



Geotechnical Engineering Series - Slope Stability

An Online Continuing Education Course for Engineers

Course Number: G-4006

Credit: 4 Hours / 4 PDH / 4 CPD

Geotechnical Engineering Series: Slope Stability

Ground stability must be assured prior to consideration of other foundation related items. Embankment foundation problems involve the support of the embankment by natural soil. Problems with embankments and structures occasionally occur that could be prevented by initial recognition of the problem and appropriate design. Stability problems most often occur when the embankment is to be built over soft soils such as low strength clays, silts, or peats. Once the soil profile, soil strengths, and depth of ground water table have been determined by field explorations and/or field and laboratory testing, the stability of the embankment can be analyzed and a factor of safety estimated. If the embankment is found to be unstable, measures can then be taken to stabilize the foundation soils.

As illustrated in Figure 1, there are four major types of instability that should be considered in the design of embankments over weak foundation soils. Recommendations on how to recognize, analyze, and solve each of the first three problems are presented in this course. Lateral squeeze is more closely related to the evaluation of foundation deformation and is outside the scope of this course.

The stability problems illustrated in Figure 1 can be classified as “internal” or “external.” “Internal” embankment stability problems generally result from the selection of poor quality embankment materials and/or improper placement of the embankment fills and/or improper placement requirements. The infinite slope failure mode is an example of an “internal” stability problem; often such a failure is manifested as sloughing of the surface of the slope. Internal stability can be assured through project specifications by requiring granular materials with minimum gradation and compaction requirements. The failure modes shown in Figure 1b, c and d, can be classified as “external” stability problems.

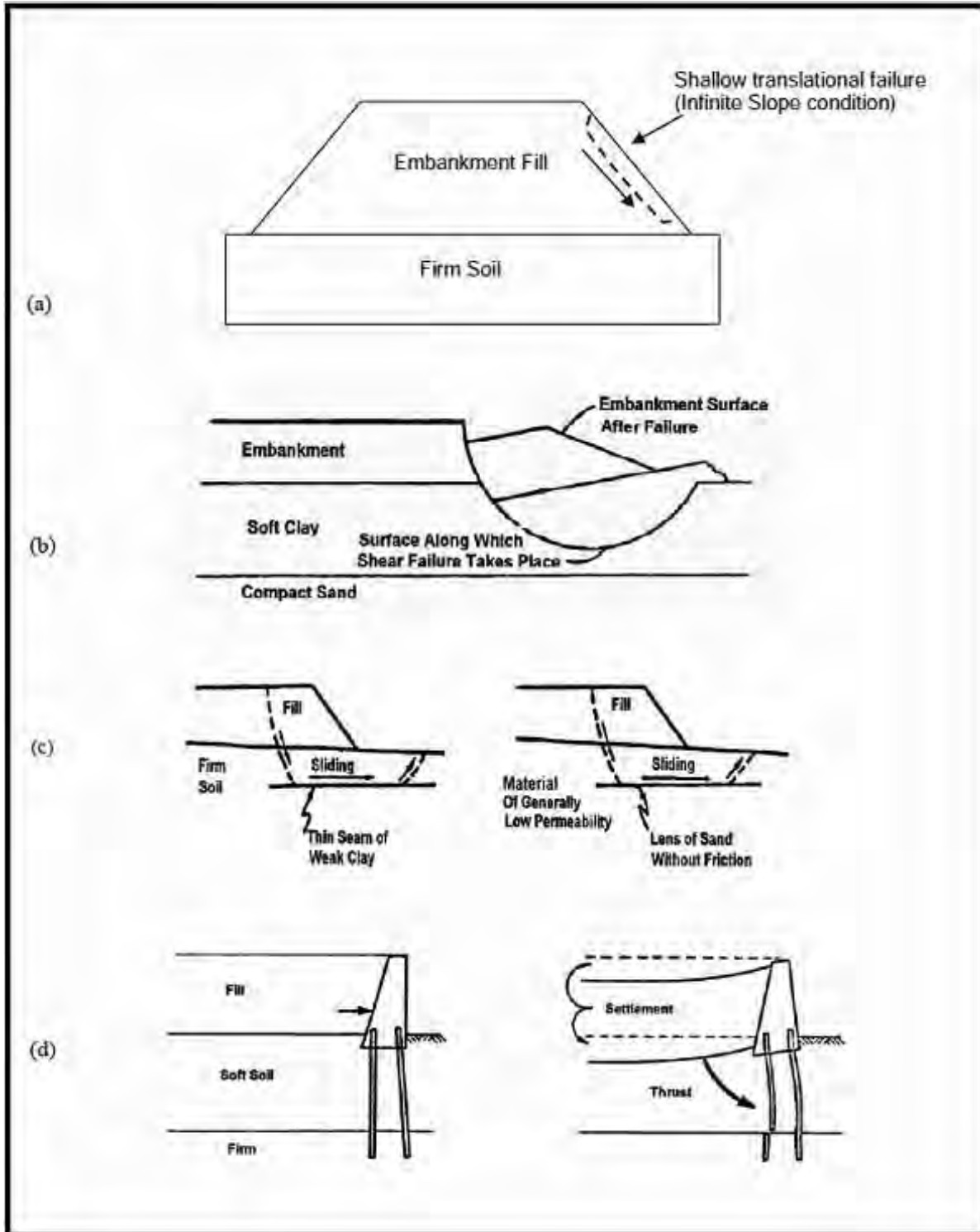


Figure 1. Embankment failures: (a) Infinite slope failure in embankment fill, (b) Circular arc failure in embankment fill and foundation soil, (c) Sliding block failure in embankment fill and foundation soil, and (d) Lateral squeeze of foundation soil.

1. EFFECTS OF WATER ON SLOPE STABILITY

Very soft, saturated foundation soils or ground water generally play a prominent role in geotechnical failures in general. They are certainly major factors in cut slope stability and in the stability of fill slopes involving both “internal” and “external” slope failures. The effect of water on cut and fill slope stability is briefly discussed below.

- **Importance of Water**

Next to gravity, water is the most important factor in slope stability. The effect of gravity is known, therefore, water is the key factor in assessing slope stability.

- **Effect of Water on Cohesionless Soils**

In cohesionless soils, water does not affect the angle of internal friction (ϕ). The effect of water on cohesionless soils below the water table is to decrease the intergranular (effective) stress between soil grains (σ'_n), which decreases the frictional shearing resistance (τ').

- **Effect of Water on Cohesive Soils**

Routine seasonal fluctuations in the ground water table do not usually influence either the amount of water in the pore spaces between soil grains or the cohesion. The attractive forces between soil particles prevent water absorption unless external forces such as pile driving, disrupt the grain structure. However, certain clay minerals do react to the presence of water and cause volume changes of the clay mass.

An increase in absorbed moisture is a major factor in the decrease in strength of cohesive soils as shown schematically in Figure 2. Water absorbed by clay minerals causes increased water contents that decrease the cohesion of clayey soils. These effects are amplified if the clay mineral happens to be expansive, e.g., montmorillonite.

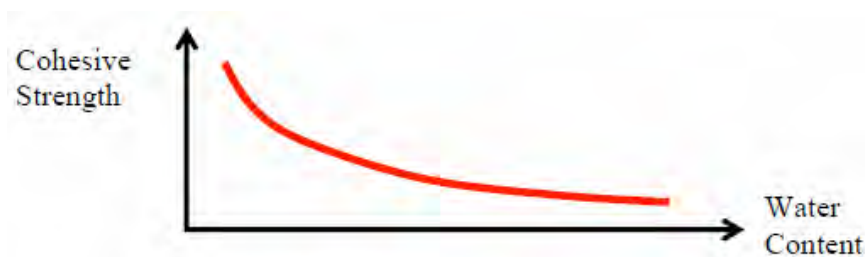


Figure 2. Effect of water content on cohesive strength of clay.

- **Fills on Clays**

Excess pore water pressures are created when fills are placed on clay or silt. Provided the applied loads do not cause the undrained shear strength of the clay or silt to be exceeded, as the excess pore water pressure dissipates consolidation occurs, and the shear strength of the clay or silt increases with time. For this reason, the factor of safety increases with time under the load of the fill.

- **Cuts in Clay**

As a cut is made in clay the effective stress is reduced. This reduction will allow the clay to expand and absorb water, which will lead to a decrease in the clay strength with time. For this reason, the factor of safety of a cut slope in clay may decrease with time. Cut slopes in clay should be designed by using effective strength parameters and the effective stresses that will exist in the soil after the cut is made.

- **Slaking - Shales, Claystones, Siltstones, etc.**

Sudden moisture increase in weak rocks can produce a pore pressure increase in trapped pore air accompanied by local expansion and strength decrease. The “slaking” or sudden disintegration of hard shales, claystones, and siltstones results from this mechanism. If placed as rock fill, these materials will tend to disintegrate into a clay soil if water is allowed to percolate through the fill. This transformation from rock to clay often leads to settlement and/or shear failure of the fill. Index tests such as the jar-slake test and the slake-durability test used to assess slaking potential are discussed in FHWA (1978).

2. DESIGN FACTOR OF SAFETY

A minimum factor of safety as low as 1.25 is used for highway embankment side slopes. This value of the safety factor should be increased to a minimum of 1.30 to 1.50 for slopes whose failure would cause significant damage such as end slopes beneath bridge abutments, major retaining structures and major roadways such as regional routes, interstates, etc The selection of the design safety factor for a particular project depends on:

- The method of stability analysis used (see Section 4.5).
- The method used to determine the shear strength.
- The degree of confidence in the reliability of subsurface data.
- The consequences of a failure.
- How critical the application is.

3. INFINITE SLOPE ANALYSIS

A slope that extends for a relatively long distance and has a consistent subsurface profile may be analyzed as an infinite slope. The failure plane for this case is parallel to the surface of the slope and the limit equilibrium method can be applied readily.

3.1 Infinite Slopes in Dry Cohesionless Soils

A typical section or “slice” through the potential failure zone of a slope in a dry cohesionless soil, e.g., dry sand, is shown in Figure 3, along with its free body diagram. The weight of the slice of width b and height h having a unit dimension into the page is given by:

$$W = \gamma b h \quad (1)$$

where γ is the effective unit weight of the dry soil. For a slope with angle β as shown in Figure 3, the normal (N) and tangential (T) force components of W are determined as follows:

$$N = W \cos \beta \quad \text{and} \quad (2)$$

$$T = W \sin \beta \quad (3)$$

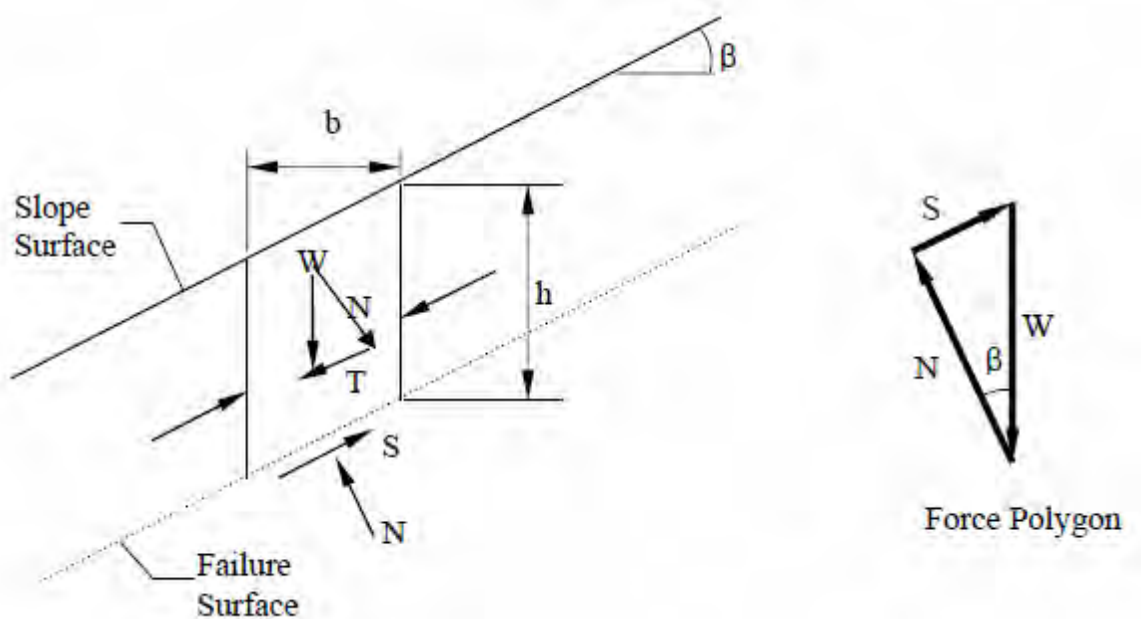


Figure 3. Infinite slope failure in dry sand.

The available shear strength along the failure plane is given by:

$$S = N \tan \phi \quad (4)$$

The factor of safety (FS) is defined as the ratio of available shear strength to strength required to maintain stability. Thus, the FS will be given by:

$$FS = \frac{S}{T} = \frac{N \tan \phi}{W \sin \beta} = \frac{(W \cos \beta) \tan \phi}{W \sin \beta} = \frac{\tan \phi}{\tan \beta} \quad (5)$$

For an infinite slope analysis, the FS is independent of the slope depth, h , and depends only on the angle of internal friction, ϕ , and the angle of the slope, β . The slope is said to have reached **limit equilibrium** when $FS=1.0$. Also, at a $FS = 1.0$, the maximum slope angle will be limited to the angle of internal friction, ϕ .

3.2 Infinite Slopes in c - ϕ Soils with Parallel Seepage

If a saturated slope in a c - ϕ soil has seepage parallel to the surface of the slope as shown in Figure 4, the same limit equilibrium concepts may be applied to determine the FS, which will now depend on the effective normal force (N'). In the following analysis, effective shear strength parameters, c' and ϕ' are used.

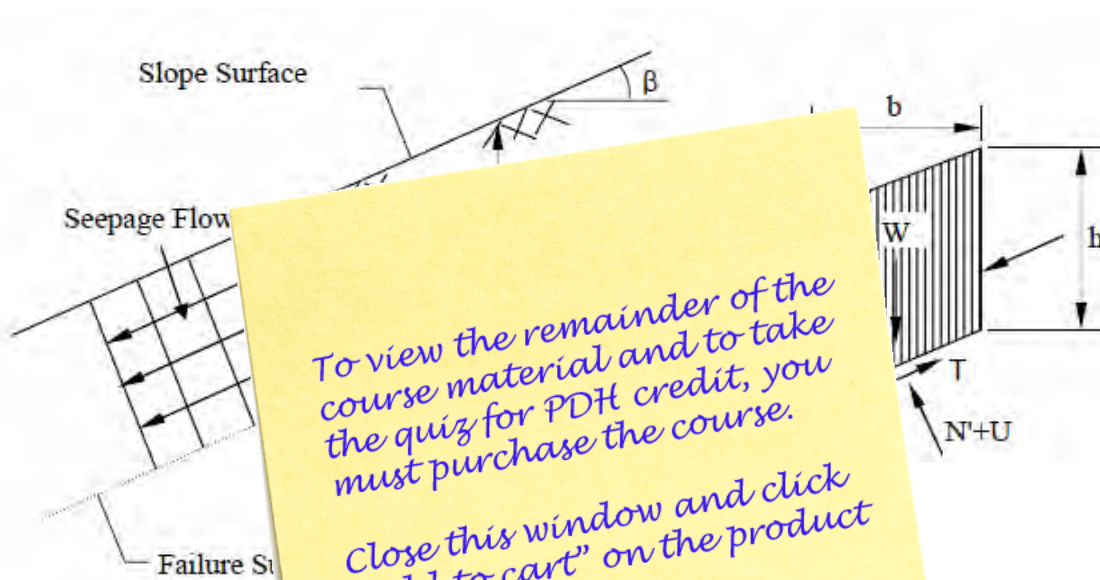


Figure 4.

epage.

From Figure 4, the pore water pressure force U acting on the failure surface is having a unit width

$$U = (\gamma_w h) b \quad (6)$$

where h is any depth less than or equal to the depth of saturation and b is a unit width.