LS-G-AN1
Software: LimitState:GEO 2.0e
Date: July 2010

Application Note - Slope Stability Analysis Worked Example

1 Introduction

This note describes the typical steps followed in setting up and analysing a slope stability problem with LimitState:GEO. It also highlights some of the differences in approach to that adopted by the limit equilibrium method of slices.

All files used in this note are available in a zip file that can be downloaded from from:

http://www.limitstate.com/files/application-notes/LSGAN1/slope_stability_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 involves the construction of a building into a slope formed within a stratum of mudstone. A 3m deep weathered zone is assumed at the surface, with a water table running approximately parallel to and below the slope surface as shown in Figure 1. Part of the building consists of a retaining wall constructed within an excavation into the slope which is backfilled with a granular material. The main problem geometry is available as a dxf file (slope_stability.dxf) and as a series of co-ordinates. It is suspected that a relict slip surface may be present along the interface between the weathered mudstone and the mudstone.

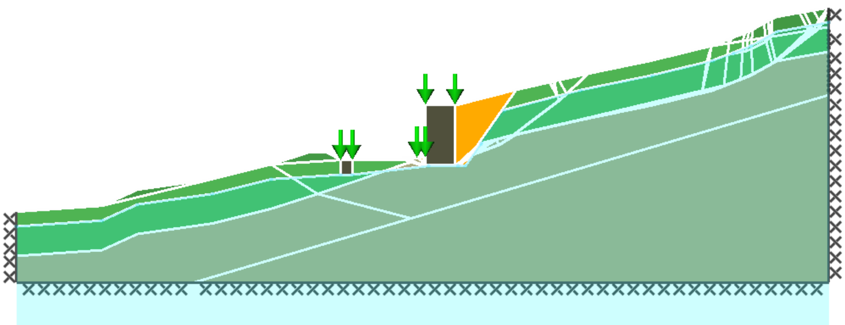

Figure 1: Global failure mechanism for Problem 1

The modelled soils and associated parameters are listed in Table 1. Wall/backfill and wall/mudstone interface properties were assumed to be $2/3\phi'$ and $0c'$.

Soil	c′ (kN/m^2)	ϕ'	γ (kN/m^3)
Weathered Mudstone	0	25°	20
Mudstone	5	25°	20
Granular backfill	0	40°	20
Relict slip surface	0	19°	-
Concrete	∞	∞	24

Table 1: Soil and rock properties

Location	Width (m)	Load (kN/m)	Pressure (kN/m^2)
LH concrete block	0.8	45	56
Floor between blocks	5.15	-	8
RH concrete block	2	45	22.5

Table 2: Imposed loads

Only the key foundation elements of the building were directly modelled as concrete sections with the remaining part represented by imposed loads as indicated in Table 2. The concrete retaining wall was of hollow construction and was modelled as a solid element with an equivalent reduced unit weight of 13 kN/m^3.

3 Setting up the model

3.1 Setting up problem geometry, materials and loading

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

1. Import the geometry from slope_stability.dxf using the **Import from dxf...** function.
2. Define material properties using **Create New Material...** and apply to the geometry (both **Solids** and wall **Boundaries**) by drag and drop.
3. Specify the applied building loads as pressures as **Loads - Permanent - Normal** via the **Property Editor**, by selecting the relevant **Boundaries**.
4. Draw the water table in approximately by hand using the draw water table function ( ). Select the water table and set the points precisely using the **Geometry editor**.
5. Set the boundary conditions on the base and sides as **Fixed**.
6. Apply the **Adequacy factor** to an appropriate unfavourable load or body force. Since the problem is a slope stability problem, the **Adequacy factor** can be applied to horizontal body forces using the seismic loading facility (set **Seismic Actions...**, **Horizontal Accel.** k_h to 1). The problem is then just stable when the **Adequacy factor** $= 0$. For further information on this approach, see Application Note .

This model is provided in slope_stability_base_1.geo.

3.2 Checking and adjusting model

LimitState:GEO searches all possible failure modes (restricted only by the density of nodes) and is therefore not restricted to a circular failure mode. There is no need to specify entry/exit points or search zones.

1. Set the **Nodal Density** to **Coarse** for initial checking runs.
2. Click **Solve** or . This first solve returns an **Adequacy factor** of 0.067. This means a horizontal acceleration of 0.067g is required to cause failure.
3. Set the **Nodal density** to **Fine** to achieve a high level of solution accuracy. **Solve** then **Animate** the solution by clicking . A significantly lower **Adequacy factor** of 0.002 is returned, implying that the slope is on the point of collapse, but no global collapse mechanism was identified.
4. Examination of the geometry of the main slope indicates that certain sections were close to or greater than the actual angle of friction of the soil. Switching to a higher nodal resolution allowed LimitState:GEO to identify such local failures/instabilities (on the upper slope surface in this case). Such local instabilities are usually not flagged up by conventional slope stability analyses, unless the specified search space includes these areas.

5. To suppress these local failures, the modelled soil was strengthened locally. These modifications are unlikely to modify the global collapse Factor of Safety (F.O.S.) significantly. This model is available as slope_stability_base_2.geo (the locally strengthened areas are coloured darker in this model).
6. Click **Solve** or ▶. **Animate** the solution. A global collapse mechanism is now identified with a corresponding numerical value of 0.060 for the **Adequacy factor** and indicates that the problem as modelled is stable (**Adequacy factor** ≥ 0.0). No localised slope failures are found.
7. It was observed that all failure mechanisms were confined to the upper right hand part of the model. Therefore to make most efficient use of the nodes in the problem, an additional boundary was added as shown in Figure 2 and the **Baseline Nodal Spacing** of zones (**Solids** and **Boundaries**) outside the failing areas set to a large value e.g. 100). This model is available as slope_stability_base_3.geo.
8. Click **Solve** or ▶. **Animate** the solution. The more efficient nodal distribution leads to a reduced value of the **Adequacy factor** (0.047) being returned as expected. The collapse mechanism (similar to that in Figure 1) intersects the left hand boundary of the problem. Normally the domain should be extended to the right until the mechanism is fully contained within the problem domain. In this example it is assumed that this boundary represents a real interface with a stronger material.

With the model now set up, stability analysis can proceed.

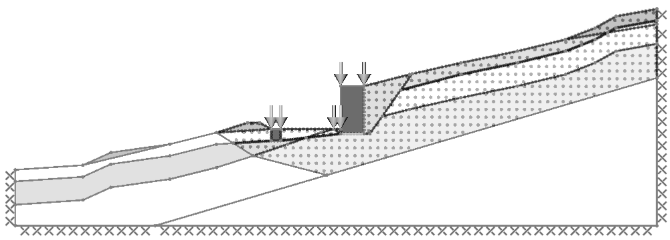

Figure 2: Typical nodal distribution used in the analyses

4 Stability analysis

4.1 General Procedure

The factor of safety (F.O.S.) commonly required in slope stability analysis is the factor on soil strength required to cause collapse. This is comparable with a method of slices approach which essentially adopts the same F.O.S. (though it may be simultaneously applied locally and globally as part of the limit equilibrium analysis). In LimitState:GEO the F.O.S. on strength is found by setting partial factors on the soil strength parameters using the **Scenario Manager** (see Section 9.3 and Chapter 23 of the User Manual for more information) and adjusting these until the **Adequacy Factor** switches from a small positive value to *unstable*. Note that this is because the adequacy factor has been applied in this case to a notional horizontal body force; if the adequacy factor had instead been applied to a real applied load then an adequacy factor ≥ 1.0 is always required.

4.2 Problem 1: Global stability

The problem was first analysed assuming that a relict slip surface was not present. The collapse mode was found to involve a non-linear failure surface at a F.O.S. on soil strength of 1.14[1] (as applied in the **Scenario Manager**) as shown in Figure 1. This model is available as slope_stability_problem_1.geo.

[1] This compares to a value of 1.34 provided by a Bishop Simplified method analysis, based on a circular slip surface that passes around the retaining wall.

4.3 Problem 2: Global stability with relict slip surface

In this scenario, the presence of the relict slip surface was assumed. This was applied in the model by selecting all the **Boundary** lines between the Mudstone and Weathered Mudstone (Unshow the water table, , to facilitate easy selection) and changing the material type to Relict slip surface. In this case the mechanism followed the interface for most of its length and the F.O.S on soil stength obtained was 0.98. This model is available as slope_stability_problem_2.geo.

4.4 Problem 3: Global stability assuming non-circular failure with relict slip surface, with heel and increased floor load

In order to increase the F.O.S the following modifications were examined:

1. Addition of a 0.75m × 0.75m heel to the base of the concrete wall at the right hand end. This was drawn in approximately using the Polygon tool (), and then the coordinates set precisely using the **Geometry Editor**. The interface material between the heel and the concrete wall was removed.
2. Increase of floor load from 8 kN/m^2 to 18 kN/m^2.

The solution obtained showed that the F.O.S. increased to 1.17. This is primarily due to the failure mechanism being forced to shear the intact Mudstone beneath the retaining wall. (This model is available as slope_stability_problem_3.geo.). A sensitivity check was carried out on the **Nodal Density**, by re-analysing the problem using a **Target Number** of nodes of 2000. The F.O.S. reduced negligibly to 1.16. This was considered acceptable.

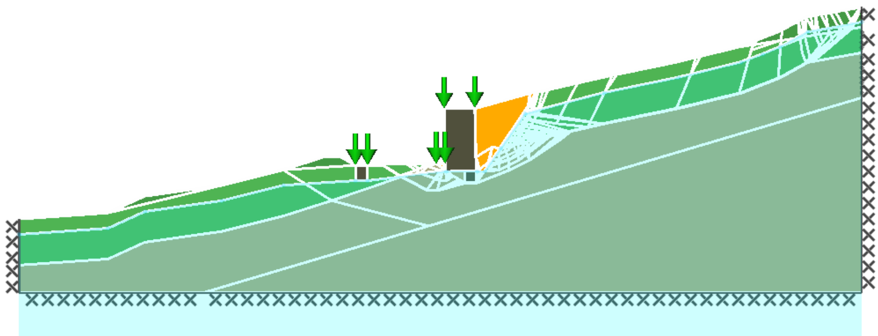

Figure 3: Global failure mechanism for Problem 3 with relict slip surface, added heel on wall and increased floor load modelled

For more information: www.limitstate.com/geo