Stability of Slopes

INTRODUCTION

- A slope in a soil mass is ecnountered when the elevation of the ground surface gradually changes from a lower level to a higher one. Such a slope may be either natural (in hilly region) or man-made (in artificially constructed embankment or excavations).
- The soil mass bounded by a slope has a tendency to slide down. The principal factor causing such a sliding failure is the self-weight of the soil. However, the failure may be aggravated due to seepage of water or seismic forces. Every man-made slope has to be properly designed to ascertain the safety of the slope against sliding failure.
- Various methods are available for analysing the stability of slopes. Generally these methods are based on the following assumptions:

1. Any slope stability problem is a two-dimensional one.
2. The shear parameters of the soil are constant along any possible slip surface.
3. In problems involving seepage of water, the flownet can be constructed and the seepage forces can be determined.

18.2. BASIS OF ANALYSIS

The soil mass must be safe against slope failure on any conceivable surface across the slope. Although the methods using the theory of elasticity or plasticity are also being increasingly used, the most common methods are based on limiting equilibrium in which it is assumed that the soil is at the verge of failure. The methods of limiting equilibrium are statically indeterminate. As the stress-strain relationships along the assumed surface are not known, it is necessary to make assumptions so that the system becomes statically determinate and it can be analysed easily using the equations of equilibrium. The following assumptions are generally made.

(1) The stress system is assumed to be two-dimensional. The stresses in the third direction (perpendicular to the section of the soil mass) are taken as zero.

(2) It is assumed that the Coulomb equation for shear strength is applicable and the strength parameters c and ϕ are known.

(3) It is further assumed that the seepage conditions and water levels are known, and the corresponding pore water pressure can be estimated.

(4) The conditions of plastic failure are assumed to be satisfied along the critical surface. In other words, the shearing strains at all points of the critical surface are large enough to mobilise all the available shear strength.

(5) Depending upon the method of analysis, some additional assumptions are made regarding the magnitude and distribution of forces along various planes.

In the analysis, the resultant of all the actuating forces trying to cause the failure is determined. An estimate is also made of the available shear strength. The factor of safety of the slope is determined from the available resisting forces and the actuating forces.

18.3. DIFFERENT DEFINITIONS OF FACTORS OF SAFETY

Three different definitions of the factor of safety are used.

(a) Factor of safety with respect to shear strength

In common usage, the factor of safety is defined as the ratio of the shear strength to the shear stress along the surface of failure. The factor of safety as defined above is known as the factor of safety with respect to shear strength.

Thus
$$F_s = \frac{s}{\tau_m} \quad \text{...(18.1)}$$

where F_s = factor of safety with respect to shear strength, s = shear strength,

τ_m = mobilised shear strength (equal to applied shear stress).

Eq. 18.1 can be written in terms of the cohesion intercept and the angle of shear resistance as

$$F_s = \frac{c + \bar{\sigma}\tan\phi}{c_m + \bar{\sigma}\tan\phi_m} \quad \text{...(18.2)}$$

where c_m = mobilised cohesion, ϕ_m = mobilised angle of shear resistance, $\bar{\sigma}$ = effective pressure.

Rearranging Eq. 18.2,

$$\frac{c}{F_s} + \frac{\bar{\sigma}\tan\phi}{F_s} = c_m + \bar{\sigma}\tan\phi_m$$

Therefore,
$$c_m = c/F_s \quad ...(18.3)$$

and
$$\tan\phi_m = \tan\phi/F_s \quad ...(18.4)$$

Eqs. 18.3 and 18.4 indicate that the factor of safety with respect to the cohesion intercept and that with respect to the angle of shearing resistance are equal to the factor of safety with respect to the shear strength.

(b) Factor of safety with respect to cohesion

The factor of safety with respect to cohesion (F_c) is the ratio of the available cohesion intercept (c) and the mobilised cohesion intercept.

Thus
$$F_c = \frac{c}{c_m} \quad ...(18.5)$$

where c = cohesion intercept, c_m = mobilised cohesion intercept,
F_c = factor of safety with respect to cohesion.

(c) Factor of safety with respect to friction

The factor of safety with respect to friction is the ratio of the available frictional strength to the mobilised frictional strength. Thus

$$F_\phi = \frac{\bar{\sigma}\tan\phi}{\bar{\sigma}\tan\phi_m}$$

or
$$F_\phi = \frac{\tan\phi}{\tan\phi_m} \quad ...(18.6)$$

where F_ϕ = factor of safety with respect to friction, ϕ = angle of shearing resistance,
ϕ_m = angle of mobilised shearing resistance.

For small angles, Eq. 18.6 can be expressed as

$$F_\phi = \frac{\phi}{\phi_m} \quad ...[18.6(a)]$$

In the analysis of stability of slopes, generally the three factors of safety are taken equal, *i.e.* $F_s = F_c = F_\phi$. However, sometimes when greater reliance is placed on the parameter ϕ than the parameter c, the factor of safety with respect to cohesion is taken greater than that with respect to friction. In such a case, the factor of safety with respect to friction is usually taken as unity *i.e.* $\phi_m = \phi$.

18.4. TYPES OF SLOPE FAILURES

A slope may have any one of the following types of failures.

(1) Rotational failure. This type of failure occurs by rotation along a slip surface by downward and outward movement of the soil mass (Fig. 18.2). The slip surface is generally circular for homogeneous soil conditions and non-circular in case of non- homogeneous conditions. Rotational slips are further divided into 3 types.

(*a*) Toe failure, in which the failure occurs along the surface that passes through the toe [Fig. 18.2 (*a*)].

(*b*) Slope failure, in which the failure occurs along a surface that intersects the slope above the toe [Fig. 18.2 (*b*)].

(*c*) Base failure, in which the failure surface passes below the toe [Fig. 18.2 (*c*)].

The slope failure occurs when a weak plane exists above the toe. The base failure occurs when a weak stratum lies beneath the toe. If a strong stratum exists below the toe, the slip surface of the base failure is tangential to that stratum. In all other cases, the failures are generally toe failures. Toe failures are most common.

(2) Translational Failure. A constant slope of unlimited extent and having uniform soil properties at the

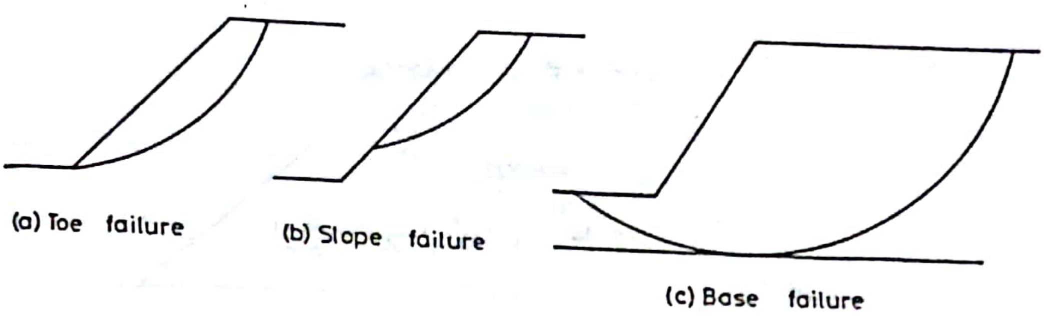

Fig. 18.2. Rotational Failure.

same depth below the free surface is known as an infinite slope. In practice, the slopes which are of considerable extent and in which the conditions on all verticals are adequately represented by average conditions are designated as *infinite slopes*.

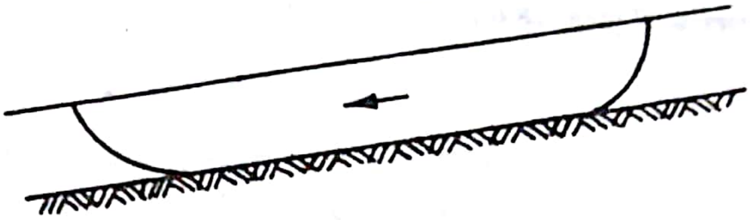

Fig. 18.3. Translational Failure.

Translational failure occurs in an infinite slope along a long failure surface parallel to the slope (Fig. 18.3). The shape of the failure surface is influenced by the presence of any hard stratum at a shallow depth below the slope surface. Translational failures may also occur along slopes of layered materials.

(3) Compound Failure. A compound failure is a combination of the rotational slips and the translational slip (Fig. 18.4).. A compound failure surface is curved at the two ends and plane in the middle portion. A compound failure generally occurs when a hard stratum exists at considerable depth below the toe.

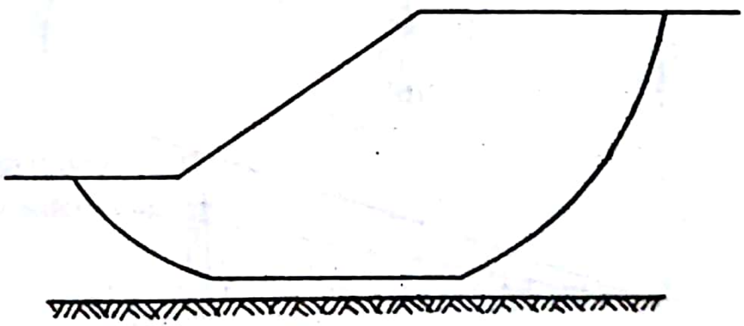

Fig. 18.4. Compound Failure.

(4) Wedge Failure. A failure along an inclined plane is known as plane failure or wedge failure or block failure (Fig. 18.5). It occurs when distinct blocks and wedges of the soil mass become separated.

A plane failure is similar to translational failure is many respects. However, unlike translational failure which occurs in an infinite slope, a plane failure may occur even in a finite slope consisting of two different materials or in a homogeneous slope having cracks, fissures, joints or any other specific plane of weakness.