Earth Slope and Slip Failures
Definitions

abg creative geosynthetic engineering

Technical Note

Introduction

An Earth Slope is an exposed surface that stands at an angle with the horizontal ground. Slopes can occur both naturally or be manmade. Slopes are often formed in the construction of highway and railway embankments, earth embankments, ponds, canals, drains, landfills, environmental applications and for architectural amenities.

Any inclined faced earth structure of 70° from the horizontal is defined as a slope. The earth has a “natural angle of repose” which is the angle it takes up when placed by itself. This angle depends on many factors such as grain size and type. For a slope to stand at a steeper angle the soil face needs to be either **reinforced** and/or **stabilised**. To reinforce a soil block, tension elements are used to hold the block together as a whole. Stabilisation is a specific action of preventing localised movements within the soil block. These definitions refer mainly to reinforcement of soils. The general term stability (as opposed to stabilisation) refers to an acceptably stable working slope.

Types of slope

1. **Infinite slope:** This type of slope refers to a constant slope which is long enough so that any boundary effects have no impact on its stability, either up or down the slope. Usually, the ground surface is parallel to the sliding surface. For example, the long slope of the face a mountain, landfill caps, etc.

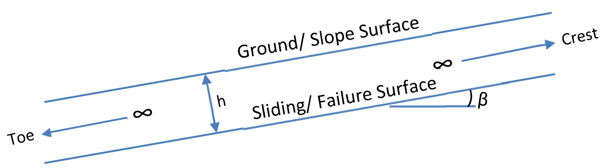

Figure 1: Infinite Slope

2. **Finite slope:** This refers to a shorter slope of known dimensions where the base, top surface and height will affect the behaviour of the slope.

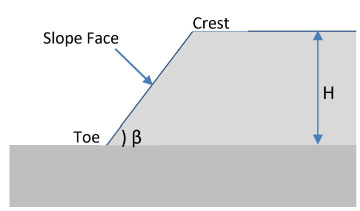

Figure 2: Finite Slope

Slope Failure

This is a downward and outward movement of the mass of the sloped soil by sliding. ***Slip plane*** or ***failure plane*** or ***slip surface*** or ***failure surface*** is the surface of sliding. The failure of slopes takes place mainly due to, gravitational forces, pore water pressure within the soil, erosion of the surface of slopes due to flowing water, sudden lowering of water adjacent to a slope, earthquakes, external loading (such as vehicle or foot trafficking) and un-planned excavation at the toe.

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Types of slope failure

1. **Translational Failure** (also called Translational Slip): This is where a shallow slip starts at some point on the slope and because of local movement it repeats or "translates" itself right up the slope. Some translational slips can be very long.

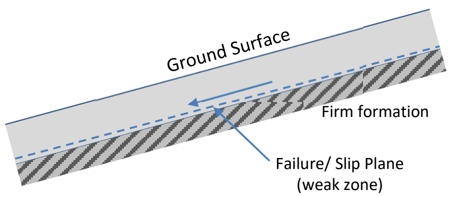

Figure 3: Translational Failure

Figure 4: Translational Failure at a landfill site

2. **Rotational Failure**: as the name suggests the failure shape is circular, and during failure the soil rotates against the stable soil. The failure forms at the weakest part of the slope and can occur as:

   a. Face (Slope) failure
   b. Toe failure
   c. Base failure (sometimes known as a "deep seated failure or slip")

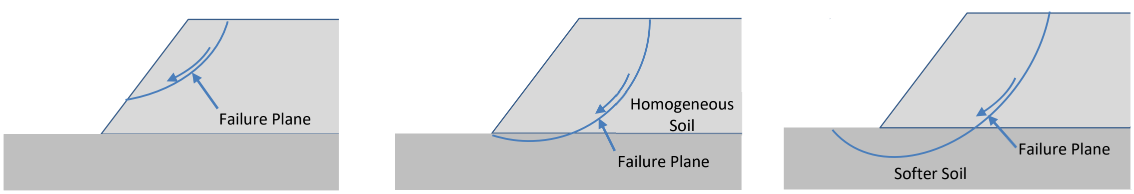

Figure 5: a) Face failure, b) Toe failure, and c) Base failure

In a) and b) above, these failures are referred to as "internal slope failures". Failures which occur in the newly constructed slope. Base failures are often much bigger failures and are "external slope failures" due to the failure of the soil outside the new slope. Due, say, to soft soil under the new structure.

Figure 6: Typical slope failures at roadsides

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3. **Compound Failure** - In some instances a combination of rotational and translational slide failure occurs due to a contrast in soil types or change in soil moisture

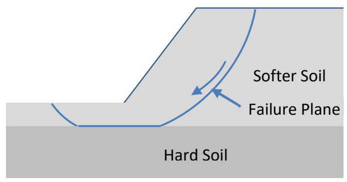

Figure 7: Compound Failure

4. **Block or Wedge Failure** this is where sections of the slope break up following weak layers or joints in the slope and can occur on infinite and finite slopes

5. **Miscellaneous Failures** - Some complex type of failures can form where the soil spreads out or starts to flow (almost like a fluid)

Slope Stability

A slope is considered stable when the limiting slope angle has been calculated based on the soil parameters and groundwater conditions. Usually then a Factor of Safety (FOS) is applied which allows for unforeseen conditions. When designing a slope consideration of slope stability is extremely important - not only in its lifetime but during the construction phase - where unique and unusual loads might be applied such as an excavator tracking a slope.

Consideration of slope stability is extremely important in the design and construction of earth slopes. The slopes constructed need to be firm and stable by employing the available techniques. If the available soil cannot be made stable by ordinary compaction equipment, the design engineer can use the following methods to make the slopes stable, both internally and externally:

Reinforcement:

a. Infinite Slope

To increase the factor of safety against translational slip of cover soil, reinforcement can be used in the form of geogrids alone or as part of a combination of geomembrane, geotextile, drainage geocomposite, geocellular mattress, etc.

The example in figure 8 shows a multi-layer capping system used on a landfill site. The waste is being capped with a layer of soil (CCL – Compacted Clay layer); overlain by a geomembrane; overlain by geotextile or geocomposite and a reinforcing grid to hold the cover soil.

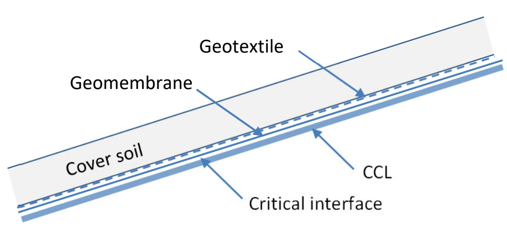

Figure 8: Reinforced Veneer

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b. Finite Slope

For manmade slopes up to 70°, geogrids (along with erosion control matting on the face) are used to create a stable slope. The reinforcing geogrids span the slip line/failure plane to ensure the internal stability. The external failure plane may need other measures to resolve this problem (e.g. slacken the slope).

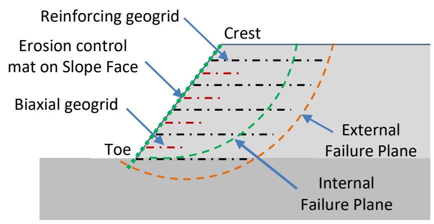

Figure 9: Geogrid reinforced slope with possible failure planes

Soil Nailing:

Steel nails are driven into the soil past the potential failure plane that then resist pull-out by their circumferential friction. This method can include a robust erosion control mat to facilitate long-term erosion control and vegetation of the slope surface. Erosion control mat can be applied alone, or along with steel mesh behind it, depending on the slope face angle and the soil type. An impermeable geocomposite drain along with shotcrete can also be used to stabilise the slope face.

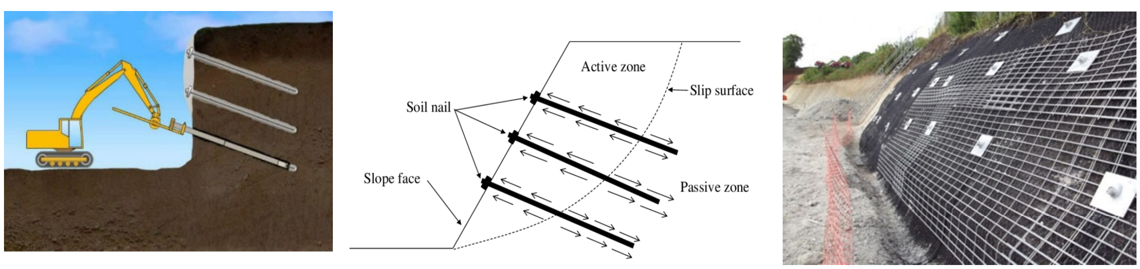

Figure 10: a) Soil nailing process, b) Soil nails in action, and c) Nailed Geosynthetic (under steel mesh)

Vegetation

This is where the roots and the surface vegetation is considered as an engineering material, sometimes called the biotechnical method. Vegetation is vulnerable to weather and contamination, so can be enhanced and protected using erosion control mats and/or geocellular mattresses, and are applicable for both infinite and finite slopes.

Drainage

Instability in soils is often caused by water. Introduction of interceptor drains, for example like a French drain with geosynthetic fin drains along the crest edge and lateral flow drains (often in a herringbone pattern) within the slope mass having frequent outfalls.

Compaction and chemical additives

Compaction of soils is fundamental to increasing the stability of soils. Soils are sometimes mixed with chemicals such as lime to increase their strength and then compacted in layers.

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Benching and Terracing

A slope can be constructed as a combination of several short height and shallow faced slopes, terraced apart to reduce the overall angle of inclination. This could overcome a base slip or deep seated slip failure.

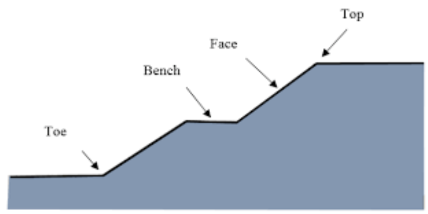

Figure 11: Benching and Terracing

Slope Stability Assessment

When carrying out a design, the designer has to consider:

- Determination of the potential failure surface,
- Forces that tend to cause slip, and
- Forces that tend to restore (stabilise).

Determination of Factor of Safety

The factor of safety is as agreed by the geotechnical professional or defined by certain clients. This is determined by the level of acceptable risk of something unforeseen. An example definition of one of the failure mechanisms would be:

The FOS against sliding failure:

$$FoS = \frac{Resisting\ Force}{Driving\ Force}$$

ABG Calculations

1. Infinite slope

Veneer stability checks

Translational failure is a common design requirement on slopes which have multiple layers. Each layer has a different friction angle with the one above or below it. This means a check has to be carried out on each layer to find the weakest layer or "veneer" (a veneer means a thin layer). The geosynthetic layer(s) may consist of a single layer geomembrane to a combination of a multiple layers of GCL, geogrids, geotextile, drainage geocomposite, erosion control geocellular webs, and then cover soil of typically a maximum of 50mm (note if more than 50mm the cover soil itself can start to slip internally, creating another slip layer).

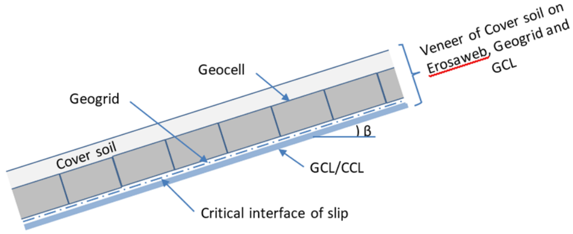

Figure 11: Veneer of cover soil on Erosaweb, ABG Geogrid and ABG Claymat GCL

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The forces are assumed to act in parallel along the critical interface of slip. The factor of safety is expressed as,

$$FoS = \frac{Restraining\ Shear\ strength\ available}{Shear\ strength\ mobilised}$$

2. Finite slope

Internal and External stability checks

ABG can carry out the design of reinforced earth **finite slopes**, with various facings e.g. Webwall, Abslope SM (steel mesh facing panel), geogrid wrapped face up to 70° and Abslope EM geogrid reinforced soil slopes (between 26°- 45°). Each slope is checked for internal stability including sliding, overturning and bearing pressure and can include external stability checks (deep seated slips).

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