Field of application

K-REA is a computer program that analyses flexible retaining walls, such as diaphragm walls, soldier-pile walls and sheet-pile walls. It enables to calculate the deformations of the retaining wall through a sequence of construction stages. This sequence includes the initial stage (phase) when the wall is "wished in place" and a number of additional stages. To each stage is associated a group of actions, such as the installation of a strut or an anchor, earthworks, the change of the water level, or the application of surcharges.

C.4. Calculation method

C.4.1. Introduction

K-REA calculates the internal forces and the deformations of a retaining wall through a number of calculation phases, as well as the external forces including the soil reactions and the external links. The height of the wall is a datum for the calculation, but the wall is assumed to extend to infinity horizontally, so that the soil analysis complies with plane-strain conditions (except for circular walls).

The wall inertia may vary with depth, and the wall may be submitted to:

- Earth and water pressures;
- Horizontal surcharges onto the wall;
- Horizontal loads (such as forces in struts or anchors);
- Moment loads;
- Rotation spring restraints.

The action of the soil and water on the wall is represented by horizontal pressures applied to the left and to the right sides of the wall. The earth pressures are related to the wall horizontal displacements using an elastic-plastic behaviour law. The parameters for this law are the soil parameters for the relevant layer, and the vertical stress in the soil (which itself depends on the excavation level, the water pressure and the surcharges if any).

C.4.2. Signs

The soil profile is separated vertically into two parts. The part "inside the wall" is called the downhill side: it is located on the left to the wall (K-REA convention). The part "outside the wall" is called the uphill side: it is located on the right to the wall. Wall displacements and forces are positive when directed to the right.

The Y-coordinates are either oriented upwards when defining **levels**, or downwards when defining **depths**. This option is set using menu **Data, Titles and options**.

As for the external forces applied onto the wall, the forces (F on figure C1) are positive when directed to the right and the moments (M on figure C1) are positive when anti-clockwise.

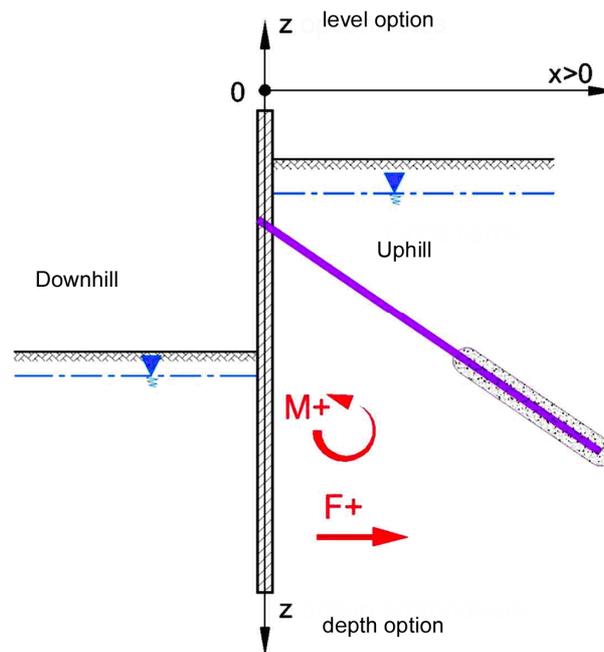


Figure C 1: Sign conventions

C.4.3. Soil behaviour

In a given calculation phase, the settings for the behaviour law at any level and for both sides are the following:

- k_h : horizontal subgrade reaction coefficient;
- p_a : horizontal active limit pressure;
- p_p : horizontal passive limit pressure;
- p_i : horizontal initial pressure (for a zero displacement);
- x : horizontal displacement, positive when directed to the uphill side.

The curve relating the horizontal pressure p to the displacement x consists in a linear part (slope k_h and Y-origin value p_i), and of two horizontal levels p_a and p_p , as shown thereafter:

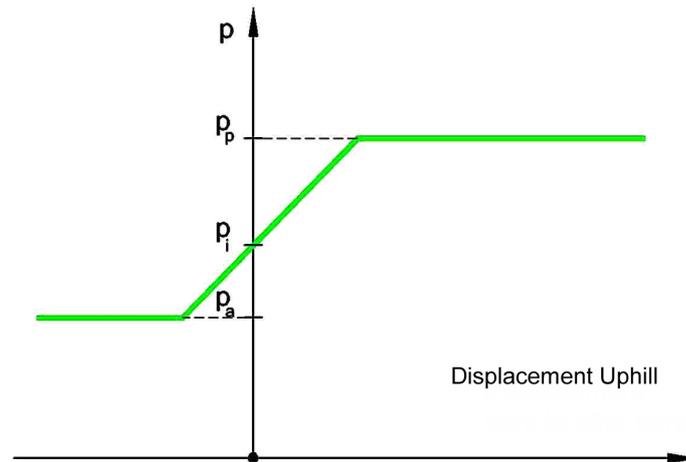


Figure C 2: Soil behaviour law

The subgrade reaction coefficient k_h (at a given level) depends on two parameters defined for each soil layer: the value for the coefficient at the top of the layer, and its linear variation with depth.

The values of plasticity levels p_a and p_p depend on the following parameters (defined for each soil layer):

- PV_h : soil weight above water table;
- PV_d : submerged soil weight below water table;
- φ : friction angle;
- c : cohesion;
- k_0 : earth pressure coefficient at rest;
- k_a : horizontal active earth pressure coefficient;
- k_p : horizontal passive earth pressure coefficient;
- c_a : coefficient of active pressure for cohesion c ;
- c_p : coefficient of passive pressure for cohesion c ;
- σ'_v : soil effective vertical stress.

and are calculated by the program as explained below:

- $p_a = k_a \cdot \sigma'_v - c_a \cdot c$ (where $p_a = 0$ if $k_a \cdot \sigma'_v - c_a \cdot c < 0$; which means that the wall is separated from the soil)
- $p_p = k_p \cdot \sigma'_v + c_p \cdot c$

The effective vertical stress σ'_v is calculated by the program with the values of PV_h and PV_d weights, the levels of the soil layers, the water pressure and surcharges if any.

The initial pressure p_i (for a zero displacement) is calculated using the earth pressure at rest, depending on the earth pressure coefficient at rest k_0 for the given soil layer. In that case:

$$p_i = p_0 = k_0 \cdot \sigma'_{v0} \quad \text{with } \sigma'_{v0} = \text{effective vertical stress at rest}$$

During an excavation phase, the initial pressure p_i (for a zero displacement) can be modified simultaneously by two phenomena:

- the soil plastification in previous phases
- the modification of the effective vertical pressure σ'_v

The soil plastification in a given phase can actually shift the pressure/displacement curve horizontally on the plasticity level, as shown below:

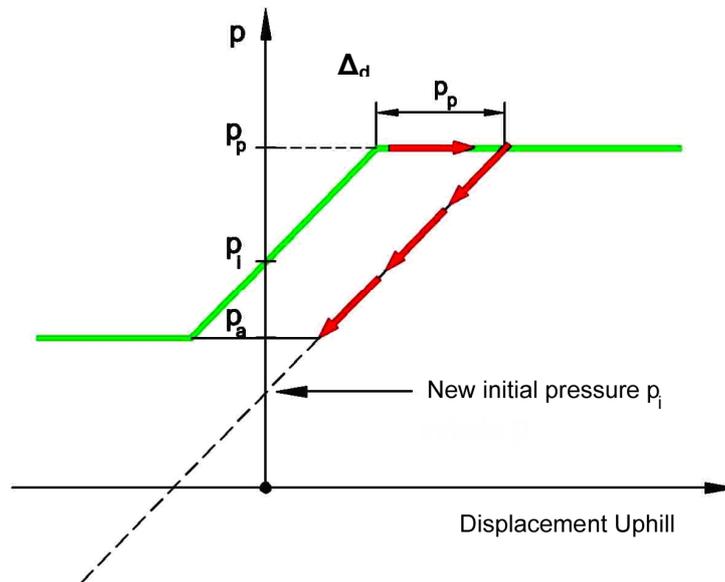


Figure C 3: Soil plastification

In the case of a separation between the wall and the soil, the curve for the "way back" is still the same and so is the initial pressure.

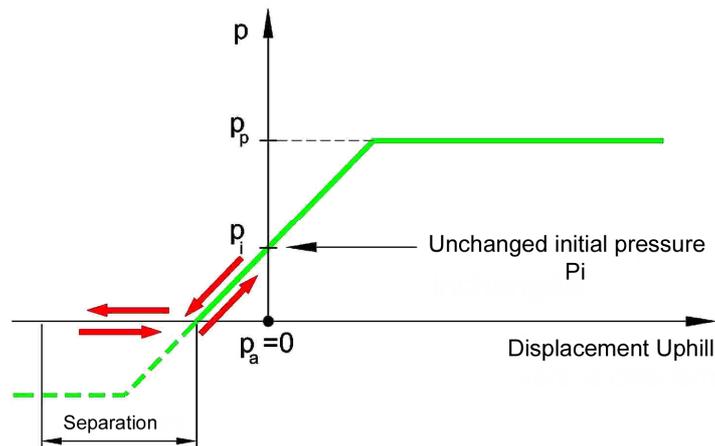


Figure C 4: Case of a separation between the wall and the soil

A modification of the soil effective vertical stress in a given phase has two consequences:

- first, it shifts the value of p_i (for a zero displacement) either downwards in case of unloading, or upwards in case of loading;
- secondly, it updates the value of both plasticity levels, as shown below:

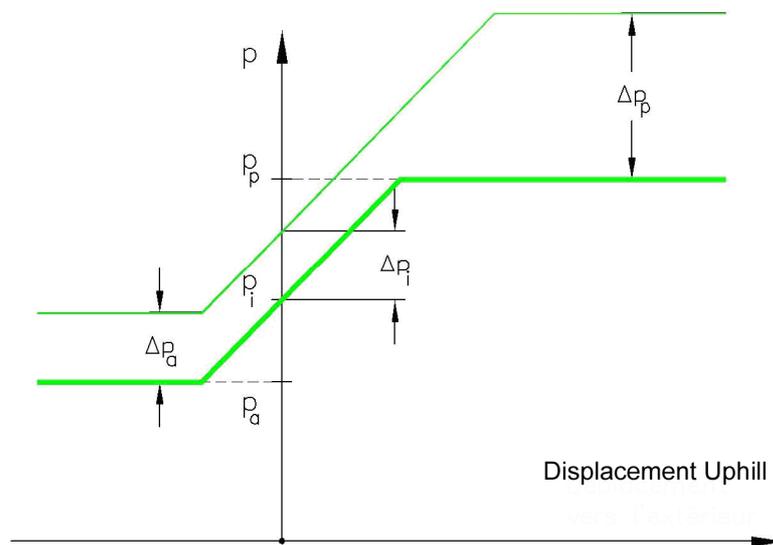


Figure C 5: Modification of the effective vertical stress

$\Delta\sigma'_v$ is the symbol for the increase of the effective vertical stress. The shift of the initial pressure Δp_i is equal to:

- $\Delta p_i = k_r \Delta\sigma'_v$ if $\Delta\sigma'_v > 0$ with k_r = reloading ratio
- $\Delta p_i = k_d \Delta\sigma'_v$ if $\Delta\sigma'_v < 0$ with k_d = unloading ratio

The plasticity levels p_a and p_p are calculated using the new value of σ'_v , and the same formula as before.

C.5. Description of the phase actions

K-REA proposes 18 different action types, that enable to simulate the construction phases of any project or any load conditions. These actions are grouped into the following categories:

Actions	
	↳ Initial phase
	↳ Caquot surcharge
	↳ Reduced pressure
	↳ Maximal pressure
	↳ Loads-Forces-Moments
	↳ Boussinesq surcharge
	↳ Graux surcharge
	↳ Moment
	↳ Horizontal load on the wall
	↳ Linear force
	↳ Earthworks
	↳ Excavation-Water
	↳ Fill
	↳ Berm
	↳ Sheeting installation
	↳ Anchors-Wall
	↳ Struts
	↳ Anchors
	↳ Rotation spring
	↳ Modification of the wall stiffness
	↳ Raising of the wall (extension upwards)
	↳ Soil properties
	↳ Modification of the soil layers
	↳ Hydraulic
	↳ Hydraulic gradient

These actions are selected using the action selection zone (as explained in part B – chapter B.2.3.2). Here are only presented the meaning and function of the parameters for each action (using the screenshot of the schematic representation for each action).

Here in part C are also presented the possible interactions between several actions (addition or compensation of surcharges for example) as well as the ways to remove the effect of an action afterwards.

Three of the actions in the table above can only be applied in the initial phase, i.e. to the initial state of the soil and wall. Chapter C.5.1 deals with them.

These three actions can only be used once and remain valid for the whole project, unless another action happens to change them (for example, the Excavation or Fill action cancels the Caquot surcharge, and the sheeting installation restores the full earth pressures).

C.5.1. Actions in the initial phase

C.5.1.1. Caquot surcharge

This actions defines a uniform surcharge loading on the whole groundlevel (downhill and uphill). It is taken into account during the calculation of the initial earth pressure.

Note: in order to define a Caquot surcharge in other phases, the Excavation-Water action should be used. It is described more precisely in chapter C.5.2.6.

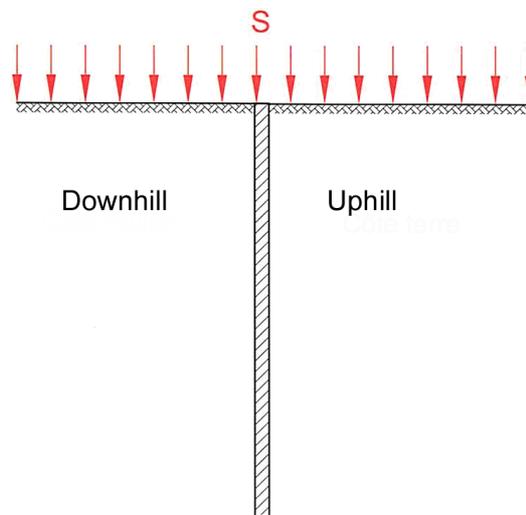


Figure C 6: Caquot surcharge

The parameter requested to define such a surcharge is:

- **S**: value of the surcharge (MPa,kPa,t/m²).

Caquot surcharge:

Surcharge S applied on the horizontal ground surface: kPa

Figure C 7: Caquot surcharge properties

This surcharge is cancelled on one side of the wall as soon as an Excavation or Fill action is defined on the same side later on during the staged construction.

C.5.1.2. Reduced pressure

This action, especially when the wall is discontinuous, is used to define that the earth and water active pressures will only be applied on part of the wall width ($0 < R < 1$), for the height from **z1** to **z2**). At the same time, the passive pressures, applied on the same height and width, can be multiplied with a coefficient **C**. The influence of the subgrade reaction coefficient is also reduced.

R = pile width / piles spacing axis to axis (see figure next page)

C = passive pressure effective width of a pile / pile width

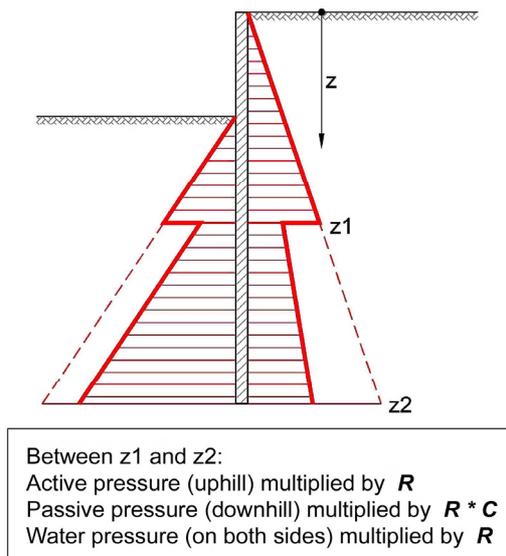


Figure C 8: Reduced pressure

The properties requested for this action are:

- **z1**: level from which the coefficients are applied (m);
- **z2**: level from which the coefficients are no longer applied (m);
- **R**: reduction coefficient applied on active pressures;
- **C**: multiplying coefficient (with **R**) applied only to passive pressures.

Reduced pressure:

z1 : m

z2 : m

R :

C :

Between z1 and z2:

Active press. (downhill s.) mult. by R
= 0.250

Passive press. (uphill s.) mult. by R*C
= 0.500

Water pressure (both sides) multiplied by R

Figure C 9: Properties for Reduced pressure

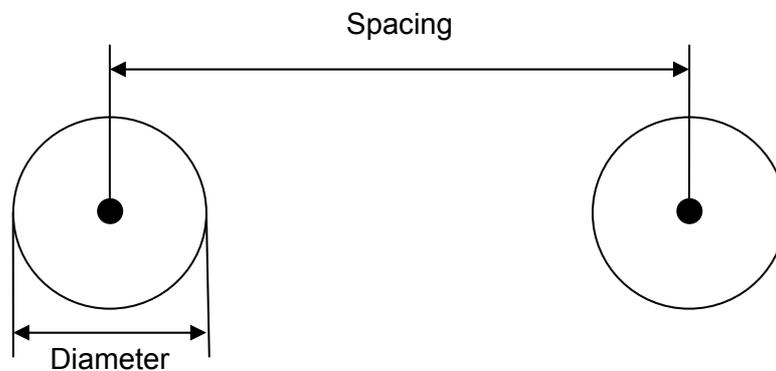
Application example for a soldier-pile wall, with an elementary wall width of one linear meter:

For piles with a diameter of 0.50 m and a horizontal spacing axis to axis of 2.00 m:
 $R = 0.50 / 2.00 = 0.25$.

Active pressures applied on the remaining 75% of the wall go “through” the wall without affecting its equilibrium. It is however assumed that, due to the wall discontinuity, the passive pressure can be enhanced. For example, one can suggest that in front of a pile, the width of application for passive pressure is twice the diameter, that is to say 1.00 m (taking into account for example friction in addition to pure passive pressure). In that case, $C = 2$.

It seems obvious that $R \cdot C$ cannot exceed 1 (100% of the wall width).

This action can also be applied for diaphragm walls with pantaloon (along the height of this pantaloon).



If the elementary wall width is for example equal to the piles horizontal spacing, then the coefficient R is equal to the pile diameter.

C.5.1.3. Maximal pressure

This action is intended for precast walls: the wall resistance may be inferior to soil resistance for parts of the wall. The value of the maximal earth pressure is limited to a specified value P_{MAX} .

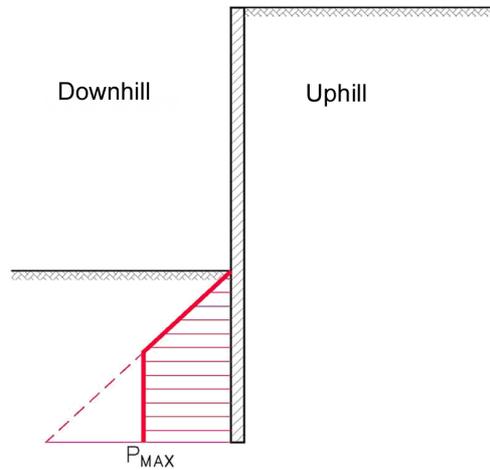


Figure C 10: Maximal pressure P_{MAX}

The parameter requested for this action is:

- P_{max} : maximal active or passive pressure (MPa, kPa, t/m^2).

Caquot surcharge:

Surcharge S applied on the horizontal ground surface: kPa

Figure C 11: Maximal pressure

C.5.2. Actions available for construction stages

The actions are presented in the same order as in the action selection zone.

Action category: Loads-Forces-Moments

C.5.2.1. Boussinesq surcharge

This action enables to apply a vertical Boussinesq surcharge onto a limited width of soil.

The additional stresses due to the surcharge through an elastic material are multiplied with an earth pressure coefficient.

In fact, the additional stress term due to the surcharge is directly added to the vertical stress for each calculation point.

The horizontal stress applied on the wall is equal to:

$$\Delta\sigma'_h = k * \Delta\sigma'_v$$

with $k = k_a, k_p$ or k_0 , depending on the plastic status of the soil.

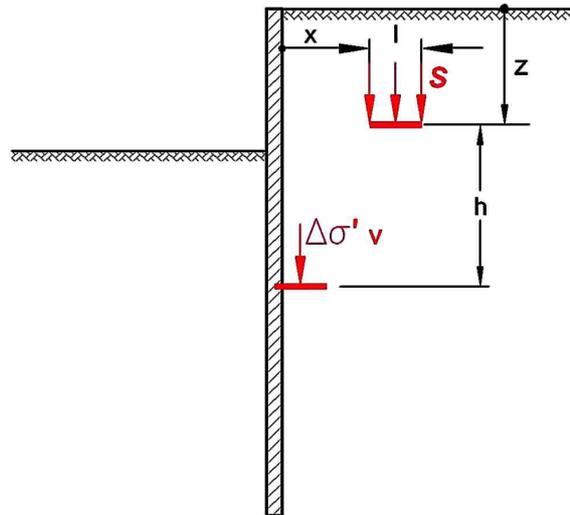


Figure C 12: Boussinesq surcharge

The properties requested for this surcharge are:

- **Downhill** or **Uphill**: side onto which the surcharge should be applied;
- **z**: surcharge level (m);
- **x**: distance to the wall >0 (m);
- **L**: width of the surcharge (m);
- **S**: surcharge value (MPa, kPa, t/m²).

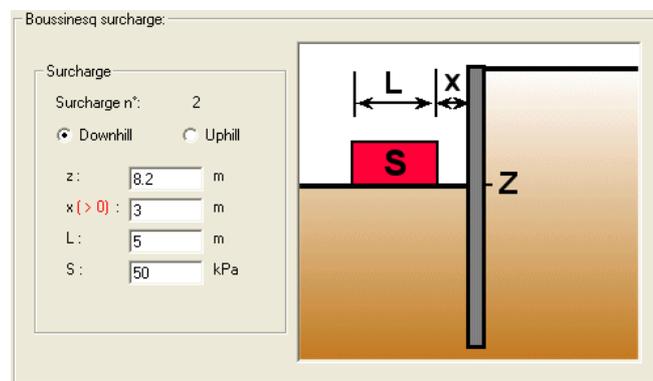


Figure C 13: Boussinesq surcharge

Several Boussinesq surcharges applied onto the same side of the wall are added together, whether they are applied in the same phase or not.

The Excavation-Water and Fill actions, whatever the depth may be, cancel the existing Boussinesq surcharges located on the same side and defined previously. In order to keep these surcharges active, it's necessary to define them again after each action Excavation-Water or Fill located on the same side.

Note: in the .P20 data file, **x** is positive when the surcharge is located uphill and negative when the surcharge is located downhill. This is handled automatically by the program when selecting the side for the surcharge (downhill or uphill). Therefore **x** should always be defined with a positive value.

C.5.2.2. Graux surcharge

This action enables to define a vertical Graux surcharge, on a limited width, as shown on figure C.14. The surcharge **S** is distributed uniformly as shown on the same figure.

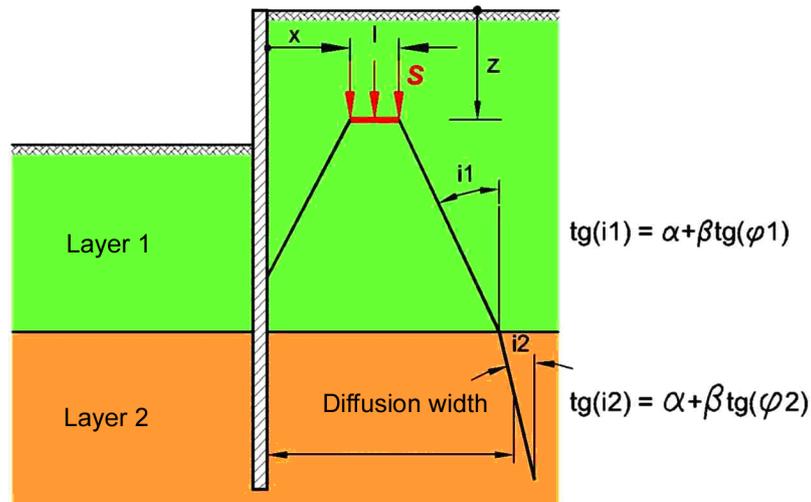


Figure C 14: Graux surcharge

The properties requested for this action are:

- **Downhill** or **Uphill**: side onto which the surcharge should be applied;
- **z**: surcharge level (m);
- **x**: distance to the wall >0 (m);
- **L**: width of the surcharge (m);
- **α**: constant angle in the formula for the diffusion angle (°);
- **β**: gradient for the friction angle tangent in the formula for the diffusion angle (°);
- **S**: surcharge value (MPa, kPa, t/m²).

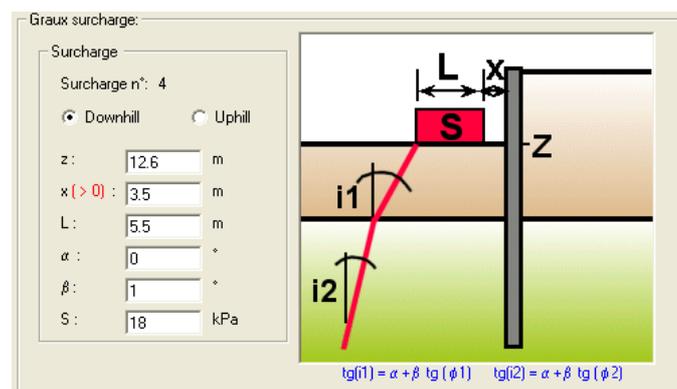


Figure C 15: Graux surcharge

Several Graux surcharges defined on the same side are added together, whether they are defined in the same phase or not.

The Excavation-Water and Fill actions, whatever the depth may be, cancel the existing Graux surcharges located on the same side and defined previously. In order to keep these surcharges active, it's necessary to define them again after each action Excavation-Water or Fill located on the same side.

Note: in the .P20 data file, **x** is positive when the surcharge is located uphill and negative when the surcharge is located downhill. This is handled automatically by the program when selecting the side for the surcharge (downhill or uphill). Therefore **x** should always be defined with a positive value.

C.5.2.3. Moment (load)

This action enables to define an external moment load onto the wall or to deactivate an existing one.

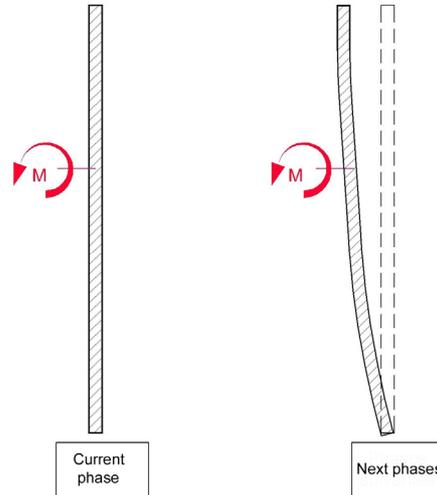


Figure C 16: Moment load

The properties requested for this action are:

- **New couple:** by default, the program assumes you want to define a new moment load. You may also choose to deactivate an existing moment load that was defined in previous phases;
- **z:** moment level (m);
- **M:** value of moment per elementary wall width (MN.m, kN.m, t.m).

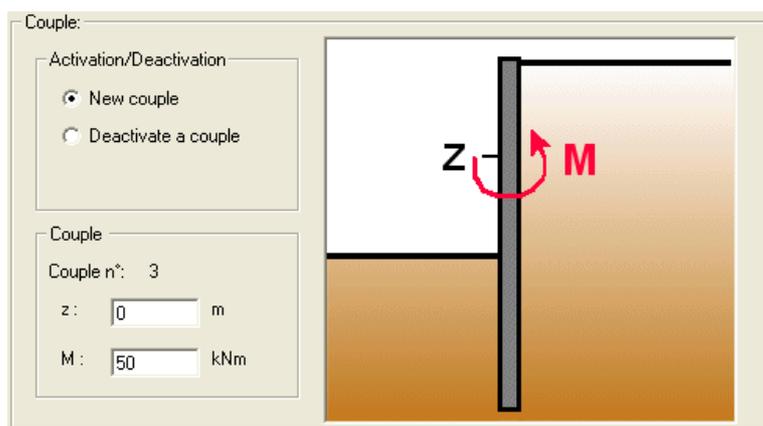


Figure C 17: Moment load

The value of the moment depends on the elementary wall width **L**:

$$M = M_{ml} * L$$

M_{ml} = value of the moment load per linear meter.

The moment value does not change during the phases following its installation.

In order to deactivate an existing moment, check the option **Deactivate a couple**. The parameters zone should then look like figure C 18. Select the moment to be deactivated (identified with its installation number, its level and its value).

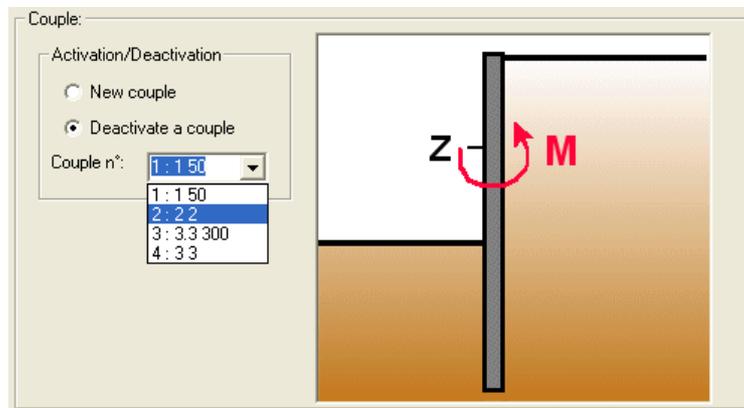


Figure C 18: Activation/Deactivation of a moment

It is possible to apply several moment loads at the same level, in which case the values of the moment loads are added together, whether they are all defined in the same phase or not.

Linear forces, struts, anchors or rotation springs (rotational spring restraints) can also be defined at the same level as a moment in order to define combined actions.

C.5.2.4. Horizontal trapezoidal load on the wall

This action enables to define a horizontal load onto the wall.

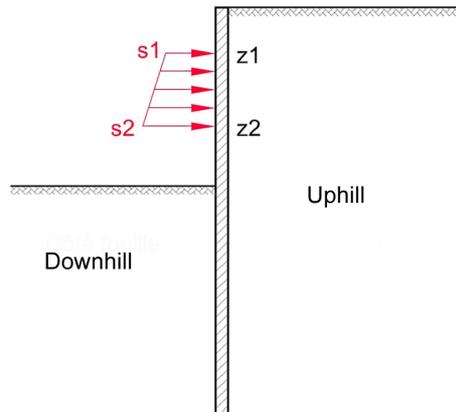


Figure C 19: Horizontal load

The load (pressure) applies along the actual width of the wall.

The properties for this action are:

- **z1**: top level (m);
- **z2**: bottom level (m);
- **s1**: value of the load at z1 (MPa, kPa, t/m²);
- **s2**: value of the load at z2 (MPa, kPa, t/m²).

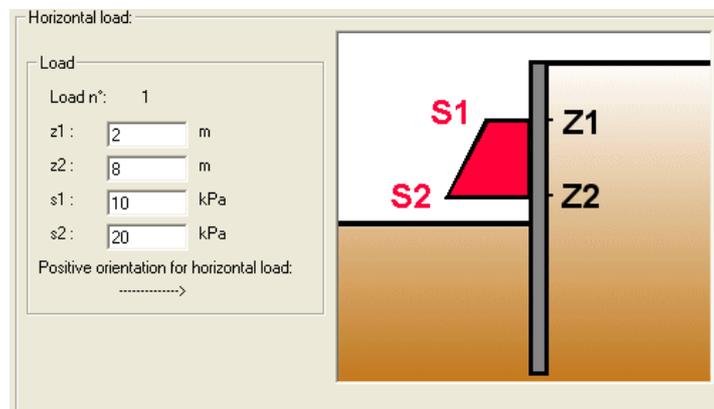


Figure C 20: Horizontal load

s1 and **s2** are positive when loads are directed from downhill to uphill and negative the other way. The loads values between **s1** and **s2** are calculated using a linear regression.

It is possible to define several horizontal loads. If they overlap each other (fully or partially) and have the same direction, they will be added. On the contrary, if they have opposite directions, they will compensate for each other (this can be used to cancel a horizontal load). Such load combinations are valid whether all loads are defined in the same phase or not.

C.5.2.5. Linear force

This action enables to activate or deactivate a linear force on the wall.

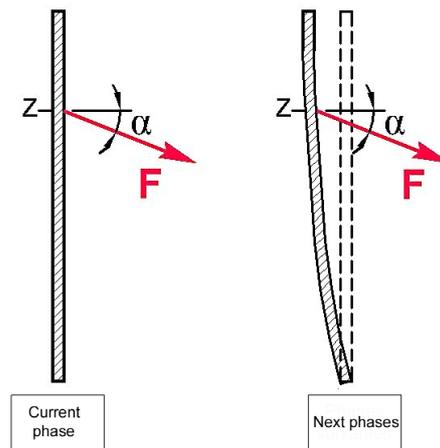


Figure C 21: Linear force

The properties for this action are:

- **Activate a new force:** default option, which enables to create a new force;
- **z:** position of the force (m);
- **F:** force value per elementary wall width (MN, kN, t);
- **K:** anchor stiffness per elementary wall width (MN/m, kN/m, t/m);
- **α:** angle between the direction of the force and the horizontal axis. The angle is positive clockwise (°).

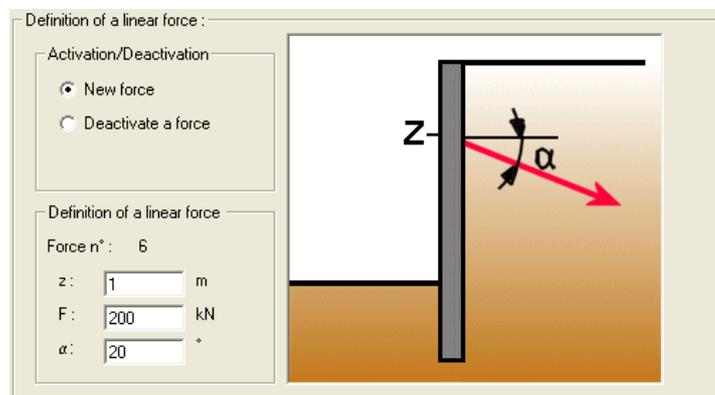


Figure C 22: Linear force

The value of the linear force depends on the elementary wall width **L**:

$$F = F_{ml} * L$$

F_{ml} = value of the force per linear meter.

The force value does not change during the phases following its installation.

In order to deactivate a linear force, check the option **Deactivate a force**. The parameters zone should then look like figure C 23. Select the force to be deactivated (identified with its installation number, its level and its value).

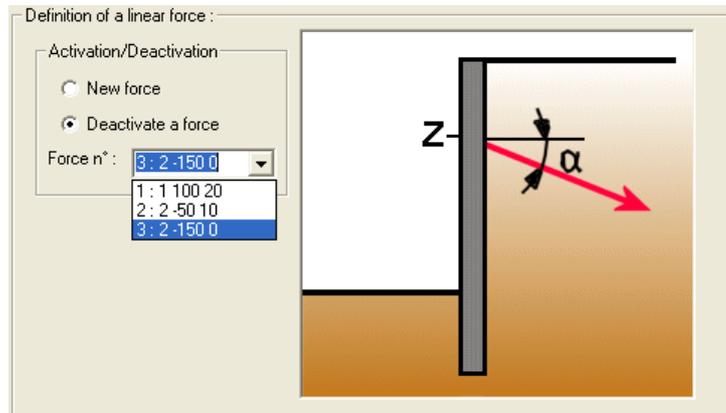


Figure C 23: Activation/Deactivation of a linear force

It is possible to apply several forces at the same level, in which case the values of the forces are added together, whether they are all defined in the same phase or not.

Struts, anchors, moment loads or rotation springs can also be defined at the same level as a moment in order to define combined actions.

Actions category: Earthworks**C.5.2.6. Excavation-Water**

In K-REA, the downhill side is always assumed to be located on the left of the wall (convention).

This action includes three actions in one.

It enables to define/change the excavation level, the water level and a Caquot surcharge (uniform surcharge loading) simultaneously on the same side of the wall. For each new action of this type, these 3 properties should be (re)defined.

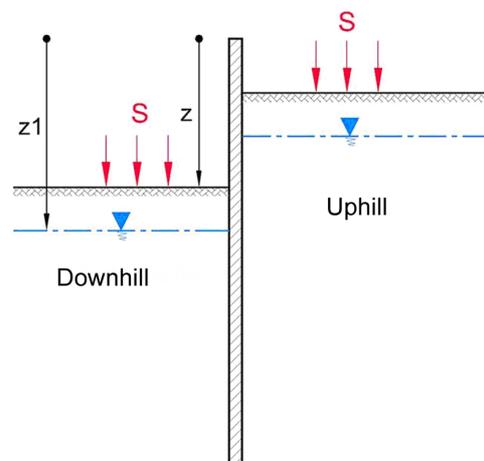


Figure C 24: Excavation-Water

The properties requested for this action are:

- **Downhill or Uphill:** side for the action;
- **z:** excavation level (m);
- **z1:** water level (m);
- **S:** value of the Caquot surcharge (uniform surcharge loading) to be applied onto the bottom of the excavation (MPa, kPa, t/m²).

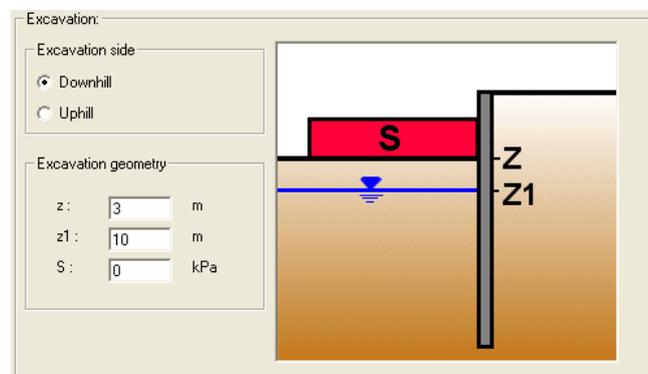


Figure C 25: Excavation-Water

The application of a new Caquot surcharge replaces the previous Caquot surcharge on the same side. Caquot surcharges cannot be added one to the other.

C.5.2.7. Fill action

This action enables to define a fill: the bottom level is not necessarily the same as the previous groundlevel (there can be a free space in between)

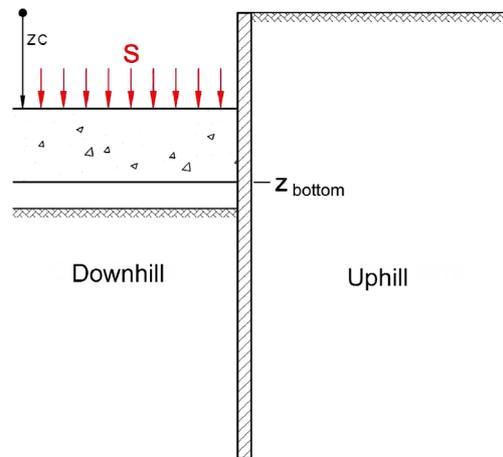


Figure C 26: Fill

The properties for this action are:

- The name of the fill layer ;
- **Downhill or Uphill:** side for the fill;
- **z_{bottom}:** bottom level (base level) of the fill (m);
- **S:** value of the Caquot surcharge applied onto the fill (MPa,kPa,t/m²);
- **z_c:** top level of the fill (m);
- **Z_{water}:** waterlevel at that moment (m);
- **PV_h, PV_d:** soil weights (MN/m³, kN/m³, t/m³);
- **φ:** internal friction angle (°);
- **c** and **dc:** cohesion and its variation with depth (MPa, kPa, t/m²);
- **k_i:** active pressure coefficient used to calculate the initial pressure;
- **k_a, k_p, c_a, c_p:** coefficients for active and passive earth pressures;
- **k_d** and **k_r:** unloading and reloading ratios for the fill;
- **k_h** and **dk_h:** subgrade reaction coefficient and its variation with depth (MN/m³, kN/m³, t/m³).

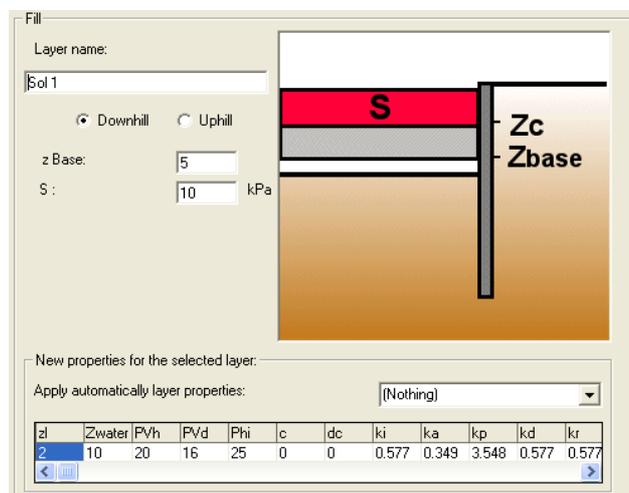


Figure C 27: Fill

Note: when setting the parameters for the fill layer, the listbox suggests using the properties of an existing soil layer, so that only a few properties need to be changed (the top level Z_c , for example)

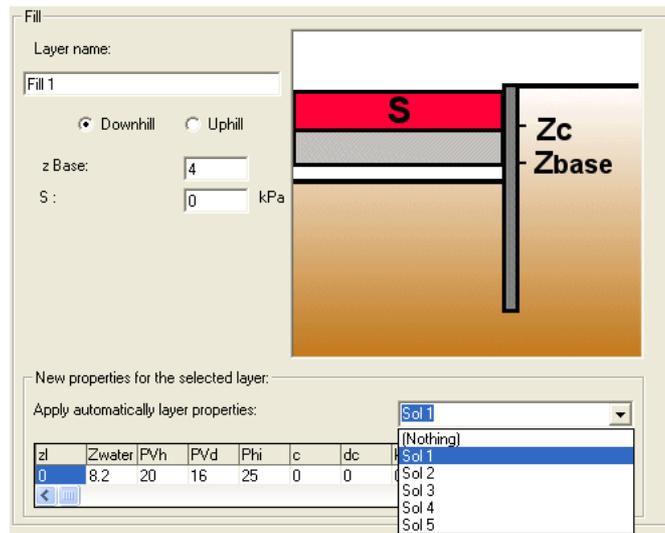


Figure C 28: Copying the properties of an existing soil layer

The default level for the bottom of the fill layer corresponds to the top of the upper layer before the present filling action. The bottom of the fill layer can only be placed higher than existing soil layers (option "base").

Note 1:

- If $Z_{\text{bottom}} = Z_{\text{excavation}}$, the fill weight generates additional vertical stresses for the layers below the fill.
- If $Z_{\text{bottom}} > Z_{\text{excavation}}$, the vertical stresses below the fill do not change.

Note 2: The horizontal earth pressure within the fill material caused by the fill activation is equal to the initial pressure. $p_i = k_i * \sigma'_v$.

Note 3: The k_i coefficient can have several values:

- $k_i = k_0$, if the initial earth pressure for the fill should be based on at-rest earth pressure;
- $k_i > k_0$, if you want to take into account that the fill material has been compacted;
- $k_i = k_a$, if the initial earth pressure for the fill should be based on active earth pressure.

Note 4: It is possible to define several fill layers with different properties on the same side of the wall (in successive phases), except for the following case: the calculation kernel is not valid when one or several fill layers are added on top of a first fill layer which was itself placed higher than existing layers (i.e. with $Z_{\text{bottom}} > Z_{\text{excavation}}$). This configuration should thus not be used during staged construction.

This action cancels Graux, Boussinesq or Caquot surcharges previously defined on the same side as the fill. In order to keep these surcharges active, they should be defined again, but in the next phase (it is impossible to define Graux or Boussinesq surcharges on the same side and in the same phase as a fill action).

C.5.2.8. Berm

This action SHOULD ONLY BE USED after an Excavation-Water action in the same phase. If there is no new excavation before the berm, the properties for the Excavation-Water action should be the same as those for the latest Excavation-Water action.

Excavation-Water Berm

Note: this Excavation-Water action before the Berm action also enables to activate a Caquot surcharge on top of the berm and to define a new waterlevel.

A berm, as for its action on the wall, is considered as a sequence of negative and semi-infinite uniform surcharge loadings. These uniform surcharge loadings simulate the horizontal slices of soil located between the infinite and the external envelope of the berm, and between the berm upper level: **z of the previous excavation** and the berm bottom level: **z of the bottom of the berm**). The resulting action is a decrease of the effective vertical stress at level **z** in front of the wall.

The properties requested to define a berm are:

- **z**: level of the bottom of the berm (m);
- **a**: width of the top of the berm > 0 (m);
- **b**: width of the bottom of the berm >0 (m).

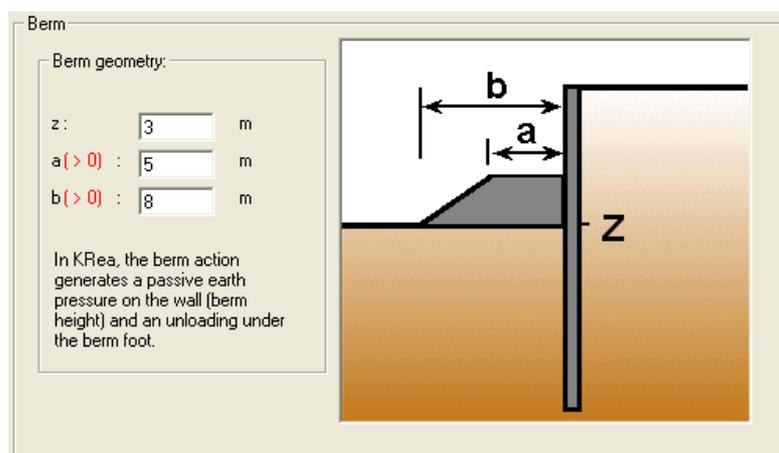


Figure C 29: Berm

Note: No stability calculation is performed for the berm geometry. It is the user's responsibility to perform such a calculation separately.

If a Fill action is defined after a Berm action, the top of the berm will be considered as the bottom of the fill.



A simple excavation action defined after a berm cancels the Berm action, even if the excavation does not reach the bottom of the berm. In order to keep the berm active, it should be defined again using its new width at the top and the former width at the bottom.

C.5.2.9. Sheeting installation (soldier-pile wall)

This action enables to model the installation of a sheeting in the frame of the construction of a soldier-pile wall.

This action **SHOULD ONLY BE USED** after an Excavation-Water action in the same phase.

Excavation-Water Sheeting installation

And the **Reduced pressure** action **MUST HAVE BEEN DEFINED** in the initial phase.

Note: this Excavation-Water action before the Sheeting installation enables to define a new waterlevel and a possible Caquot surcharge on the bottom of the excavation.

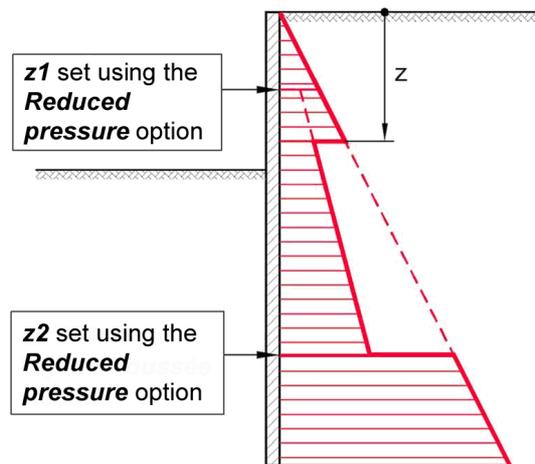


Figure C 30: Sheeting installation for a soldier-pile wall

The property requested for a sheeting installation is:

- **z**: bottom level of the sheeting installation (m).

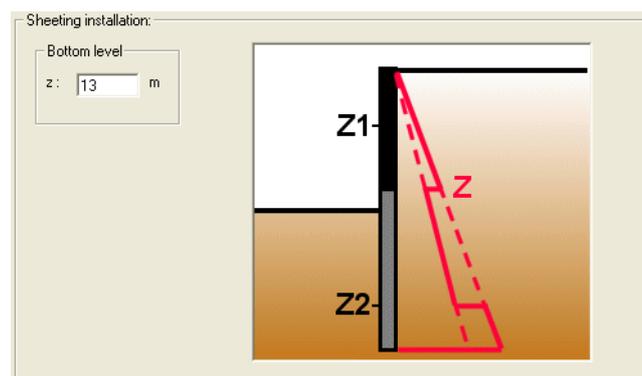


Figure C 31: Sheeting installation

If the active pressure has been reduced using the **Reduced pressure** option, then it is restored to 100% of its value above level **z**. This is valid also for the passive pressure, the water pressure and the subgrade reaction coefficient.

Such a sheeting installation always starts from the top of the wall and is completed in several installation steps.

Actions category: Anchors-Wall

C.5.2.10. Struts

This action enables to activate or deactivate a strut.

The horizontal compression T_h in the strut is equal to:

$$T_h = K \cdot \Delta \text{ with } \Delta = \text{differential displacement at the given node.}$$

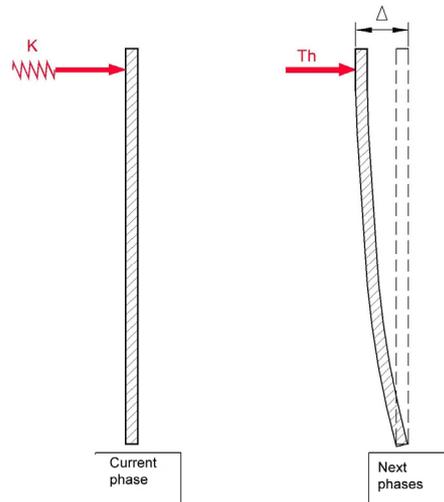


Figure C 32: Struts

The properties requested to define a strut are:

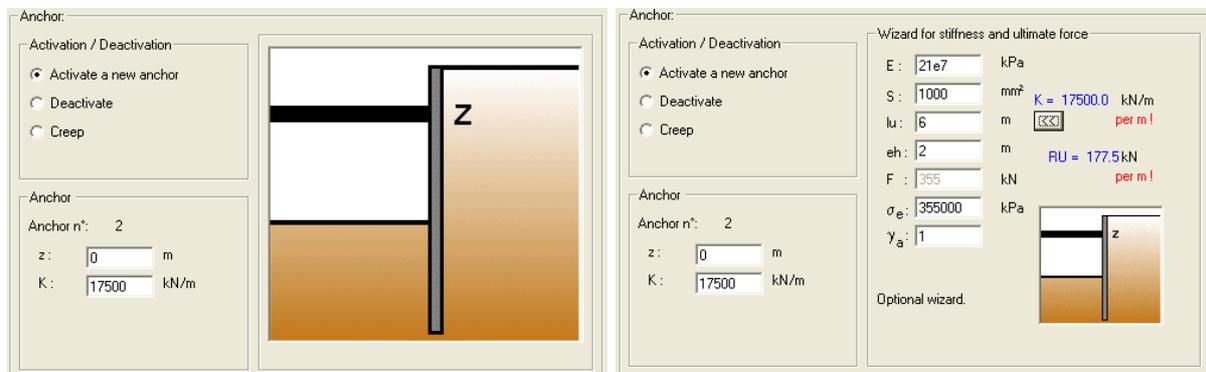


Figure C 33: Struts. Click on the diagram to zoom in/out. Zooming out makes the wizard for the stiffness and resistance visible.

- **Activate a new strut:** default option, which enables to create a new strut;
- **z:** level of the strut (m);
- **K:** stiffness of the strut for the elementary wall width (MN/m, kN/m, t/m).

It is not compulsory to use the **Wizard for stiffness and ultimate force**. It is intended as a help to define the strut parameters, to display them and also enables to display the forces in the strut resulting from the calculation (for each strut rather than per elementary wall width).

The stiffness of the strut is calculated as shown:

$$K = \frac{ES}{l_u} * \frac{L}{e_h}$$

With:

- E = Young's modulus of the material (MPa, kPa, t/m²);
- S = section (m²). It should be input in mm² in the wizard;
- l_u = equivalent (useful) length (m);
- e_h = horizontal spacing (m);
- L = elementary wall width (m), equal to 1 m in the wizard.

The ultimate force RU is calculated as shown:

$$RU = \frac{S\sigma_e}{\gamma_a} * \frac{L}{e_h}$$

With:

- S = section (mm²);
- σ_e = yield stress of steel (MPa,kPa,t/m²);
- (F = Sσ_e = ultimate compression force in the strut)
- L = elementary wall width (m), equal to 1 m in the wizard;
- e_h = horizontal spacing (m);
- γ_a = partial safety factor on the strut (may take into account a partial safety factor on the steel yield stress).

All the results in the wizard are provided per linear meter.

In order to deactivate an existing strut, check the **Deactivate** box. The strut parameters zone appears as shown on figure C 34. Select the strut to be deactivated in the listbox. Struts are identified using their installation number, their level and their stiffness value.

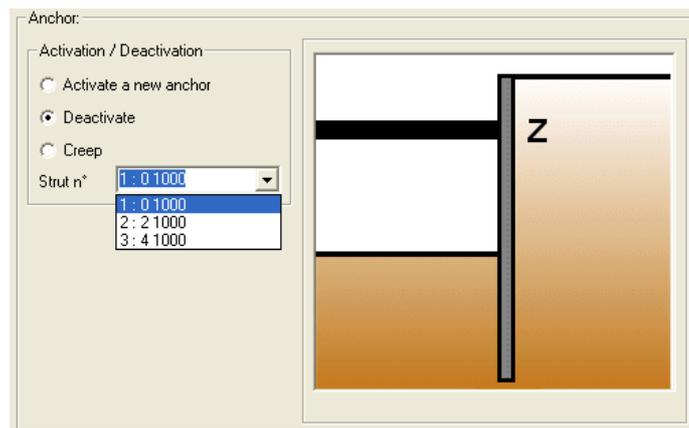


Figure C 34: Deactivation of an existing strut

In order to change the stiffness of a strut in a given phase, you may use the Creep option and define the new stiffness value, as illustrated below:

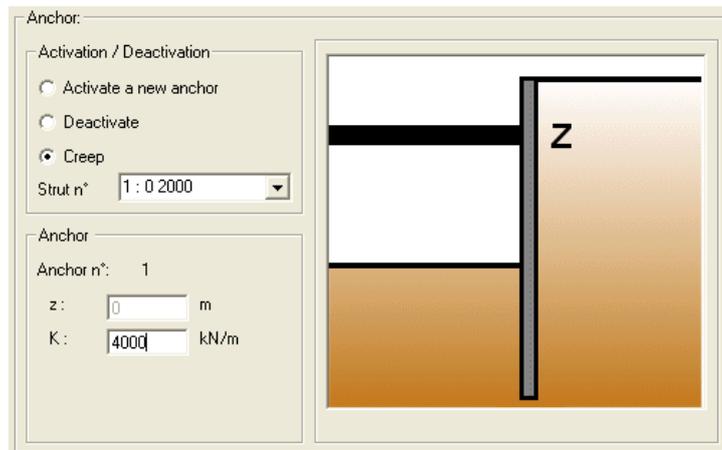


Figure C 35: Creep of an existing strut

It is possible to define any other force (linear force, anchor, moment, rotation spring) at the same level as a strut, to simulate combined actions.

C.5.2.11. Anchors

This action enables to activate and deactivate an anchor.

The traction T in an anchor is equal to: $T = P + K \cdot \Delta \cdot \cos(\alpha)$

And the corresponding horizontal force is: $T_h = P \cdot \cos(\alpha) + K \cdot \Delta \cdot \cos^2(\alpha)$

with Δ = differential displacement at the given node.

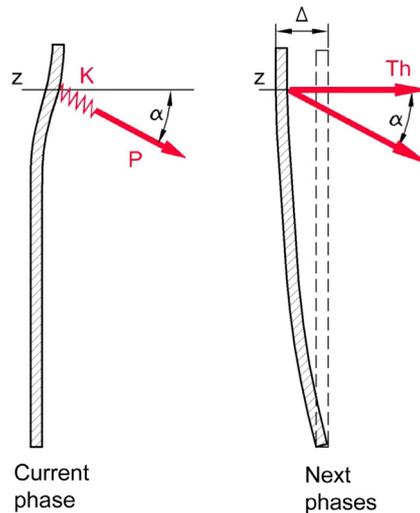


Figure C 36: Definition of an anchor

The properties requested to define an anchor are:

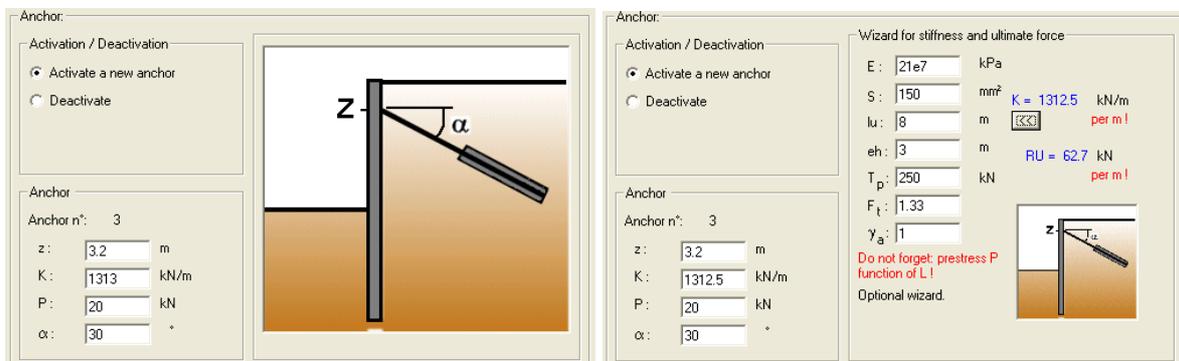


Figure C 37: Anchor. Click on the diagram to zoom in/out. Zooming out makes the wizard for the stiffness and resistance visible.

- **Activate a new anchor:** default option, which enables to create a new anchor;
- **z:** level of the anchor (m);
- **P:** prestress force for the anchor per elementary wall width (MN, kN, t);
- **K:** anchor stiffness per elementary wall width (MN/m, kN/m, t/m);
- **α:** angle between the direction of the anchor and the horizontal axis. The angle is positive clockwise (°).

The prestress for the anchor is a function of the elementary wall width L :

$$P = \frac{P}{eh} * L$$

$\frac{P}{eh}$ = prestress value per linear meter.

It is not compulsory to use the **Wizard for stiffness and ultimate force**. It is intended as a help to define the anchor parameters, to display them and also enables to display the forces in the anchor resulting from the calculation (for each anchor rather than per elementary wall width).

The stiffness of the anchor is equal to:

$$K = \frac{ES}{l_u} * \frac{L}{e_h}$$

- E = Young modulus of the material (MPa,kPa,t/m²);
- S = section (mm²);
- l_u = equivalent (useful) length (m);
- e_h = horizontal spacing (m);
- L = elementary wall width (m), equal to 1 m in the wizard.

The service limit traction RU is calculated as shown below:

$$RU = \frac{T_p}{F_t \gamma_a} * \frac{L}{e_h}$$

With:

- T_p = yield stress of steel (MN, kN, t);
- L = elementary wall width (m), equal to 1 m in the wizard;
- e_h = horizontal spacing (m);
- F_t = safety factor on the anchor resistance;
- γ_a = partial safety factor for the anchors.

All the results in the wizard are provided per linear meter.

In order to deactivate an existing anchor, check the **Deactivate** box. The anchor parameters zone appears as shown on figure C 38. Select the anchor to be deactivated in the listbox. Anchors are identified using their installation number, their level, their stiffness, their prestress and their angle.

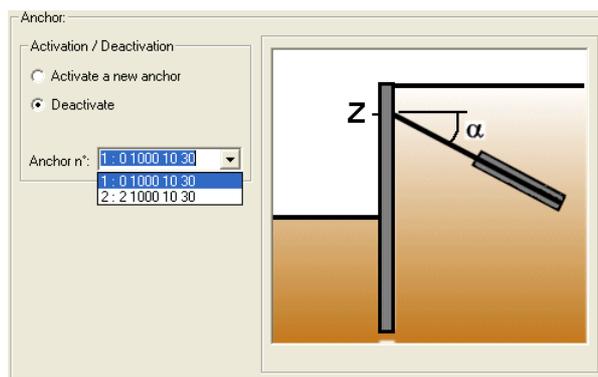


Figure C 38: Deactivation of an existing anchor

When installing an anchor, only the prestress force is taken into account in the calculation of the installation phase. The anchor stiffness is taken into account starting from the next phase (the one after the installation).

In order to change the prestress force or the stiffness of an anchor, first deactivate it, then create a new anchor at the same level with the new prestress and stiffness values.

It is possible to define any other force at the same level as an anchor.

Note 1: The anchor prestress force may be used to simulate a linear load on the wall (as an alternative to the linear force action).

Note 2: Such a linear load can be oriented downhill to uphill if the prestress force is positive and oriented uphill to downhill if the prestress force is negative.

C.5.2.12. Rotation spring (rotation stiffness)

This action enables to define a rotation stiffness **R** that creates a moment **C**, related to the wall differential rotation Δi .

This moment is equal to: $C = -R \cdot \Delta i$ ($\Delta i > 0$ anti-clockwise)

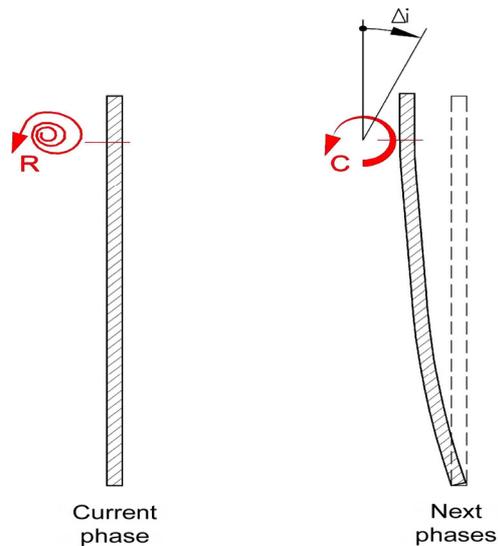


Figure C 39: Rotation spring (rotation stiffness)

The properties requested to define a rotation spring:

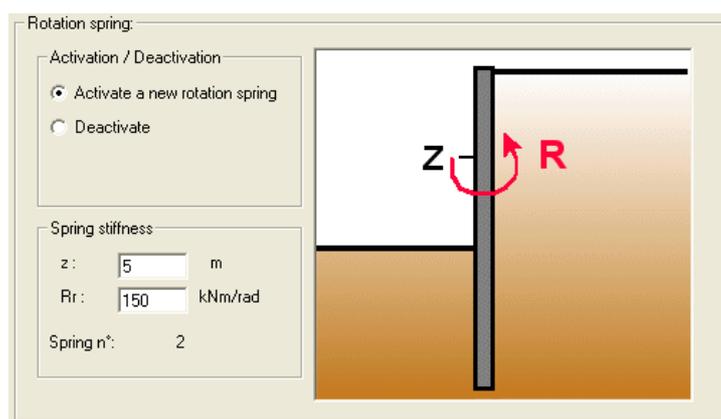


Figure C 40: Rotation spring definition zone

- **Activate a new rotation spring:** default option, which enables to create a new rotation spring;
- **z:** level of the rotation spring (m);
- **R:** rotation stiffness per elementary wall width (MN.m/rad, kN.m/rad, t.m/rad);

The rotation stiffness is a function of the elementary wall width **L**:

$$R = R_{ml} * L$$

R_{ml} = value of the rotation stiffness per linear meter.

In order to deactivate an existing rotation spring, check the **Deactivate** box. The spring parameters zone appears as shown on figure C 41. Select the spring to be deactivated in the listbox. Springs are identified using their installation number, their level, and their rotation stiffness.

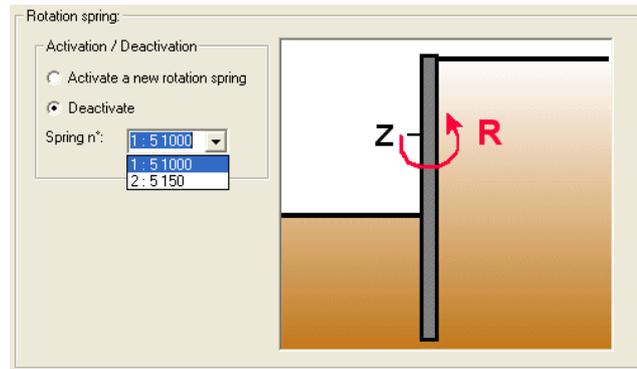


Figure C 41: Deactivation of an existing rotation spring

This action, combined with the Moment action, enables to simulate the action of an external structure (floor) embedded into the wall and subjected to an embedment moment.

C.5.2.13. Modification of the wall inertia

This action enables to change the product of inertia for parts of the wall, using their upper and lower levels, if the wall has been defined with its product of inertia (rather than with its modulus and thickness).

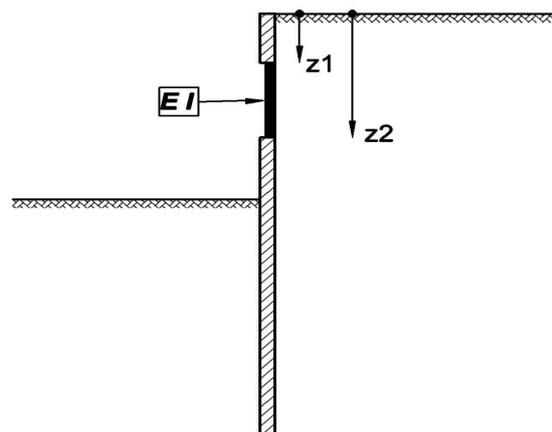


Figure C 42: Modification of the wall inertia

The properties requested for a modification of the inertia of a part of the wall are:

- **z(top)**: upper level for the wall element (m);
- **z(bottom)**: lower level for the wall element (m);
- **EI**: new value for the product of inertia (MN.m², kN.m², t.m²);
- **Rc**: new value for the cylindrical rigidity in the case of a circular wall (MN/m³, kN/m³, t/m³).

Changes of the wall properties:

Product of inertia Wizard

Cylindrical wall

z(top) = m

z(tip) = m

EI = kNm²

R_c = kN/m³

N°	Z [m]	EI [kNm ²]	L [m]	Cylindric rigidity [kN/m ³]
1	-2	104167	1	5556
2				

N°	Z [m]	EI [kNm ²]	L [m]	Cylindric rigidity [kN/m ³]
1	0	104167	1	5556
2				

: Zb: bottom level

Figure C 43: Change of the wall stiffness (if the wall has been defined using its product of inertia)

Note: the new wall properties (EI, R_c) should be defined as a function of the elementary wall width (defined initially in the wall properties dialogue box). This elementary wall width may be checked in the initial wall zone.

If the wall has been defined using its thickness and its Young's modulus, then the only property needed in order to change the wall stiffness is:

- **E:** new Young modulus (MPa, kPa, t/m²). In this case, the wall inertia is changed for the total height of the wall.

Changes of the wall properties:

Thickness

New wall Young's modulus

E = kPa

Figure C 44: Parameters zone for the stiffness of the wall (if the wall has been defined using its thickness).



The product of inertia of any section of the wall should always be decreased. Indeed the calculation engine only provides relevant results for decreasing values.

The new value of the EI product is used in the equilibrium equations directly and thus influences the wall total displacements.

It is not possible to input a zero value for a product of inertia. On the other hand, it is possible to raise the wall, as explained thereafter.

C.5.2.14. Wall raising (wall extension)

This action enables to extend the wall upwards.

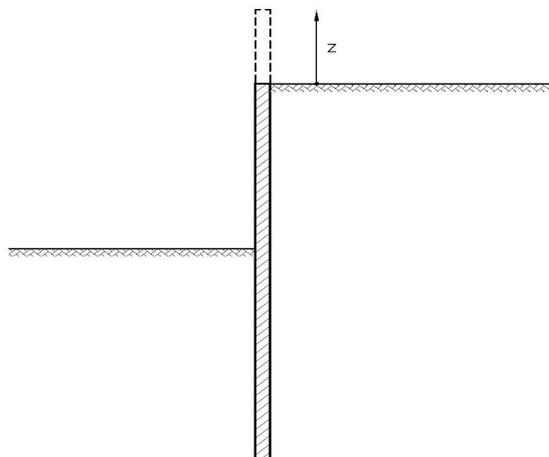


Figure C 45: Wall raising

Only walls that have been defined using their product of inertia can be extended upwards. The requested properties are:

- **z** = new top level of the wall (m);
- **EI** = total product of inertia (MN.m², kN.m², t.m²);
- **L** = elementary wall width (default value is 1 m; use the advanced properties to change it);
- **R_c** = vault stiffness or cylindrical rigidity (MN/m³, kN/m³, t/m³).

Wall raising:

Definition mode: Wizard

Circular wall

Wall raising: 1 : -2 104167 1 5556

N°	Z [m]	EI [kNm ²]	L [m]	Cylindrical rigidity [kN/m ³]
1	-2	104167	1	5556

Initial wall:

N°	Z [m]	EI [kNm ²]	L [m]	Cylindrical rigidity [kN/m ³]
1	0	104167	1	5556
2				
3				
4				

21.3 : Zb: bottom level

Figure C 46: Wall raising

Note: the properties for the new wall element (EI, R_c) should be defined as a function of the elementary wall width. This elementary wall width may be checked in the initial wall zone.

C.5.2.15. Modification of soil properties

This action enables to change the properties of an existing soil layer.

This change may be defined either on one single side of the wall, or on both sides of the wall. The requested properties are:

- Downhill or Uphill or both (default choice);
- The **name** of the layer to be changed: use the listbox to select the layer;
- ϕ , **c**: the new values for the geotechnical properties (MPa, kPa, t/m²);
- **k₀**, **k_a**, **k_p**, **k_d**, **k_r**, **c_a**, **c_p**: the new values for active and passive earth pressure coefficients;
- **k_h** and **dk_h**: the new values for the horizontal subgrade reaction coefficient, and its variation per meter depth (MN/m³, kN/m³, t/m³).

New characteristics for a soil layer:

Layer to be modified: Hydraulic fill

Side: Downhill Uphill

Current properties for phase n-1:

Phi	c	k ₀	k _a	k _p	k _d	k _r	c _a	c _p	k _h	dk _h	da/p
32	0	0.47	0.26	5.951	0.47	0.47	0	0	20000	0	0.66

New properties for the selected layer:

Phi	c	k ₀	k _a	k _p	k _d	k _r	c _a	c _p	k _h	dk _h	da/p
32	0	0.47	0.26	4	0.47	0.37	1.2	5.69	10000	0	0.66

Restore properties from phase n-1 ca/cp wizard

Figure C 47: Modification of soil properties

In a phase where there is a modification of the soil layers properties, the calculation of the displacements and pressure is based "as usual" on the results of the previous phase.

Note 1: In the zone "New properties for the selected layer", the button **Restore parameters from phase n-1** can be used to fill in automatically the properties (then you just have to change the values which indeed change). The button **ca/cp wizard** enables to recalculate the coefficients as a function of the new friction angle. The other wizards (**ka/kp/kh**) can be reached with the buttons from the main button bar.

Note 2: This action enables to change either some of the properties of a soil layer, or all of them.

Note 3: You can only change the properties for a given layer at a time. In order to change the parameters of another layer, you need to define another action **New soil properties** in the same phase, to select another layer to change and to input its new properties. This action may be repeated as often as necessary.

C.5.2.16. Hydraulic gradient

This action SHOULD ONLY BE USED after an action Excavation-Water in the same phase: this action Excavation-Water is needed to define non-hydrostatic water pressure profiles.

Non-hydrostatic pressure profiles may be defined on both sides of the wall, to model a variety of complex conditions including:

- Seepage
- Submerged ground
- Perched water tables
- Uplift pressures under structures

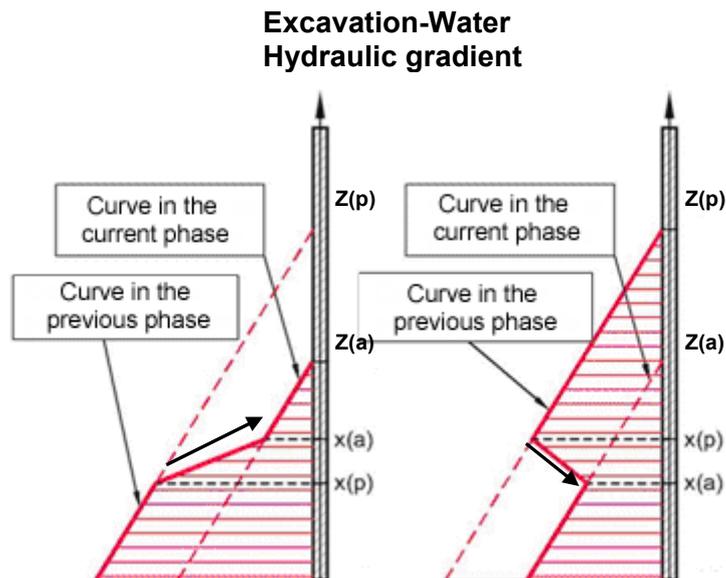


Figure C 48: Hydraulic gradient, either "ascending" or "descending", for "level" option

The requested parameters are:

- **x_p**: level (or depth) of the connection point with the water pressure curve of the previous phase;
- **x_a**: level (or depth) of the connection point with the water pressure curve of the current phase i.e. the waterlevel of the action Excavation-Water ($z_1=z_a$);

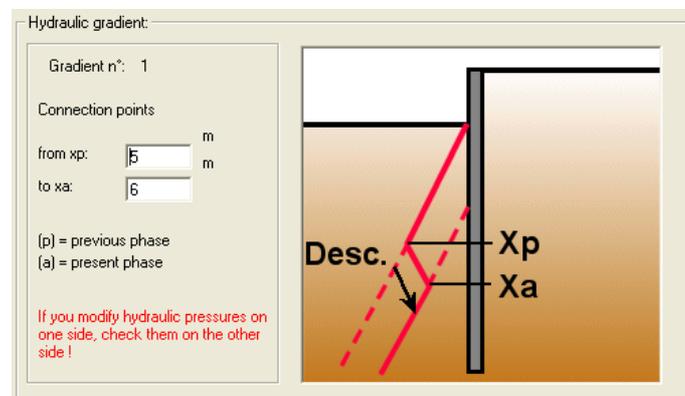


Figure C 49: Hydraulic gradient

This action enables to balance water pressures for both sides of the wall (after an excavation for example), or to join discontinuous water pressure curves (because of impermeable layers for example).

The action picture is automatically updated depending of the "connection direction" between both curves (previous phase and current phase). This connection direction has no physical meaning, and is defined this way:

For "level" option (as opposed to "depths"), let's call **zp** the water level provided for the action Excavation-Water in phase n-1, and **za** the water level provided for the action Excavation-Water in phase n (just before the hydraulic gradient action in phase n):

- If $z_a > z_p$ and $x_p \geq x_a$ then the connection is **descending**
- If $z_a > z_p$ and $x_a > x_p$ then the connection is **ascending**
- If $z_p > z_a$ and $x_p > x_a$ then the connection is **descending**
- If $z_p > z_a$ and $x_a \geq x_p$ then the connection is **ascending**

Example of a hydraulic gradient intended to balance water pressures at the bottom of the wall:

Let's consider a 12m-high wall. The wall top level is +24 m and its foot is at +12m. The groundwater level is the same as the groundlevel.

A 5m-deep excavation is performed (with struts), with a drawdown of the waterlevel to the excavation level on downhill side.

The groundlevel and waterlevel downhill are thus at +19 m.

A hydraulic gradient on each side of the wall may be considered in order to simulate the equilibrium of water pressures at the bottom of the wall.

If such an equilibrium existed without the gradients, the corresponding water level would be at + 20,8 m.

The water pressure profiles are drawn below with legends that indicate how to set the gradients in K-REA:

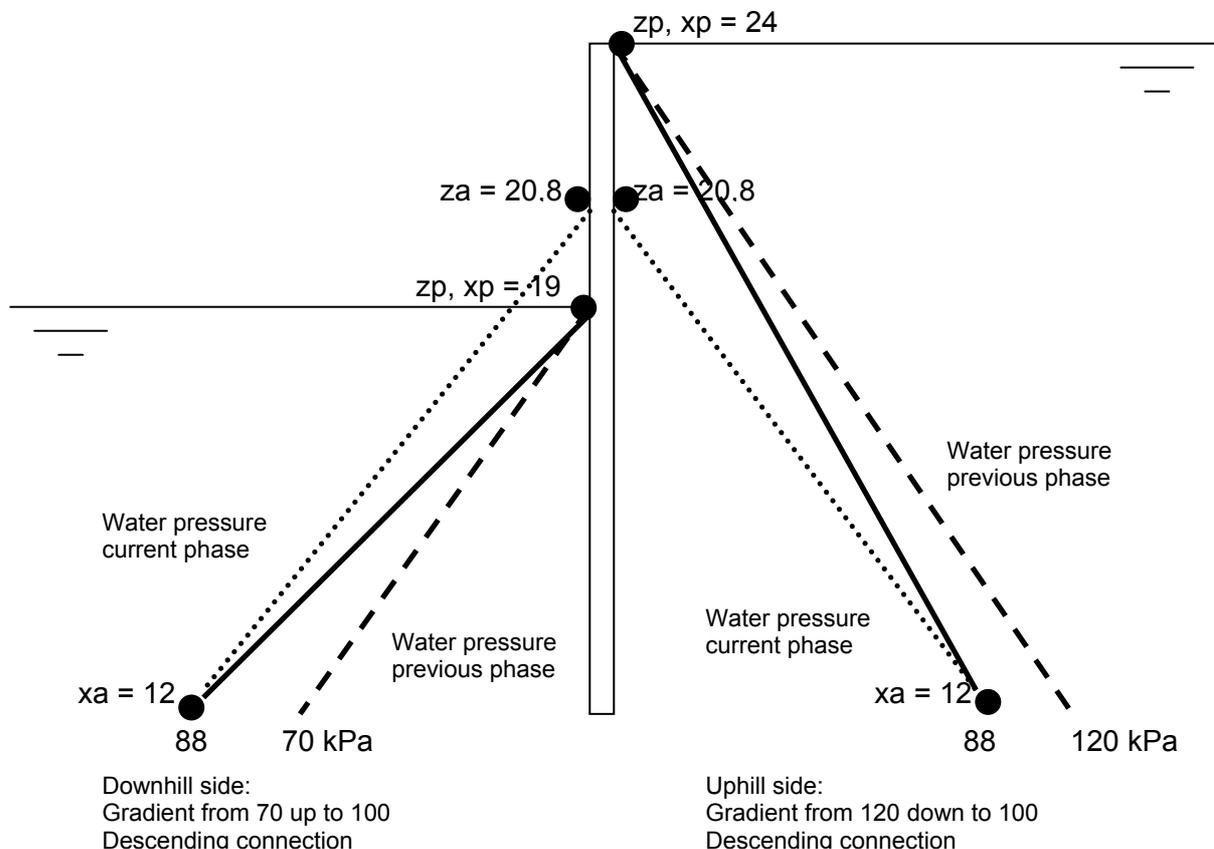


Figure C 50: Drawing of water pressure curves with desired connection

Here are the way these actions should be defined in K-REA:

1: Excavation-Water action downhill

2: Hydraulic gradient action downhill

3: Excavation-Water action uphill

4: Hydraulic gradient action uphill

Figure C 51: Example of application of a hydraulic gradient (K-REA screenshots)

C.6. K-Rea datafile structure

K-REA automatically generates a datafile when saving a project or when performing a calculation. This datafile is of the ASCII-type. Its extension is .P20.

The calculation engine reads this datafile, and thus applies the instructions provided by the user through the user-interface. It generates an output file (results).

The structure of the datafile is described thereafter (although users don't need to create or modify the file manually).

The main entity for data is the line. Each line begins with an alphanumerical word corresponding to a command. The format used for each line is free. The lines order is also globally free but should respect some general guidelines (general data should be placed before construction data, soil layers should be defined with increasing depth, and properties of a given soil layer should be placed after the position of that same soil layer...).

If some data values are missing at the end of a line, they will be assumed to be zero.

The variables are dynamic (pointers); thus there is no limitation for the number of lines or elements, except in the case of a saturation of the computer memory or, which is the case here, in the case of a limitation by the user-interface. Two different data types should be considered:

- The data that are compulsory for the program to work properly;
- The data requested to describe the project.

In the datafile, the word “interieur” (inside) stands for “downhill” and “exterieur” (outside) stands for “uphill”.

C.6.1. Compulsory data

- **TITRE** title
- **SYSTEME** number water_weight
 with number = 1 for MN, MPa & m units system
 number = 2 for kN,kPa & m units system
 number = 3 for t, t/m² & m units system
 water_weight = water weight
- **LANGUE** i_language
 with i_language = 1 for output in French (default value)
 i_language = 2 for output in English

soil layers:

- **COUCHE** Z_l Φ c PV_d PV_h Z_{water} k_h dk_h

with Z_l = top level of the layer (in depths if z is increasing, in levels otherwise)
 Φ = friction angle
 c = cohesion
 PV_d = submerged soil weight
 PV_h = soil weight above water table
 Z_{water} = water level
 k_h = horizontal subgrade reaction coefficient
 dk_h = variation of the subgrade reaction coefficient with depth

- **COEFF** k_a k_p c_a c_p k_0 k_d k_r

with k_a = horizontal active earth pressure coefficient
 k_p = horizontal passive earth pressure coefficient
 c_a = coefficient of active pressure applied to cohesion c
 c_p = coefficient of passive pressure applied to cohesion c
 k_0 = coefficient of earth pressure at rest
 k_d = unloading ratio
 k_r = reloading ratio

- **VARIATION** dc (optional)

with dc = variation of the layer cohesion per meter depth in the layer, from the top of the layer

- **NOM** title

with title = name of the layer [maximum 20 letters]

Note: the lines COUCHE, COEFF, and possibly VARIATION and NOM should always follow each other. There are as many lines blocks as layers in the project.

Definition of the wall, using its thickness:

- **BETON** concrete

with concrete = Young's modulus of the wall material

- **PAROI** Z e L stiff_vault

with Z = top level for wall section (1st level=top of the wall)
 e = wall thickness
 L = wall elementary width
stiff_vault = vault stiffness or cylindrical rigidity

[Variation for the BETON + n PAROI lines]

C.6.2. Additional data stored before the phases (before the keyword PHASE)

Definition of the anchors properties and of the forces properties:

- **POUSSEE** Pmax
with Pmax = maximal pressure (its default value is -999)
- **POUSSEE REDUITE** z1 z2 R C
with z1 = upper level of the reduced pressure zone
z2 = lower level of the reduced pressure zone
R = reduction coefficient applied to all pressures (earth and water, active and passive)
C = additional coefficient applied to passive pressure (default value is 1)
- **TIRANT** n° z K P α
with n° = anchor number
z = anchor head level
K = anchor stiffness per elementary wall width
P = anchor prestress force per elementary wall width
 α = anchor angle (positive clockwise)
- **BUTON** n° z K
with n° = strut number
z = strut head level
K = strut stiffness per elementary wall width
- **MOMENT** n° z M
with n° = moment number
z = moment level
M = moment value per elementary wall width
- **ENCASTRE** n° z R
with n° = rotation spring number
z = rotation spring level
R = rotation spring stiffness per elementary wall width
- **FORCE** n° z F α
avec n° = force number
z = force level
F = force value
 α = force inclination (positive clockwise) per elementary wall width
- **SURCHARGE** S (Caquot)
with S = horizontal surcharge at initial groundlevel

C.6.3. Data for phases

Surcharges data:

- **SURCHARGE BOUSSINESQ** S x l z

with S = surcharge value
 x = distance to the wall ($\neq 0$)
 l = application width
 z = surcharge level

Note: x is positive for surcharges uphill, and negative for surcharges downhill.

- **SURCHARGE BOUSSINESQ SUPERPOSER** S x l z

with S, x, l, z = same definition as hereabove

Remarque : this option enables to sum the horizontal component related to Boussinesq loads with other effective vertical stresses.

- **SURCHARGE LOCALISEE** S x l z α β

with S = surcharge value
 x = distance to the wall ($\neq 0$)
 l = application width
 z = surcharge level
 α = constant angle in the formula for the diffusion angle
 β = gradient for the friction angle tangent in the formula for the diffusion angle

Note: x is positive for surcharges uphill, and negative for surcharges downhill.

- **FORCE** n°

with n° = number of the activated force
 -n° = number of the deactivated force

- **MOMENT** n°

with n° = number of the activated moment
 -n° = number of the deactivated moment

- **SURCHARGE HORIZONTALE** z1 s1 z2 s2

with z1 = upper level
 s1 = pressure at z1 level
 z2 = lower level
 s2 = pressure at z2 level

Note: s1 and s2 are positive for pressures applied from downhill to uphill.

Earthworks:

- **FOUILLE** side z z1 S

with side = INTERIEUR (Downhill) or EXTERIEUR (Uphill)
 z = excavation level
 z1 = waterlevel
 S = horizontal surcharge applied onto the bottom of the excavation

Note: both lines FOUILLE INTERIEUR and FOUILLE EXTERIEUR may be used in the same phase. In that case, there is no parameter “side”. However, it is not possible to define two excavations on the same side in the same phase.

- **REMBLAI** side

with side = INTERIEUR (Downhill) or EXTERIEUR (Uphill) for the fill

- **DEFINITION** z Phi c PV_d PV_h Z_{water} k_h dk_h

with z = level of the top of the layer (in depths if z is increasing, in levels otherwise)
 Phi = friction angle
 c = cohesion
 PV_d = submerged soil weight
 PV_h = soil weight above water table
 Z_{water} = water level
 k_h = subgrade reaction coefficient
 dk_h = variation of the subgrade reaction coefficient

- **COEFF** k_a k_p c_a c_p k₀ k_d k_r

with k_a = horizontal active earth pressure coefficient
 k_p = horizontal passive earth pressure coefficient
 c_a = coefficient of active pressure applied to cohesion c
 c_p = coefficient of passive pressure applied to cohesion c
 k₀ = coefficient of earth pressure at rest
 k_d = unloading ratio
 k_r = reloading ratio

- **VARIATION** dc (optional)

with dc = variation of the layer cohesion per meter depth, from the top of the layer.

- **NOM** title

with title = name of the layer [maximum 20 letters]

- **SURCHARGE** S

with S = surcharge at groundlevel (on top of the fill)

- **BASE** zBase (only if the fill is disconnected from the top layer)

with zBase = bottom level of the fill

Note: the lines: REMBLAI, DEFINITION, COEFF, and possibly VARIATION, NOM, SURCHARGE and BASE always have to follow each other.

- **RISBERME** z a b

with z = bottom level of the berm
 a = superior width of the berm ($\neq 0$)
 b = inferior width of the berm

Note: the lines FOUILLE and RISBERME "work" together when defined in the same phase.

- **BERLINOISE** z

with z = bottom level of the sheeting installation

Note: the lines FOUILLE and BERLINOISE "work" together when defined in the same phase.

Note: This command is complementary to the command POUSSEE REDUITE, which should be defined in the initial phase.

Anchors-Wall:

- **TIRANT** n°

with n° = number of the activated anchor
 -n° = number of the deactivated anchor

- **BUTON** n°

with n° = number of the activated strut
 -n° = number of the deactivated strut

- **BUTON** n° K

with n° = number of the activated strut
 K = new stiffness value

Note: This option enables to define creep for a strut.

- **ENCASTRE** n°

with n° = number of the activated rotation spring
 -n° = number of the deactivated rotation spring

Modification of the wall properties (depending on the definition mode chosen for the wall):

- **BETON** concrete

with concrete = new Young's modulus for the wall material

- **RAIDEUR** EI Z₁ Z₂ stiff_vault

with EI = new product of inertia
 Z₁ = top level of the modified section
 Z₂ = bottom level of the modified section
 stiff_vault = vault stiffness or cylindrical rigidity

Raising of a wall defined using its product of inertia:

- **EXTENSION** n z EI width stiff_vault
with n = 1
z = top level of the raised section
EI = product of inertia of the raised section
width = elementary wall width
stiff_vault = vault stiffness or cylindrical rigidity

Modification of the properties of a soil layer:

- **COUCHE** side Z_c Phi c k_h dk_h
Side = INTERIEUR (Downhill) or EXTERIEUR (Uphill)
Z_c = level of the top of the layer (a default value is provided)
Phi = friction angle
c = cohesion
k_h = subgrade reaction coefficient
dk_h = variation of the subgrade reaction coefficient per meter depth
- **COEFF** k_a k_p c_a c_p k₀ k_d k_r
with k_a = horizontal active earth pressure coefficient
k_p = horizontal passive earth pressure coefficient
c_a = coefficient of active pressure applied to cohesion c
c_p = coefficient of passive pressure applied to cohesion c
k₀ = coefficient of earth pressure at rest
k_d = unloading ratio
k_r = reloading ratio

Note: lines COUCHE and COEFF have to follow each other.

- **GRADIENT** zp xp xa za
with xp = level (or depth) of the connection point with the water pressure curve of the previous phase
xa = level (or depth) of the connection point with the water pressure curve of the current phase i.e. the waterlevel of the action Excavation-Water (z1=za)
zp and za = water level provided for the action Excavation-Water in phase n-1, and water level provided for the action Excavation-Water in phase n ; the values in the combination {zp, xp, xa, za} determine whether the connection is "ascending" or "descending". xp and xa can have the same value (discontinuity of the water pressure curve)

Note: the lines FOUILLE and GRADIENT "work" together when defined in the same phase.

- **COMMENT** text
with text = comment

Note: this option enables to define comments in the datafile.

C.7. Calculation procedure

The schematic calculation procedure is illustrated on the figure below.

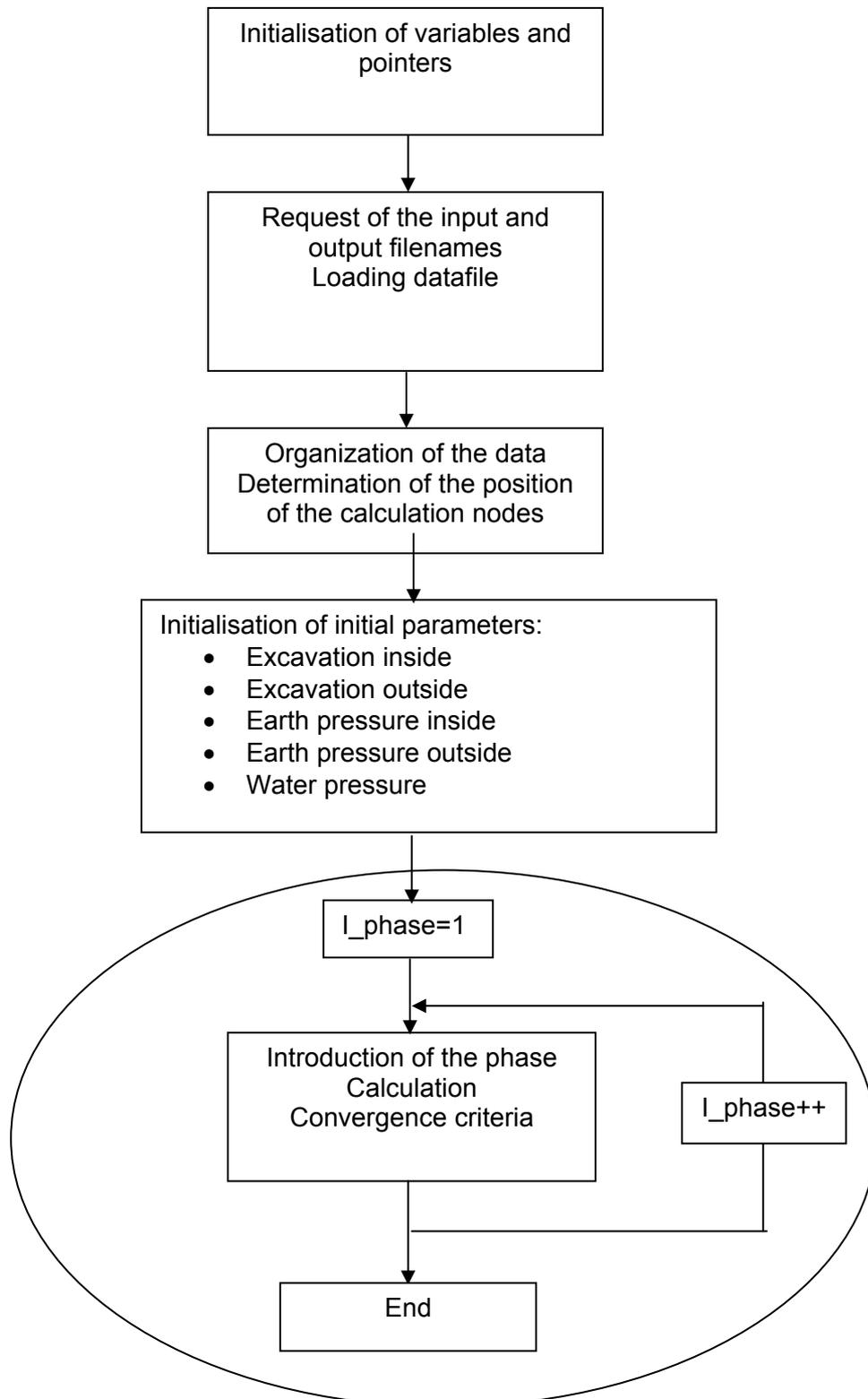


Figure C 52: K-REA general flow chart

The calculation sub-program is based on the following principle:

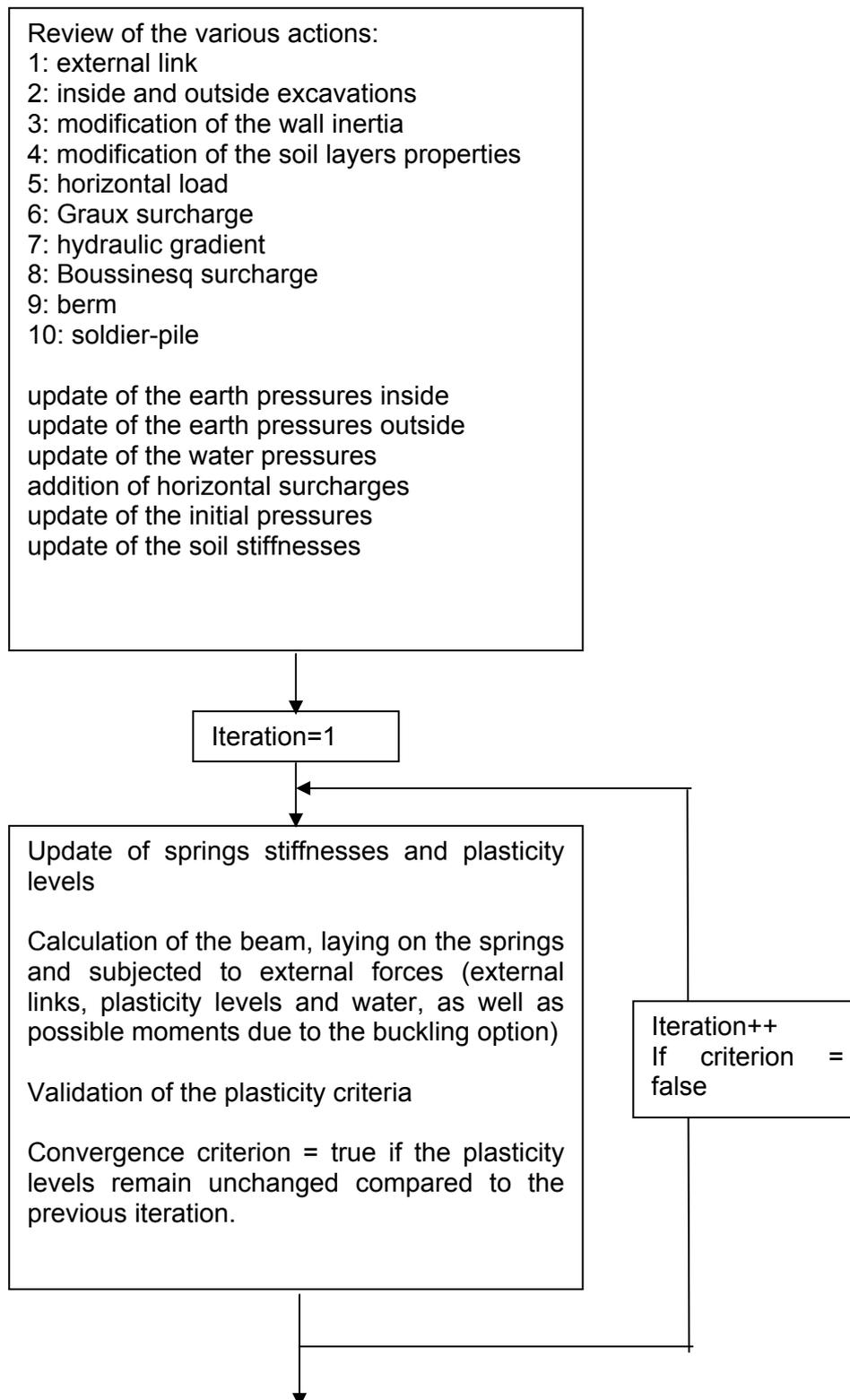


Figure C 53: Flow chart for the calculation sub-program

It usually takes 3 or 4 iterations for the calculation to converge.