RECLAMATION
Managing Water in the West

Design Standards No. 13

Embankment Dams

Chapter 20: Geomembranes
Phase 4 (Final)

U.S. Department of the Interior
Bureau of Reclamation

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over time and are also susceptible to damage from such things as rocks, debris, equipment, wind uplift, overall environmental degradation, animal intrusion, and vandalism.

20.4.10 Protective Cover Design

The design of protective covers should include two aspects: (1) stability of the lining system (i.e., protective cover, geomembrane liner, and associated drainage layers) under the effect of gravity forces, seismic actions, and pore water pressures and (2) resistance of the protective cover to wave action. In many instances, geomembranes used for dams are protected by a soil or concrete cover. Movement of the cover can cause problems. For example, large movements resulting from instability of a soil cover on a slope can affect the integrity of the cover and damage the geomembrane. Also, small differential movements between a concrete cover and a geomembrane may induce tensile stresses in the geomembrane. In all cases, it is important to first verify that the geomembrane itself is able to withstand its own weight on a slope with no cover material.

20.4.10.1 Soil Cover

Usually a minimum of two layers of cover materials are required. The first layer closest to the geomembrane is used to protect the geomembrane. The smallest possible particles are used to best protect the geomembrane. Rounded particles are good, but must be stable on the slopes. The second and subsequent layer is used for armor protection to resist wave action. The two layers should be filter compatible with each other especially where wave action is expected.

When a soil cover is placed over a geomembrane, or any geosynthetic, the gravity stresses increase dramatically. This may cause two types of movements: (1) sliding within the soil cover and (2) sliding along the soil geosynthetic or a geosynthetic/geosynthetic interface. Two cases must be considered for soil cover stability evaluation: (1) a soil cover with a uniform thickness and (2) a soil cover with a nonuniform thickness. Additionally, stability considerations during rapid drawdown are discussed.

20.4.10.1.1 Stability for Uniform Soil Cover Thickness

In many cases, the soil cover has a uniform thickness. In this case, two types of analysis can be considered: (1) infinite slope analysis and (2) finite slope analysis.

20.4.10.1.1.1 Infinite Slope Analysis

A simple approach in the stability analysis of soil-geosynthetic systems on slopes is to consider the slope to be infinite. This is generally true if the thickness of the soil-geosynthetic system is small compared to the length of the slope. A free-body diagram is shown on figure 20.4.10.1.1.1-1 for the idealized infinite slope under consideration.

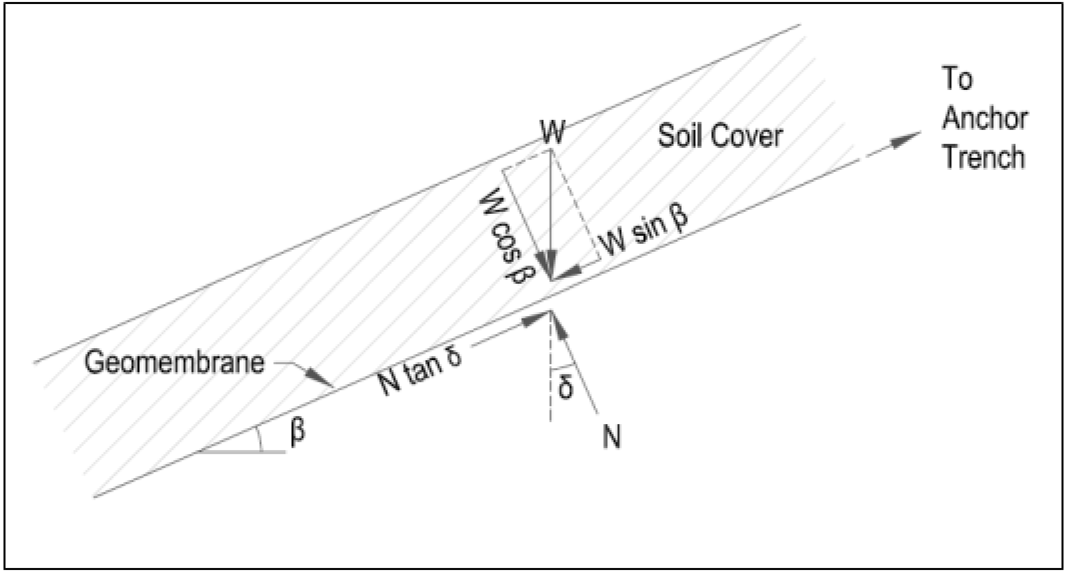

Figure 20.4.10.1.1.1-1. Infinite slope stability free-body diagram.

If the behavior of the soil and the geosynthetic interfaces is governed solely by friction (i.e., no soil cohesion or interface adhesion), the factor of safety against slippage in an infinite slope is based on limit equilibrium and is given by:

$$FS = \frac{resisting\ forces}{driving\ forces}$$

$$FS = \frac{F}{W \sin \beta} = \frac{N \tan \delta}{W \sin \beta} = \frac{W \cos \beta \tan \delta}{W \sin \beta} = \frac{\tan \delta}{\tan \beta}$$

Where:

β = Slope angle (degrees)
δ = Friction angle between the soil cover and geomembrane (degrees)
W = Weight of overlying soil cover (lb) [2]
F = Resisting force (lb)
N = Force normal to the failure plane (lb)

The equation above indicates that the soil cover overlying a geosynthetic system on a slope is likely to be stable if the slope angle is less than the friction angle between the soil cover and geomembrane.

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[2] Use buoyant weight if soil cover is submerged.

20.4.10.1.1.2 Finite Slope Analysis

In reality, slopes are not infinite, and slopes determined to be unstable from "infinite slope" analysis could be stable. Two reasons for a finite slope to be more stable than an infinite slope are:

- **Geosynthetic Anchorage at the Crest**. Geosynthetics are usually anchored at the crest of the slope. As slippage along the critical geosynthetic interface occurs, tensile forces are generated in the geosynthetics located above the critical interface. These tensile forces contribute to the stability of the potential sliding block.
- **Soil Buttress at the Toe.** The soil cover, at its toe, is assumed to rest on a firm foundation. As slippage along the critical interface occurs, downward movement of the soil cover is buttressed by the firm foundation. This "toe buttressing effect" contributes to the stability of the soil layer.

The method presented hereafter [4] is valid for either cohesionless or cohesive soils. For finite length slopes, there exists a small passive wedge at the toe of the slope, above which the active wedge is located. A free-body diagram is shown on figure 20.4.10.1.1.2-1 of a finite length slope with a uniform thickness of soil cover.

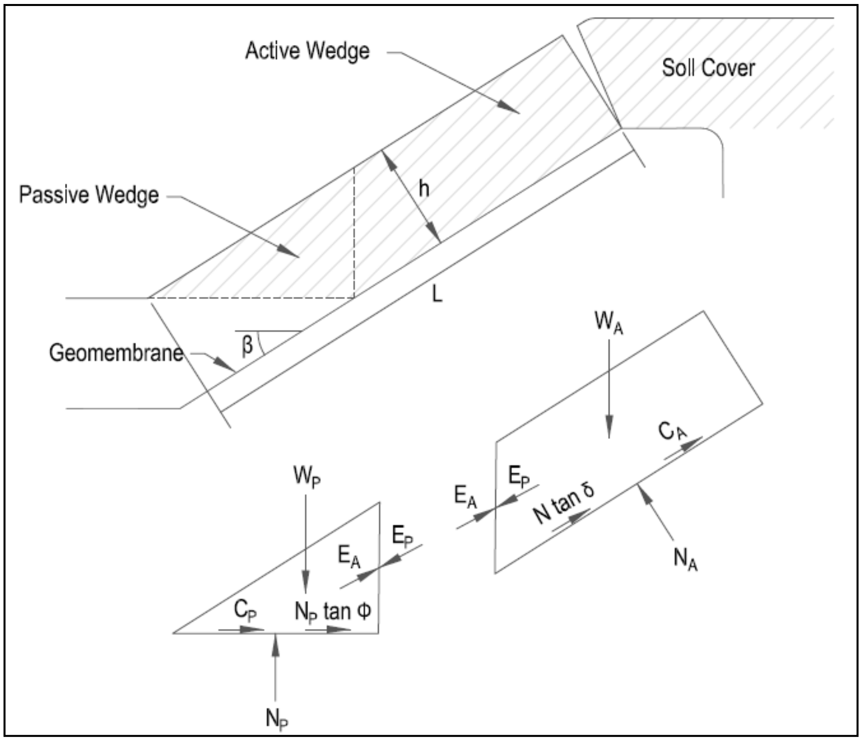

Figure 20.4.10.1.1.2-1. Finite slope stability cross section and free-body diagram.

The factor of safety for the conditions described above is given by:

$$FS = \frac{-b + \sqrt{b^2 - 4ac}}{2a}$$

Where:

$a = (W_A - N_A \cos\beta)\cos\beta$

$b = -[(W_A - N_A \cos\beta)\sin\beta\tan\varphi + (N_A \tan\delta + C_a)\sin\beta\cos\beta + \sin\beta(C_P + W_P \tan\varphi)]$

$c = (N_A \tan\delta + C_a)\sin^2\beta\tan\varphi$

W_A = Total weight of the active wedge (lb)
$= \gamma h^2 \left(\frac{L}{h} - \frac{1}{sin\beta} - \frac{tan\beta}{2}\right)$

W_P = Total weight of the passive wedge (lb)
$= \frac{\gamma h^2}{sin2\beta}$

N_A = Effective force normal to the failure plane of the active wedge (lb)
$= W_A cos\beta$

γ = Unit weight of the cover soil (lb/ft^3) (use buoyant when submerged)

h = Thickness of soil cover (ft)

L = Length of slope measured along the geomembrane (ft)

β = Soil slope angle beneath the geomembrane (degrees)

φ = Soil internal angle of friction (degrees)

δ = Interface friction angle between cover soil and geomembrane (degrees)

C_a = Adhesion between active wedge soil cover and geomembrane (lb/ft^2)

C_P = Adhesion between passive wedge soil cover and geomembrane (lb/ft^2)

If the factor of safety calculated using the equation above is below Reclamation guidelines outlined in chapter 4 of Design Standards No. 13, it can be increased by flattening the slope, using a tapered soil cover thickness that widens at the base, or by using geosynthetics that result in a higher interface friction (i.e., textured geomembrane).

20.4.10.1.2 Nonuniform Soil Cover Thickness

In some dams, the soil overlying the geomembrane has a nonuniform thickness. As previously discussed, two types of movements may cause instability of the soil cover/geosynthetic system: (1) sliding within the soil cover and (2) sliding at the soil cover/geosynthetic interface. The first case can be analyzed using the conservative infinite slope analysis. The classical wedge analysis can be also used to evaluate the stability of a soil cover/geosynthetic interface. The designer is encouraged to use two-dimensional, limit equilibrium software for the evaluation of a tapered or nonuniform soil cover while adhering to the guidelines outlined in chapter 4 of Design Standards No. 13 [41].