

Application Note - Gravity Wall Analysis

1 Introduction

This note describes the typical steps followed in setting up and analysing a gravity wall stability problem with LimitState:GEO. It also describes the analysis of a trench excavation in front of the wall.

All files used in this note are available in a zip file that can be downloaded from http://www.limitstate.com/files/application-notes/LSGAN3/gravity_wall_analysis.zip

Familiarity with the use of LimitState:GEO is assumed. The reader is referred to the user manual for further information on any features discussed in this note.

2 Problem definition

The specified problem depicted in Figure 1 involves analysis of an 8 m high wall with vertical back retaining 6 m of dense gravel overlain by 2 m of loose sand. The surface of the sand is level with the top of the wall and supports a surcharge of 5 kN/m². The wall and the layer of dense gravel are underlain by stiff clay. The problem is to be checked against Eurocode 7 Design Approach 1 Combination 1 and 2 requirements for long and short term conditions. Passive resistance of the soil in front of the wall is to be included.

The main problem geometry is available as a series of co-ordinates. The modelled soils and associated parameters are listed in Tables 1, 2 and 4 in Section 3.

Details of how to set up the problem manually are given in Section 3. To skip direct to the analysis stage, please go to Section 4.

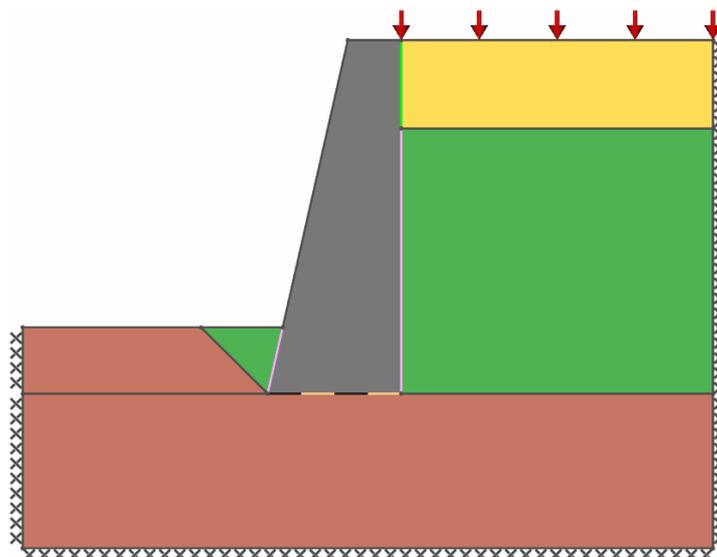


Figure 1: Gravity wall problem geometry

3 Setting up problem geometry, materials and loading

In this example, the LimitState:GEO model was created using the built in gravity wall wizard:

1. Start the wizard using **File/New.../Gravity Wall Project**. You will be asked to complete tables with geometry, properties etc. in order to define the problem. In the **Project** tab, enter any general information about the project. Then click **Next>**.
2. In the **Geometry** tab, define the problem geometry using the parameters shown in Figure 2. Click **Next>**.

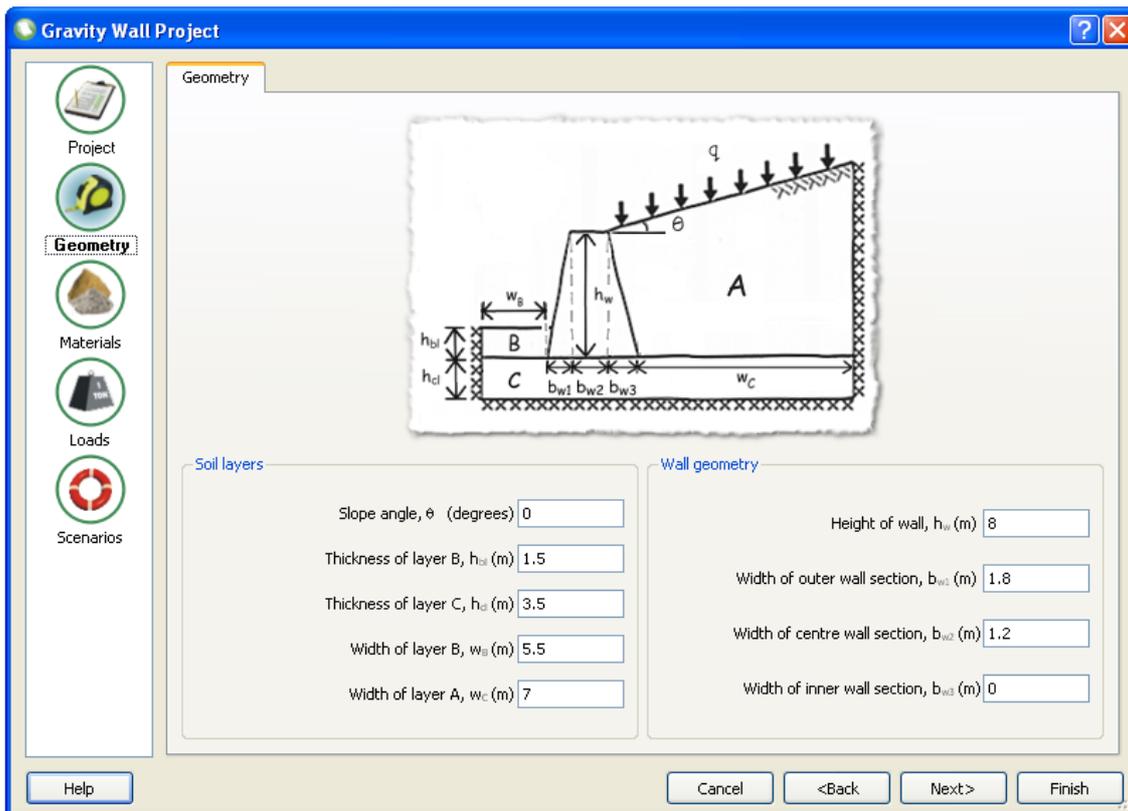


Figure 2: Gravity wall wizard - geometry section

3. Specify the properties of the soil layers with the values as listed in Table 1 and click **Next>**. For Soil Layers A and B, a new material is to be created. For Soil Layer C the existing default material *Stiff Clay* is used. When specifying properties of Layer B choose the **Use Layer A material** option. Note that ϕ' in Table 1 and elsewhere in this example is conservatively set as the critical state angle of shearing resistance i.e. $\phi' = \phi'_{crit}$.

Soil layer	Soil name	Material drainage behaviour	c_u (kN/m ²)	c' (kN/m ²)	ϕ'	γ (kN/m ³)	γ_{sat} (kN/m ³)
A	Dense Gravel	Always drained	-	0	37°	18	21
B	Dense Gravel	Always drained	-	0	37°	18	21
C	Stiff Clay (default)	Drained/undrained	120	4	22°	21	21

Table 1: Soil properties

4. Use the default material properties of the wall (as listed in Table 2) and click **Next>**.
The wall itself is modelled as a Mohr-Coulomb material where c_u represents the shear strength of the wall

and allows LimitState:GEO to model internal wall failure by shearing. However, if internal structural failure is not of interest, then for computational efficiency use of a *Rigid* material is recommended. This can be applied to the wall using drag and drop after finishing the initial set up with the wizard. For more information on modelling resistance of the structures in LimitState:GEO, see Technical Note: **Modelling Structural Resistance LS-G-TN4**

The values of the multipliers on the soil/wall interface properties specified in the Wizard are not relevant to this example since a different approach for their creation is used. See box below for more information.

Material Name	c_u (kN/m ²)	γ (kN/m ²)	Multiplier on $\tan \phi$	Multiplier on c', c_u
Wall	5000	24	1	1

Table 2: Wall and soil-wall interface properties

Key modelling concept: *Soil/structure interface properties in LimitState:GEO*

Often when dealing with soil/structure interaction problems, it is desirable to define a soil/structure interface property that is a function of the adjacent soil. A typical example is a retaining wall where the interface adhesion and friction will be some multiplier (≤ 1) of the adjacent soil strengths. This may be set using **Derived Mohr Coulomb Material** type and entering multipliers for cohesion (c' , c_u) and shear resistance ($\tan \phi'$) in the **Property Editor**. If the Wizard is used, this material is automatically applied to all the soil-structure interfaces using the specified multipliers.

Note that:

- If the interface friction property is to be a function of ϕ' rather than $\tan \phi'$, a standard material type (e.g. **Mohr Coulomb**) instead of a derived material type should be used.
- If the interface friction property is to be a function of ϕ_{crit} but the actual value used for the adjacent soil in LimitState:GEO is not a critical state angle of shearing resistance but e.g. a peak value, then it will be necessary either to make a modification to the multiplier or to use a standard material as above.

5. In the **Loads** tab, set the **Variable vertical surcharge pressure** to 5 kN/m² and click **Next**>.
6. In the **Scenarios** tab, application of partial factor sets and long/short term analysis modes can be specified. In this example Eurocode 7 Design Approach 1 Combinations 1 and 2 (EC7 DA1/1 and DA1/2) for both short and long term analyses are to be checked. Select **Multiple scenarios** and create the four Scenarios as defined in the first two columns of Table 3. Click **Finish**. (NB For simplicity, the pore pressures in the clay are assumed to be zero in the drained analyses, assuming the water table lies a short distance beneath the problem geometry.)
7. Switch on the **Grid** using the **View/Show Grid** function or .
8. Add the layer of loose sand overlying the dense gravel. Draw a horizontal line with $y = 9.5$ m from the back of the wall to the right hand boundary of the model using **Draw/Line** or  (the y -axis with heights is displayed on the left side of the model). Apply the pre-defined **Loose Sand** material to the new upper

Scenario	Scenario details	Adequacy Factor
1	EC7 DA1/1, long term analysis	1.360
2	EC7 DA1/2, long term analysis	1.028
3	EC7 DA1/1, short term analysis	3.193
4	EC7 DA1/2, short term analysis	2.374

Table 3: Scenarios and analysis results

soil layer by drag and drop. (Whilst dropping the material, the **combined material** dialog will appear. Select the **Replace** option.)

9. Soil/structure interface properties were determined using the following assumptions:

- Soil/wall friction angle $\delta = (2/3)\phi'_{crit}$
- Soil/wall base adhesion $c_w = c_u$ (short term analysis)
- Soil/wall base adhesion $c'_w = 0c'$ (long term analysis)

Interface materials automatically created by the Wizard therefore have to be replaced as explained in the box above. Create the required new materials for the soil-wall interfaces using **Tools/Create New Material**. Use the properties as listed in Table 4.

Soil/wall interface	Material type	Material drainage behaviour	c' (kN/m ²)	ϕ' (kN/m ²)	c_u	γ (kN/m ³)	γ_{sat} (kN/m ³)
loose sand/wall	Mohr-Coulomb	Always drained	0	20.0°	-	0	0
dense gravel/wall	Mohr-Coulomb	Always drained	0	24.7°	-	0	0
stiff clay/wall	Mohr-Coulomb	Drained/undrained	0	14.7°	120	0	0

Table 4: Soil/wall interface properties

10. Apply the created materials to the appropriate boundaries by drag and drop. (Whilst dropping the material, the **combined material** dialog will appear. Select the **Replace** option.)
11. In order allow the modelling of a possible tension crack, apply the default *No-Tension Cutoff* material (available in the **Material Explorer**) to the stiff clay/wall boundary (i.e. the wall base). Whilst dropping the material, the **combined material** dialog will appear. Select the **Add** option. This will give no tensile strength to the clay/wall interface. Although in this problem it will have very minor influence on the result it is good practice to add a *No-tension cutoff* material to the all interfaces of solid objects if they are bounded by a material possessing cohesion.

Key modelling concept: *Cohesive soil/structure interface tensile strength in LimitState:GEO*

When a cohesive material is modelled using the Mohr-Coulomb failure envelope, the mathematical representation may give the material an unrealistically large tensile strength. For many problems dominated by compressive forces this is not an issue. However for e.g. slope stability or retaining wall problems, unrealistic tensile stresses may arise. To model such cases, it is possible to model a **combined material** with both cohesive and tension cutoff properties. The latter is specified using a *Cutoff* material. The property defined is the normal stress at which tensile failure occurs and may be specified in the **Property Editor**. The predefined *No-Tension Cutoff* material has a zero tensile cutoff.

12. Create a block of Dense Gravel in front of the wall. Create a **Vertex** using the toolbar function at coordinates ($x = 4.0$, $y = 5.0$). Draw a line (using) connecting the created **Vertex** and the toe of the wall to split the left hand surface soil layer into two parts. Apply the pre-defined **Stiff Clay** material to the left hand **Solid** of the two (the model should now look similar to Figure 1, apart from choice of colours).
13. Apply the **Adequacy Factor** to an appropriate surcharge load and/or body force. In this example the **Adequacy Factor** is simultaneously applied to the surcharge load, weight of the *Loose sand* and weight of the retained *Dense gravel*. In the **Property Editor** under **Self Weight Loading**, set the **Adequacy** of the **Solids** containing the *Loose sand* and *Dense gravel* to *True*. Also set the corresponding **Loading Type** to *Unfavourable*. It is assumed that the wall weight is favourable in this problem (though this should be checked following an analysis). Set the **Loading Type** of the Wall **Solid** to *Favourable*.
14. Set the **Nodal Density** to **Fine**.

4 Problem Analysis

The LimitState:GEO model may be set up manually as described in Section 3. Alternatively the complete model may be loaded by opening the file [gravity_wall.geo](#).

Click **Analysis/Solve** or to obtain the **Adequacy Factors** listed in Table 3. The critical scenario (depicted in Figure 3) is found to be the **Long term analysis** with $DA1/2$ which has an **Adequacy Factor** of 1.028. A value above 1.0 means that in Eurocode 7 terms the design is safe. The additional margin of safety (or overdesign factor) of 1.028 is given in terms of the load (or loads) to which the **Adequacy Factor** was assigned (see Step 13 in Section 3).

If analysis results are required in terms of an alternative factor of safety (F.O.S.) such as factor on soil strength see the LimitState:GEO manual Section 8.2.3 and/or the Application Note: **Gabion Wall Analysis LS-G-AN2** for more information. Note that the Eurocode 7 $DA1/1$ analysis is carried out with factors on actions applied at source by LimitState:GEO. In this problem, with cohesionless backfill, and for the identified failure mode this is also essentially equivalent to applying the factors to the actions as measured at the soil/wall interface (i.e. the active earth pressures). Further discussion on this issue may be found in the LimitState:GEO manual Section 8.3.2.

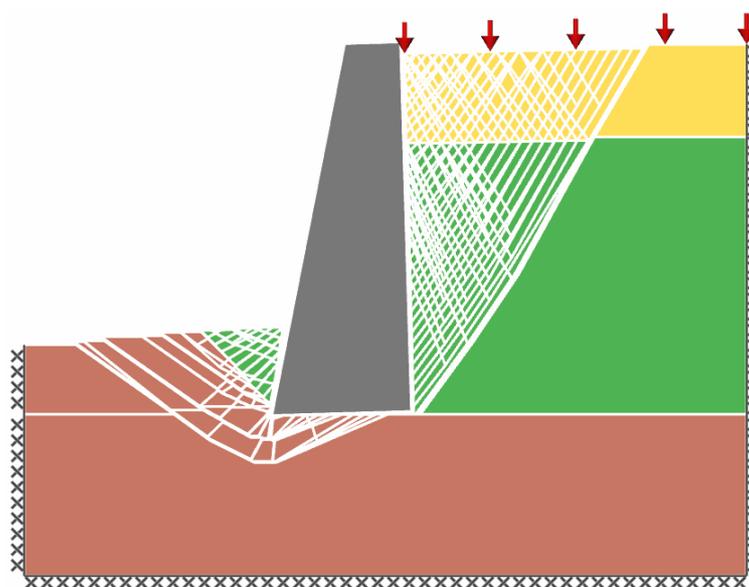


Figure 3: Critical failure mechanism for analysed problem

5 Further analysis - trench excavation

The model is now altered by the excavation of a 4.5 m deep trench, 3.5 m away from the front face of the gravity wall as depicted in Figure 4.

1. Unlock the project using .
2. Draw a trench using **Draw/Solid/Polygon** or  function. The co-ordinates of the diagonally opposite vertices used in the example are: $x=1.0$, $y=5.0$ and $x=2.0$, $y=0.5$. It is recommended to use **Grid** when drawing the trench.
3. Left click on the drawn rectangles in turn and press Delete (on the keyboard).
4. Apply the **Adequacy Factor** to an appropriate body force. Here in addition to the previous settings the **Adequacy Factor** is also to be applied to the weight of the gravity wall since increasing its weight decreases the stability of the model. Set the **Loading type** on the wall as *Unfavourable* and the **Adequacy** setting to *True*.
5. In this problem it will be assumed that only the short term DA1/2 analysis is of interest, since this is now a global stability problem for which DA1/1 is less suited. Remove the long term DA1/1 and DA1/2 and the short term DA1/1 analysis scenarios from the list of scenarios to be performed by LimitState:GEO using the **Analysis/Scenario manager.../ <Delete...>** function.
6. Click **Solve** or .

This returns an **Adequacy Factor** of 1.38 for the DA1/2 scenario (compare with 3.19 for the problem prior to the trench excavation). Since this value is above 1.0 the structure is safe in the short term. The complete altered model as defined above is provided in [gravity-wall-trench.geo](#). (Note that for the identified failure mode, it could be argued that the weight of *all* soil bodies should have been set to *Unfavourable*. However this is not relevant in a DA1/2 analysis, but would affect a DA1/1 analysis).

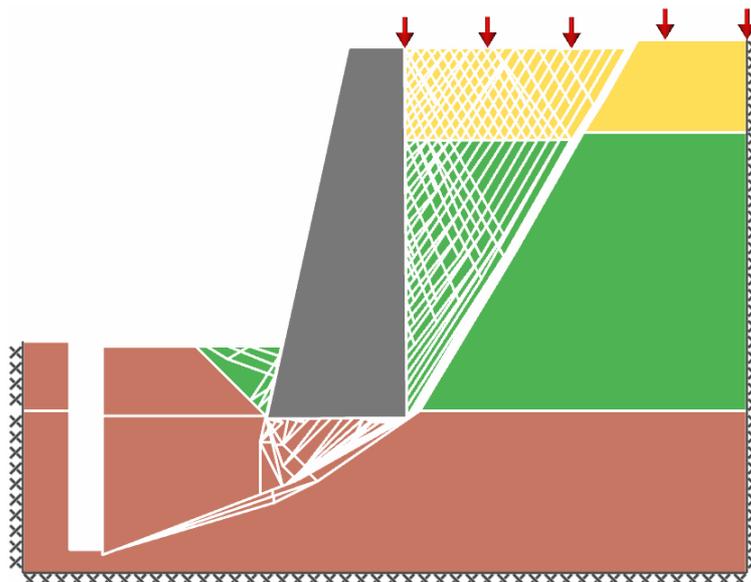


Figure 4: Failure mechanism for the problem after trench excavation

6 Frequently Asked Questions

1. *Why does LimitState:GEO provide only one failure mode and an associated **Adequacy Factor** whilst conventional limit equilibrium based software performs checks for several different standard failure modes?*

LimitState:GEO identifies the critical failure mode (which may not be a standard mode) from millions of potential mechanisms instead of checking a few pre-specified collapse modes. Thus only the critical solution is returned.

2. *How can the wall geometry be changed?*

The geometry of the wall can be easily modified after finishing work with the wizard e.g. by adding new vertices and changing co-ordinates of the existing ones. New geometry can be added to the model using **Polygon**  tool. Alternatively the **Wizard** for Stem Walls might be used. For more complex structures it is recommended to import the geometry from a dxf file.

3. *How accurate will the solution be?*

The accuracy of the solution depends on the resolution of the nodes at the failure mechanism. The accuracy can be refined either by increasing the **Nodal Density** or by optimizing the nodal distribution. For more information on how to improve solution accuracy see the LimitState:GEO manual Section 8.4.

For more information: www.limitstate.com/geo