The Use of Design Approaches with PLAXIS

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With the release of Plaxis 2D2011 a convenient facility is introduced named "Design Approach" to help Plaxis users set up an Ultimate Limit State (ULS) calculation. This facility is set up in a generic way such that any safety approach based on partial factors can be easily introduced (Eurocode 7, LRFD, etc.). Main advantages of this tool:

- more structured and efficient way of modelling since you can store a coherent set of partial factors (a "Design Approach (DA)") for loads and materials in one location. This DA can be easily applied during the definition of phases to make an ULS calculation in addition to a Serviceability Limit State (SLS) calculation;
- easy exchange of design approaches between different Plaxis projects due to the possibility to import/export a defined DA.

In this article it is explained in more detail how to work with this new facility. It does so by first discussing a number of issues relevant for setting up an ULS calculation in Plaxis. Hereafter an example project is presented in which a DA based on the Eurocode 7 [ref.1] is introduced.

Work flow for an ULS calculation in Plaxis

A possible work flow for an ULS calculation is presented in figure 1. It is suggested here to first go trough the "normal work flow" in order to set up the project and to create the stress history and SLS in Plaxis (before adding an ULS calculation). However this work order is not strictly necessary.

To illustrate the work flow for an ULS calculation more clearly and to explain the introduced term "material case" an example is presented later on in this article in which the Design Approach facility is used. Before starting on such an example it is important to realise the possible ways an ULS design can be performed in relation to the "normal" serviceability state calculations.

Relation of SLS and ULS calculations

In order to perform design calculations, new phases need to be defined in addition to the serviceability state calculations. There are two main schemes to perform design calculations in relation to serviceability calculations (Bauduin et al., 2000).

Scheme 1:

0. Initial phase		
1. Phase 1 (SLS)	>	4. Phase 4 (ULS)
2. Phase 2 (SLS)	>	5. Phase 5 (ULS)
3. Phase 3 (SLS)	>	6. Phase 6 (ULS)

In this scheme, the design calculations (ULS) are performed for each serviceability state calculation separately. This means that Phase 4 starts from Phase 1, Phase 5 starts from Phase 2, etc. Note that in this case a partial factor on a stiffness parameter is only used to calculate additional displacements as a result of stress redistribution due to the factored (higher) loads and the factored (reduced) strength parameters.

Scheme 2:

0. Initial phase	>	4. Phase 4 (ULS)
1. Phase 1 (SLS)		5. Phase 5 (ULS)
2. Phase 2 (SLS)		6. Phase 6 (ULS)
3. Phase 3 (SLS)		

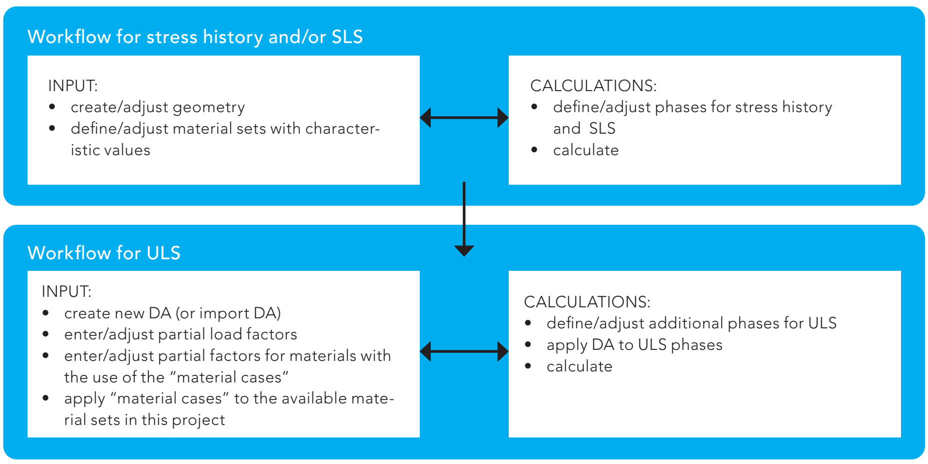

Figure 1: Workflow for stress history, SLS and ULS calculations

In this scheme, the design calculations (ULS) start from the initial situation and are performed subsequently. This means that Phase 4 starts from the Initial phase, Phase 5 starts from Phase 4, etc. In general it is recommended to establish the initial stress field from characteristic values of K0 (some exceptions however may occur), also see [ref.3].

Case: ULS design of an embedded sheet pile wall

This example presents the calculation of the Structural and Ground Limit State of an embedded sheetpile wall. The case is based on example 9.2 from [ref.2]. The geometry of the structure is shown in figure 2. The wall has a nominal excavation depth of 5 m and an additional excavation depth of 0.4 m (due to accidental overdig) is foreseen. The wall is supported by one row of anchors at an elevation level of -1.0 m (anchorage inclination is 10 degrees with horizontal). The free anchor length is 11 m and the length of the anchor body is approximately 6.5 m.

Input for the calculations

The ground profile consists of two layers (layer interface is at -4.0 m). The characteristic properties of these layers are presented in Table 1. In this example the long term situation is analysed so only effective stress parameters are presented.

For the different layers we use the following water conditions after excavation:

- layer A -> hydrostatic;
- layer B -> steady state situation (due to head difference as a result of the lowered water table inside the pit).

Other parameters used in the calculation:

- variable surcharge 10 kPa on active side;
- steel sheet pile: EA=3.675E6 kN/m, EI = 5E4 kNm2/m, no corrosion considered, weight 1.4 kN/m/m;
- anchor stiffness: EA = 16.5E3 kN/m;
- anchor pre-stress determined at 100 kN/m;
- the embedment depth of the sheetpile wall has already been determined at -12 m (total wall length 12 m).

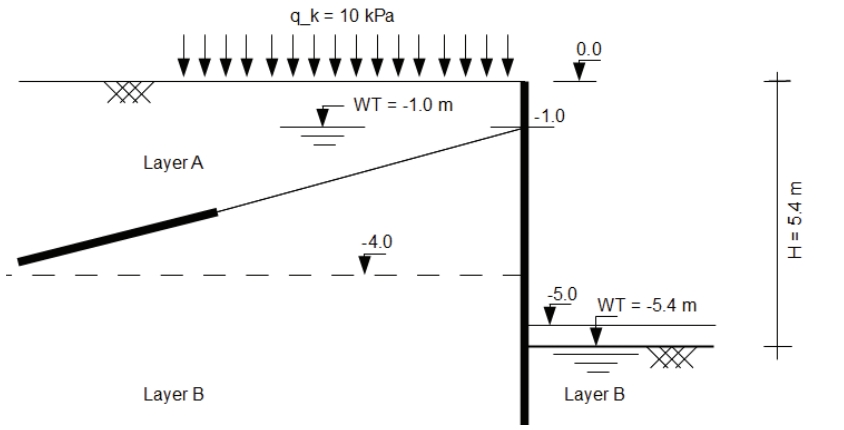

Figure 2: Geometry of the embedded sheet pile wall

		Layer A	Layer B
Material model	[-]	HS	HS
Drainage type	[-]	Drained	Drained
Gamma unsat/sat	[kN/m3]	18/20	20/20
E50_ref/Eoed_ref/Eur_ref	[kN/m2]	20000/20000/60000	12000/8000/36000
Power (m)	[-]	0.5	0.8
nu_ur	[-]	0.2	0.2
φ'	[degrees]	35	24
c'	[kPa]	1	5
Wall-ground interface (R_inter) active/passive	[-]	0.67	0.67
K0	[-]	0.5	0.95
k_x = k_y	[m/day]	1	0.001

Table 1: Characteristic soil properties

Geometry

The defined PLAXIS geometry is presented in figure 3.

Safety philosophy

The safety philosophy is introduced using the following starting points and assumptions:

- for this example it is chosen to use EC7-DA3 for the structural (STR) and ground (GEO) Limit State verification. At the end of this example however also the results of an alternative approach using EC7-DA2 are presented. The partial factors are taken from EC7, appendix A and presented in Table 2 and 3.;
- no partial factors are applied to the structural elements, so calculated structural forces need to be checked against allowable forces;
- it is assumed that all water levels are strictly controlled, so no additional safety surcharge is applied during ULS;
- accidental overdig is taken into account so an additional excavation depth is applied in the ULS calculations;
- in this example no stiffness variation for soil and structural elements is applied during the ULS calculations;
- in this example only an unfavourable load factor is used for the (variable) surcharge load, in practice it might also be necessary to investigate the effect of favourable load factors.

Staged construction

For the purpose of this example the drained stress history is used to analyse the SLS and ULS of the structure. The modelled phases are presented in Table 4.

Notes:

- to clearly define what is calculated in which phase, an addition is added in table 4 to each phase indicating its "state":
  - SLS: phase is used for either a stress-history and/or a SLS situation
  - ULS: phase is used for an ULS situation
- for the purpose of this example we have chosen to use both scheme 1 and 2 to perform design calculations in relation to serviceability calculations as explained before. In practice it is sufficient to choose only one.

Using the DA facility

It is assumed here that the geometry and the relevant phases representing the stress history and SLS are already defined. We will now use the DA facility to enter a coherent set of partial factors and the corresponding ULS phases. The work flow is explained in figures 4a to 4d. Note that the work flow is only explained for EC7-DA3. At the end of this example the workflow for EC7-DA2 is discussed in more detail.

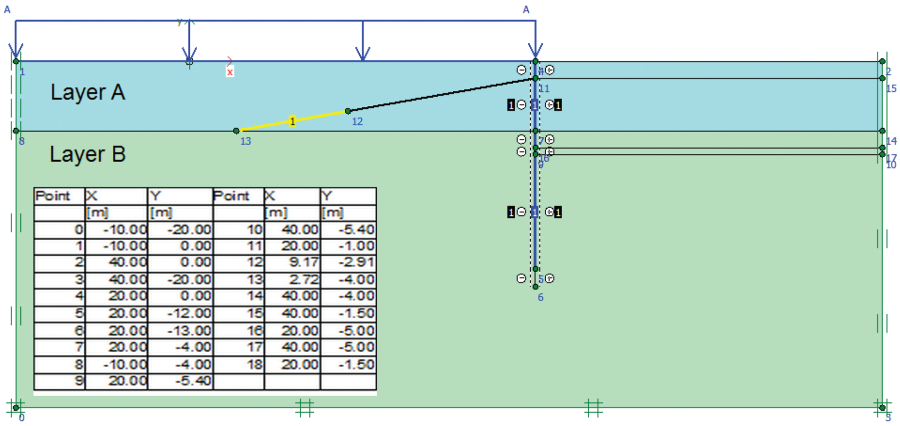

Figure 3: PLAXIS geometry

action		EC7-DA2	EC7-DA3
permanent	Unfavourable	1.35	1
	Favourable	1	1
variable	Unfavourable	1.5	1.3
	Favourable	0	0

Table 2: Partial factors on actions (STR/GEO LS, default values according to EC7, appendix A)

Soil parameter	EC7-DA2	EC7-DA3
Angle of shearing resistance (tan φ')	1	1.25
Effective cohesion	1	1.25
Undrained shear strength	1	1.4
Weight density	1	1

Table 3: Partial factors on soil parameters (STR/GEO LS, default values according to EC7, appendix A)

	phase	State	Phase no.	Start from	Calculation type
	Initial		0		K0
	Activate wall	SLS	1	0	Plastic drained
	Surcharge 10 kPa & excavate to -1 m	SLS	2	1	Plastic drained
	Activate anchor & pre-stress 100 kN/m	SLS	3	2	Plastic drained
	Full excavation and dewatering to -5.0 m	SLS	4	3	Plastic drained
	Full excavation and dewatering to -5.4 m (including over dig)	SLS	5	4	Plastic drained
Scheme 1	ULS – long term – phase 2	ULS	6	2	Plastic drained
	ULS – long term – phase 3	ULS	7	3	Plastic drained
	ULS – long term – phase 4	ULS	8	4	Plastic drained
	ULS – long term – phase 5	ULS	9	5	Plastic drained
Scheme 2	Surcharge 10 kPa & excavate to -1 m	ULS	10	1	Plastic drained
	Activate anchor & pre-stress 100 kN/m	ULS	11	10	Plastic drained
	Full excavation and dewatering to -5.0 m	ULS	12	11	Plastic drained
	Full excavation and dewatering to -5.4 m (including over dig)	ULS	13	12	Plastic drained

Table 4: Staged construction phases

Figure 4a
In Input open the DA facility by selecting "Loads/ Design Approaches".

In the DA facility window first a new name should be added for a new Design Approach (step 1). In case a DA already exists it can be imported from the global repository. A newly created DA can also be exported here to the global repository.

After creating "EC7 – GEO/STR LS – DA3" the partial factors for loads can be entered (step 2) according to Table 2. Note that a number of names of partial load factors have been predefined: "permanent unfavourable", "permanent favourable", variable unfavourable" and "variable favourable". The possibility exists to add more user defined values (in total up to 10 values). Here the values are entered for the 4 pre-defined partial factors corresponding to the chosen safety philosophy.

After entering the partial load factors we switch to the second tab sheet "partial factors for materials".

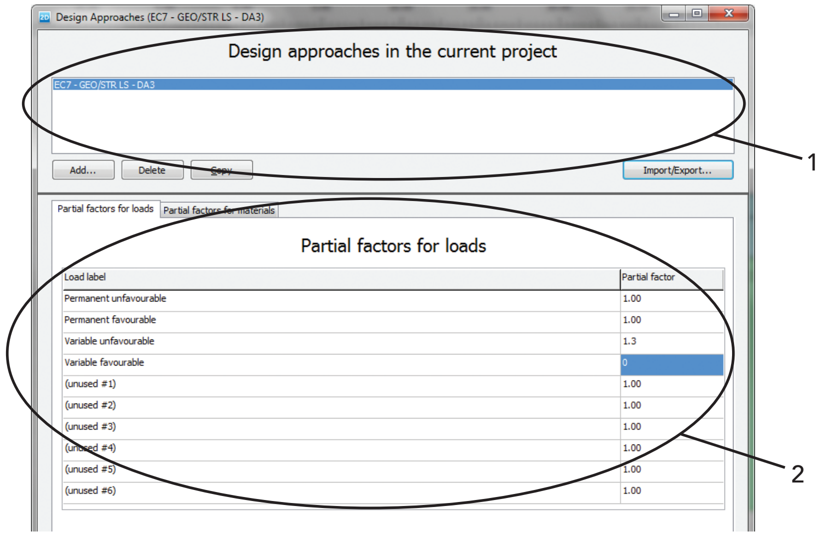

Figure 4a: DA facility, tab "partial factors for loads"

Figure 4b
Considering partial factors for materials, a first distinction is made between the different material models, because different models have different sets of parameters. If a project contains Mohr-Coulomb (MC) materials as well as Hardening Soil (HS) materials, separate sets of partial factors need to be defined for MC and for HS, even when the parameters to be factored happen to be the same (e.g. φ' and c').

A further distinction can be made between different cases of how the parameters or the materials are used. For example, when using a HS model, soil strength may be defined in terms of effective strength (using φ' and c', i.e. the Drained or Undrained A approach) or in terms of undrained strength (using su, i.e. the Undrained B or Undrained C approach), for which different partial factors may apply. Hence, separate sets of partial factors may be defined for a case named for example 'Effective strength' and a case named 'Undrained strength'.

Here we have chosen to define an Effective strength material case (step 1). For demonstration purposes here also an Undrained strength material case is created although this material case is not used in this example. This would however allow for a future analysis of an ULS for the (short term) undrained situation. We will use the HS model to represent soil behaviour so for both material cases we have specified the relevant partial factors for the HS model according to Table 3 (step 2).

After defining the material cases (step 1) and defining all partial factors for all relevant material models within a material case (step 2) we can add the material cases to the materials in the current project (step 3). We can do so at the right side of the tab "partial factors for materials" by selecting the desired material case from the drop down list. Note that it is not strictly necessary to enter values for the structural elements since per default unity values are applied for the partial factors. Once all relevant materials have been considered we can leave the DA facility.

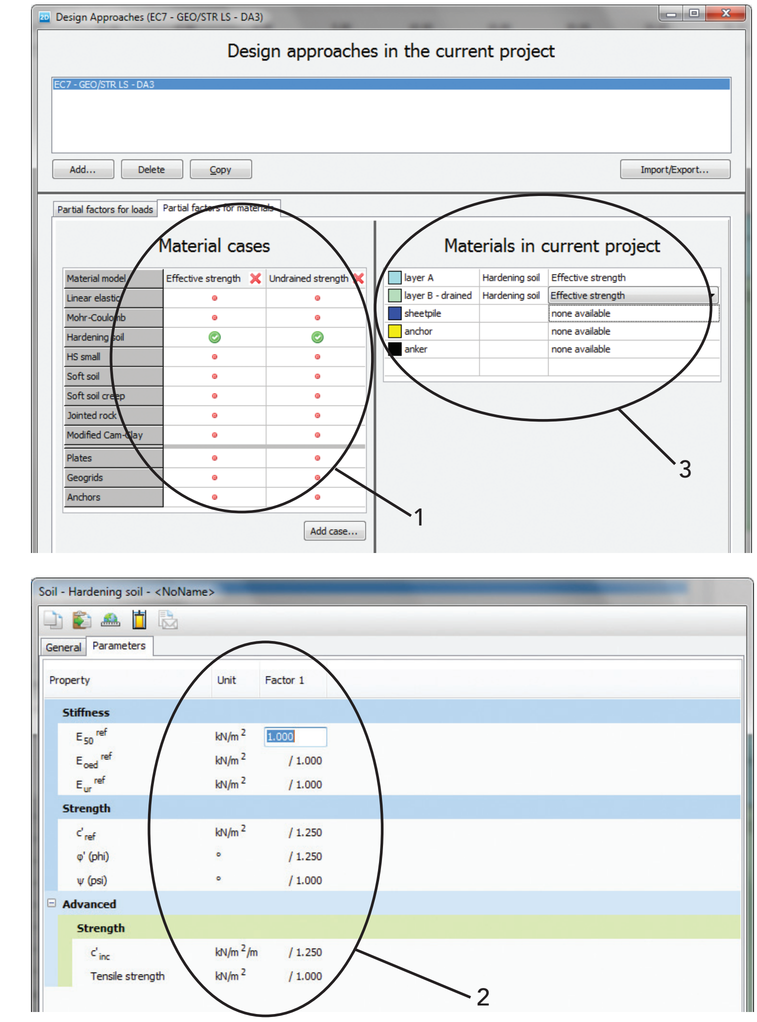

Figure 4b: DA facility, tab "partial factors for materials" and input window for HS model/partial factors

Figure 4c

The user should check the design values in the material properties window (step 1). If all Input is considered OK we can proceed to the Calculations window. In the Calculations window we can add additional ULS phases and then proceed to "define/staged construction" to define the desired ULS conditions.

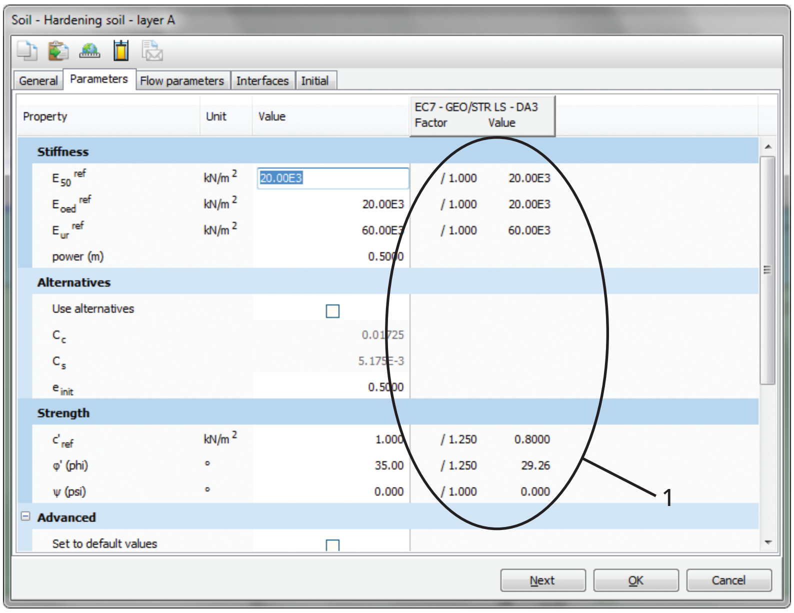

Figure 4c: Material properties window with reference value/partial factor/design value

Figure 4d

In the "define/staged construction" window you can select the desired DA at the top left (step 1). Now the coherent set of partial factors is applied to the loads and material sets in this phase. Please note that per default the load case "permanent unfavourable" is applied to all loads. By double clicking them you can change the load case to any other of the defined load cases within the applied DA (step 2). The user should check the design values used.

If required (for the ULS considered) you should also adjust the geometry and/or water conditions. When everything is defined go back to Calculations and calculate your project.

Results

In table 5 the results of the drained calculations have been presented.

Discussion

In this article the focus has been on discussing a number of issues relevant for setting up an ULS calculation in Plaxis and explaining the work flow required for working with the new DA facility. In the calculation example both EC7-DA2 and DA3 have been used in order to show the possibilities of the various EC7 approaches in Plaxis calculations. When looking at the calculation results some general observations are made:

- using scheme 1 or scheme 2 gives fairly similar values in structural forces for both EC7-DA2 and EC7-DA3 for this case, note however that differences may be larger in other situations;
- for a number of phases EC7-DA2 gives relatively large values for the anchor force compared to EC7-DA3, which is the result of the fact that the pre-stress value is entered as a characteristic value in EC7-DA3.

The user should realise that, although committees are being formed to set up more guidelines, most design Codes at this moment include only very general remarks on the use of FE calculations for ULS. So it may be expected that in the near future in a lot of situations (a continued) use has to be made of Engineering Judgement to decide how to deal with the ULS concept in a FE calculation. With the release of the DA facility, Plaxis hopes to contribute to the further development of a solid design strategy using FEM. Due to this reason feedback on the use of this tool is highly appreciated. Please send your comments and remarks to our support department: support@plaxis.com.

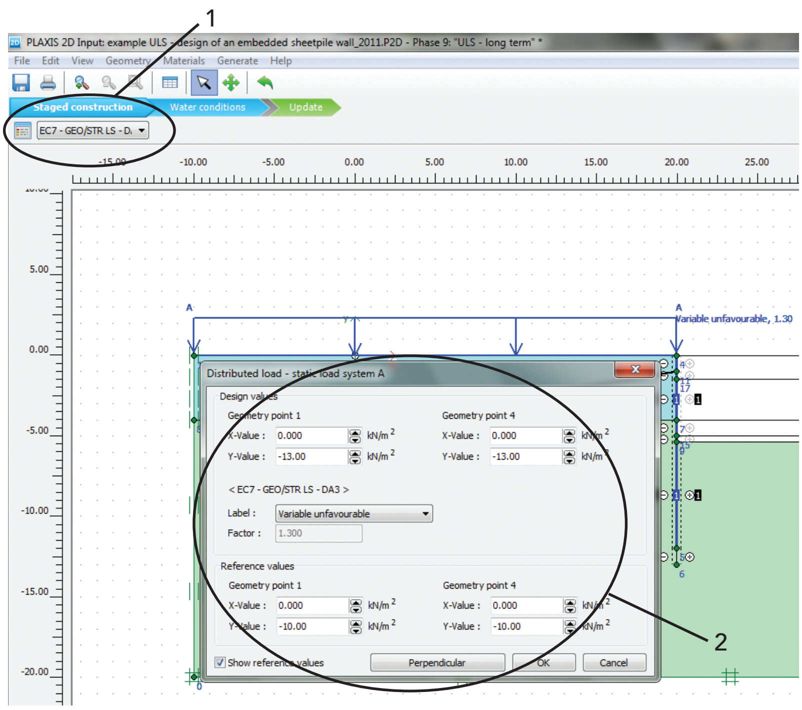

Figure 4d: Applying the DA in the define/staged construction window

				EC7-DA3			EC7-DA2 (*)	
	phase	State	Phase no.	Max. hor. wall def. [mm]	Max. anchor force [kN/m]	Max. bending moment [kNm/m]	Max. anchor force [kN/m]	Max. bending moment [kNm/m]
	Initial	SLS	0	-				
	Activate wall	SLS	1	-	-	-	-	-
	Surcharge 10 kPa & excavate to -1 m	SLS	2	1	-	4	-	4
	Activate anchor & pre-stress 100 kN/m	SLS	3	-10	100	-34	100	-34
	Full excavation and dewatering to -5.0 m	SLS	4	50	119	-173	119	-173
	Full excavation and dewatering to -5.4 m (including over dig)	SLS	5	70	130	-216	130	-216
Scheme 1	ULS – long term – phase 2	ULS	6	1	-	6	-	1.35 * 4 = 5
	ULS – long term – phase 3	ULS	7	-10	100	-36	1.35 * 100 = 135	1.35 * -34 = -46
	ULS – long term – phase 4	ULS	8	80	136	-231	1.35 * 120 = 162	1.35 * -177 = -239
	ULS – long term – phase 5	ULS	9	130	161	-321	1.35 * 130 = 176	1.35 * -220 = -297
Scheme 2	Surcharge 10 kPa & excavate to -1 m	ULS	10	1	-	7	-	1.35 * 4 = 5
	Activate anchor & pre-stress 100 kN/m	ULS	11	-10	100	-28	1.35 * 100 = 135	1.35 * -33 = -45
	Full excavation and dewatering to -5.0 m	ULS	12	100	143	-249	1.35 * 120 = 162	1.35 * -175 = -236
	Full excavation and dewatering to -5.4 m (including over dig)	ULS	13	150	165	-332	1.35 * 131 = 177	1.35 * -217 = -293

Table 5: Calculation results

(*) Note on EC7-DA2 calculation

In this approach the actions from the soil on the wall ("geotechnical actions") are calculated using characteristic values for the soil properties. A partial factor should now be applied to these "geotechnical actions". However within a FE model this approach is not possible. Eurocode 7 however also allows within EC7-DA2 to apply the partial factors directly to the action effects (such as the bending moments in the wall and the anchor forces). In [ref.2] the following practical method is used: a factor of 1 is used for the permanent unfavourable actions (instead of 1.35) and a factor of 1.5 / 1.35 = 1.11 for the variable unfavourable actions (instead of 1.5). The actions effects should now be scaled up with a factor of 1.35.

References

- Bauduin C., De Vos M., Simpson B (2000 International Workshop on Limit State Design in Geotechnical Engineering. Melbourne, Australia.
- Eurocode 7 (2004): Geotechnical design – Part 1: General rules (EN1997-1)
- Frank R., Bauduin C., Driscoll R., Kavvadas M., Krebs Ovesen N., Orr T., Schuppener B. (2004) Designer's Guide to EN1997-1 Eurocode 7: Geotechnical design – General rules