

Application Note - Reinforced Soil Analysis

1 Introduction

This note describes the typical steps followed in setting up and analysing a reinforced soil problem with LimitState:GEO.

All files used in this note are available in a zip file that can be downloaded from http://www.limitstate.com/files/application-notes/LSGAN6/reinforced_soil_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 the construction of a reinforced soil wall to a height of 6m in a stratum of sandy silt. The wall is formed of compacted fill with the placement of 4m long geotextile layers at 1 m vertical intervals. The facing skin is formed of concrete panels seated on a strip foundation. The geotextile has a design tensile strength of 35 kN/m and pullout coefficient $C_{po} = 0.8$ for the fill material. A 2m wide variable surface load of 20 kN/m² is applied 1m back from the top of the wall.

The main problem geometry is available as a dxf file ([reinforced_soil.dxf](#)). The modelled soils and associated parameters are listed in Table 1.

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.

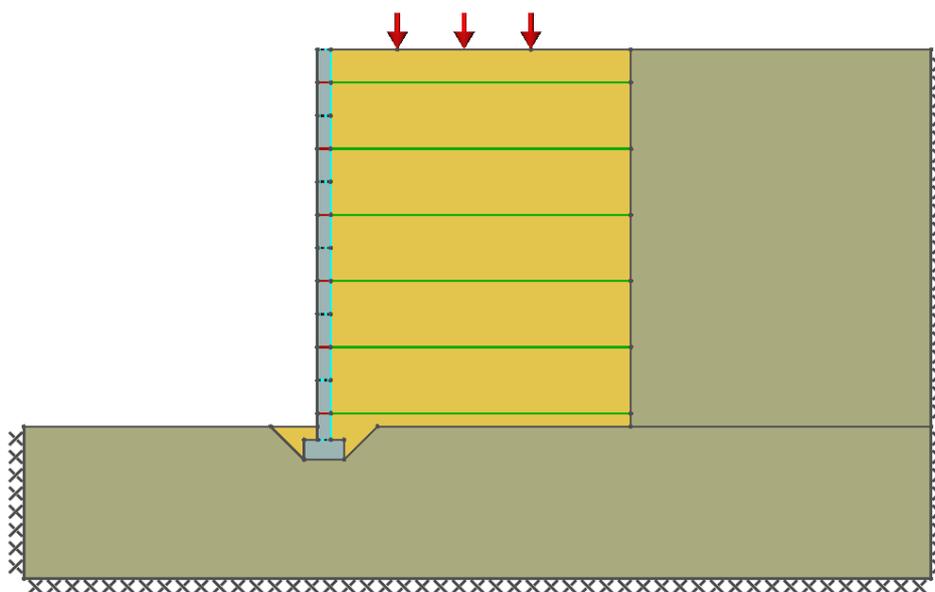


Figure 1: Problem geometry

3 Setting up problem geometry, materials and loading

Creation of the LimitState:GEO model was undertaken in the following stages:

- 1) Import the geometry from [reinforced_soil.dxf](#) using the **File/Import from Dxf...** function. Remove any residual construction lines using **Draw/Construction Line/Clear All** since these will not be needed.
- 2) Define soil properties as listed in Table 1. Create materials using **Tools/Create New Material...** and apply to the appropriate **Solids** by drag and drop.

Material name	Material type	Material drainage behaviour	c_u (kN/m ²)	c' (kN/m ²)	ϕ'	γ (kN/m ³)	γ_{sat} (kN/m ³)
Compacted backfill	Mohr-Coulomb	Always drained	-	0	32°	18	21.5
Sandy silt	Mohr-Coulomb	Always drained	-	0	28°	19	21

Table 1: Soil properties

Alternatively for this example, these and other relevant pre-defined materials may be imported from [reinforced_earth.csv](#) using the **Tools/ Import Materials...** function. Materials are named by the type of **Solid** or **Boundary** they should be applied to.

Key modelling concept: *modelling facing skin in LimitState:GEO.*

It is a common practice in design of reinforced earth structures to assume no contribution of the facing skin to the resistance. To allow for this in LimitState:GEO, the horizontal interfaces between facing units have to be defined as **combined material** consisting of **Frictionless** and **No-Tension Cutoff** material. This will allow for free relative sliding and rotation of facing blocks.

To create a **combined material** two materials can be dragged and dropped onto the same object. Whilst dropping the second one, the **combined material** dialog will appear. Select the **Add** option.

- 3) Define properties of the facing skin. Create materials with properties as listed in Table 2 using **Tools/Create New Material...** and apply together with default material *No-Tension Cutoff* to the appropriate **Solids** and **Boundaries** by drag and drop. The backfill/facing panel interface is to be modelled as *Frictionless*, and the horizontal interfaces between adjacent panels are to be modelled with the combined material *Frictionless* and *No-Tension Cutoff*. Note that as an alternative to drag and drop it can be quicker to select multiple **Boundaries** or **Solids** using the rectangle select tool (see the LimitState:GEO manual Section 15.7.2)

Material name	Material type	c_u (kN/m ²)	c' (kN/m ²)	ϕ'	γ (kN/m ³)	γ_{sat} (kN/m ³)
Facing panel	Rigid	-	-	-	24	24
Frictionless	Mohr-Coulomb	0	0	0	0	0

Table 2: Facing panel material properties

- 4) Define properties of the geotextile as listed in Table 3 using **Tools/Create New Material...** Apply created materials to the appropriate **Boundaries** by drag and drop. The *Geotextile* material is to be assigned to the reinforcement within the backfill, while the *Geotextile tensile strength* material is to be assigned to the reinforcement within the facing panels.

Material name	Material type	Application	T_c (kN/m ²)	T_q (-)	N_c (kN/m ²)	N_q (-)	M_p (kN.m/m)
Geotextile	Engineered Element (1D)	Other	0	0.25	0	0	1e+30
Geotextile tensile strength	Engineered Element (1D)	Other	175	0	1000	0	1e+30

Table 3: Geotextile material properties

Key modelling concept: *modelling soil reinforcement in LimitState:GEO*

Soil reinforcement is typically modelled using the **Engineered Element** material in LimitState:GEO. This is a material that can be applied to **Boundaries** to provide essentially one dimensional (in section) objects such as geotextiles or reinforcing strips. The special properties of an **Engineered Element** allow soil to flow through or past it if required as would be expected of e.g. reinforcing strip. It can also be considered a good approximation to the fully flexible behaviour of geotextiles.

The parameters defining the behaviour of an Engineered element are the Pullout Factors T_c and T_q , the Lateral factors N_c and N_q and the plastic moment M_p . The theoretical background to these parameters is given in the LimitState:GEO manual Section 6.1.5.

The pullout resistance T will normally be selected based on experimental evidence, or on appropriate theory for the situation. LimitState:GEO allows T to be computed as linear function of the nominal vertical effective stress at the element as follows:

$$T = T_c + T_q \sigma'_v \tag{1}$$

In this example, T_c , as the property of the geotextile in the facing skin (see dark red boundaries in Figure 1) is also used to represent the tensile strength of the geotextile and/or strength of the connection between the geotextile and the facing panel. In the former case it is assumed that geotextile can fail in tension only at the connection with the facing skin (which is where the highest tensile force will typically be found). T_c as the tensile strength property is defined as follows:

$$T_c = T_t/d \tag{2}$$

Where T_t is the tensile resistance of the geotextile or the connection strength and d is the length of the geotextile modelled within the facing skin in the model.

In this note it was assumed that the pullout resistance of the geotextile within the backfill is expressed in the form of:

$$T = 2\sigma'_v \times C_{po} \times \tan\phi' \tag{3}$$

Thus the pullout parameters to be specified in LimitState:GEO are: $T_c = 0$ and $T_q = \frac{C_{po} \times \tan 32}{2} = 0.25$. The pullout resistance of the geotextile within the facing panel is defined from its tensile strength. Thus the pullout parameters to be specified in LimitState:GEO are: $T_c = 35/0.2 = 175 \text{ kN/m}^2$ and $T_q = 0$. To prevent lateral movement of the reinforcement within the facing panel, the lateral resistance N_c was set to a nominal high value (1000 kN/m^2). Note that these values are unaffected by any partial factors specified in the **Scenario Manager**.

- 5) Specify the applied variable surface load of 20 kN/m^2 by selecting the relevant **Boundary** and by using **Loads - Variable - Normal** via the **Property Editor**. Set the **Loading Type** for this to *Unfavourable*.
- 6) Set the boundary conditions on the base and sides of the model to *Fixed*.
- 7) Apply the **Adequacy factor** to an appropriate surcharge load and/or body force. (Click on the load or body and set **Adequacy** to *True* in the **Property Editor**). In this example it is recommended that the **Adequacy Factor** be simultaneously applied to the surcharge load, weight of the compacted fill and weight of the retained native soil. Set the **Loading Type** for these **Solids** to *Unfavourable*.
- 8) Choose the required Partial factor set using **Scenario Manager**. In this example the problem will be investigated using Unit partial factors. Select *Unity* from the drop down box. Also tick the **Long term analysis** box to specify a drained analysis. (N.B. since all materials have been defined as *Always drained* this is not strictly necessary but is good practice).
- 9) Set the **Nodal Density** to **Fine**.

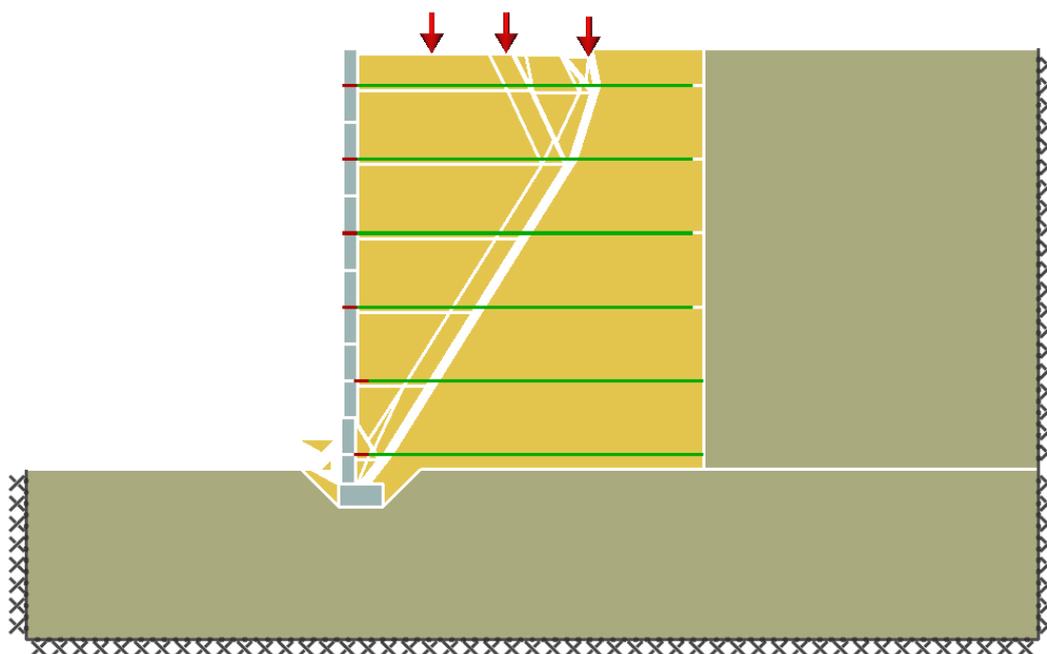


Figure 2: Failure mode for the problem

4 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 [reinforced_soil.geo](#).

Click **Analysis/Solve** or  to obtain an **Adequacy Factor** of 2.009. The identified critical failure mode involves tensile failure of the bottom two reinforcement elements while the remaining reinforcement is pulling out of the soil behind the identified soil wedges. Note that the analysis in LimitState:GEO is fully general and can handle multiple wedges as shown in this example. An **Adequacy factor** above 1.0 means that the structure is safe. The additional margin of safety (or overdesign factor) of 2.009 is given in terms of the load(s) to which the **Adequacy Factor** was assigned.

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.

5 Frequently Asked Questions

- 1) *Why does LimitState:GEO provide only one failure mode and an associated **Adequacy Factor** whilst in conventional analysis several different standard failure modes are checked?*

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) *Is it possible to model tensile strength of the geotextile more generally so that it can fail in tension anywhere along its length?*

It is intended to implement this feature in the next version of LimitState:GEO. However when a conventional two wedge analysis is considered, the maximum tensile force is expected to occur within the wedge as a constant value and therefore to include the connection with the facing panel as is modelled in this example.

- 3) *How do I model reinforcing strips in LimitState:GEO?*

Reinforcing strips can be modelled in the same way as geotextiles. Note however that properties of the strip are to be specified per m width. Thus instead of real strip properties, the average properties per m width have to be specified.

- 4) *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