Significance of Laboratory Studies of Soil and Rock in Slope Stability Analysis

*Mukteshwar Tiwari and *S.C.Srivastava

Abstract

Mass wasting processes contributed by natural or manmade slope degradation/instability is one of the major problems in developmental work. It is, therefore, necessary to investigate and device the means for controlling or minimising the unstable slopes. In analysing the stability of slopes, some of the parameters, which plays major role are often ignored by the field geologists. This paper deals with such properties which are essentially required to be studied for useful analysis and interpretation.

Introduction

Since time immemorial, like other hazardous natural phenomena, which threaten life and property, such as earthquake and floods, landslides and slope instability have attracted the attention of Man. In areas of active landslide they represent important factor in transforming the landscape and cause great damage to forest growth, form land and endanger the development of engineering structure including communication routes in slopy terrain. It has generally been observed that while some slopes are stable at steep angles and higher height, many flat slopes fail at much smaller heights. Probably, the inclination of discontinuity surfaces present within the rock mass is responsible for such feature. When the discontinuities are vertical or horizontal, simple sliding cannot take place and slope failure will involve fracture of intact block of rock as well as movement along some of the discontinuities. In contrast, when the rock mass contains discontinuity surfaces dipping towards the slope face at 30° to 70°, simple sliding can occur and the stability of the slopes is significantly lower than those in which only horizontal and vertical discontinuities are present. But over and above the slope angle of the discontinuity surface, the more important parameter responsible in the mechanics of stability or instability is the shear characteristics of the material at the contact of the discontinuity surface. The slides cannot be eliminated but can be controlled and/or stabilised by providing certain stability measures. Therefore, for the proper stability analysis, knowledge of certain geotechnical parameters is essential.

The most important properties which, are required to be determined in laboratory for stability analysis in soil are Grain size analysis, Atterberg Limits (Liquid Limit, Plastic Limit and Shrinkage Limit), in-situ moisture content and density, shear properties (Cohesion "C" and Angle of Internal Friction "f"). Similarly, density, Uniaxial Compressive Strength, shear properties i.e. Cohesion "C" and Angle of Internal Friction "f" of discontinuity surface are important parameters in rock, which need to be determined for slope stability analysis. These parameters are being discussed separately for soils and rocks.

*Geological Survey of India, NR, Aliganj, Lucknow 226 024

A. Soil

Grain Size Analysis

A quantitative determination of the grain size distribution in a soil is made by sieve analysis and sedimentation analysis. In a soil, the gravel, sand, silt and clay fractions are recognised as containing particles of decreasing magnitude.

Coarse Grained Components

Gravel - 75 mm to 4.75 mm IS Sieve,
Sand - 4.75 mm to 75 micron IS Sieve

Two methods are given for finding the distribution of grain sizes larger than 75-micron IS Sieve. The first method is wet sieving applicable to all soils while the second method is dry sieving which is applicable only to soils which do not have an appreciable amount of clay.

Fine Grained Components

Silt and Clay - Finer than 75 micron IS Sieve

The analysis of soil finer than 75 micron IS Sieve is done by sedimentation (Pipette Method) after executing proper treatment to the material for neutralising soluble solids. This method is not applicable if less than 10% of the material passes 75 micron IS Sieve.

The whole spectrum of grain size commencing from gravel, sand, silt and clay (in percent by weight) is deciphered by sieve and sedimentation analysis. The fine grained (silt and clay) data when blended with the Atterberg limits defines the properties which are most suitably used in engineering application.

Atterberg's Limits

The liquid and plastic limit of soils are both dependent on the amount and type of clay in a soil and form the basis for the soil classification system for cohesive soils based on the plasticity tests. Besides their use for identification, the plasticity test gives information concerning the cohesion properties of soil.

Liquid Limit

The basic principle is to observe depths of penetrations of soils at various initial moisture contents of a metal cone of certain weight and apex angle with the point barely touching the surface is allowed to drop into the surface. The standardization has been to identify liquid limit (water content) for a specified depth (20mm) of penetration.

A graph representing water content on the Y-axis and the cone penetration on the X-axis is prepared and the best fitting straight line is drawn. The water content corresponding to cone penetration of 20 mm is taken as liquid limit of the soil and is expressed to the nearest first decimal place.

Plastic Limit

The water content expressed in percentage of the weight of oven dry soil, at the boundary between the plastic and the semisolid states of consistency of the soil. For purpose of determination, plastic limit is defined at which a soil will just begin to crumble when rolled into approximately 10 cm long and 3 mm dia thread.

Plasticity Index (Ip) = Liquid Limit (WL) - Plastic Limit (Wp)

In case of sandy soils, plastic limit cannot be determined, the plasticity index is reported as non-plastic (Np). When the plastic limit is equal to or greater than the liquid limit, the plasticity index is reported as zero.

Shrinkage Limit

The object of the test is to determine the shrinkage limit (% of water content), shrinkage index, shrinkage ratio and volumetric shrinkage. The test is done mainly for the shrinkage limit from which other factors can be obtained.

$$\text{Water content (w)} = \frac{W - Wo}{Wo} \times 100$$

Where, W = moisture content of the soil pat, W = weight of the wet soil pat, Wo = weight of the dry soil pat

$$\text{Shrinkage Limit Ws} = w - \frac{V - Vo}{Wo} \times 100,$$

Where, Ws = Shrinkage Limit in %, V = Volume of the wet soil pat, Vo = Volume of the dry soil pat

Shrinkage Index (Is) = Ip - Ws, Shrinkage Ratio (R) = Wo/Vo

Volumetric shrinkage (Vs) = (W1 - Ws) x R, Where, W1 = given moisture content in %.

Unit Weight

The in situ sample is brought in a sampler, the weight of the soil is divided by the volume of undisturbed cylindrical sample to obtain unit weight or density.

Water Content

It is the ratio of the quantity of water in a soil (by weight) to the weight of the soil solids (dry soil), expressed as percent.

So far as the consistency of the soil is concerned, there lies two domains-plastic and non plastic. Shear strength of soil is the property of Cohesion 'C' and internal friction 'f'. These two combined together is known as shear parameter. In laboratory, the shear parameters of soil can be determined by Direct Shear test.

Shear Strength Parameters by Direct Shear Test

The test covers methods for determination of shear strength of soil with a maximum particle size of 4.75 mm is in undrained, consolidated undrained and consolidated drained conditions. The undrained test can be performed only for high impermeable clays. When silty clays and silts are involved, partial drainage is inevitable.

Cohesive soils are compacted to the required density and moisture content. The sample is extracted and trimmed to required size. Specimens of cohesionless soils are prepared by filling a constant mass of soil directly into the shear box.

The test is conducted by applying shear load to failure or 20% longitudinal displacement, whichever occurs first. The shear load is applied by the load cell and corresponding longitudinal displacement is measured by transducer at regular intervals. The vertical compression of soil specimen is also measured.

A minimum of three (preferably four) tests are conducted on separate specimens of the same density at different normal stress. The normal stress selected for the test should be as per field conditions.

The result is presented in the form of a graph in which the applied normal stress is plotted as abscissa and the maximum shearing stress is plotted as ordinate to the same scale. The angle which the resulting straight line makes with the horizontal axis and the intercept, which the straight line makes with the vertical axis is reported as the angle of shearing resistance and cohesion respectively.

B. Rocks

It is a common practice in rock testing to select a set of conditions so that the combined effects of extraneous factors are relatively small and hence the measured results are indicative of rock properties. The test results depend not only on the properties of rocks but also on the manner and the environment in which the rock is tested. Factors affecting the test data include sampling procedure, specimen size, specimen shape, smoothness of specimen surfaces, temperature, rate of loading, moisture content etc.

The terms and symbols used to denote the masses and volumes of rock constituents when calculating index properties such as porosity and density are:

Grains/the solid component of the sample- mass, Ms and Volume, Vs; Pore water mass, Mw and Volume, Vw; Pore air - zero mass and Volume, Va; Pores (Voids) volume, Vv = Vw + Va; Bulk sample mass, M = Ms + Mw; Bulk sample volume, V = Vs + Vv and Density of water, ρω = mass of water per unit volume.

Grain Mass

The grain mass, Ms of the sample is defined as the mass of the sample after oven drying at a temperature of 105°C. The sample should be regarded as oven dry when successive mass determination at intervals of 4 hours yield values differing by less than 0.1% of the sample mass.

Various physical properties defined in terms of rock samples constituents are:

Specific Gravity

It is defined as the ratio of the weight of rock to the weight of equal volume of water:

$$G = \frac{Ws}{Vs} * \ pw = \frac{Vs}{Vw}$$

But the value of True Specific Gravity is determined in laboratory through set norms.

Density

It is defined as mass per unit volume and often expressed as gm/cc or kg/m3. The bulk density, dry density and saturated density can be determined by the method as discussed earlier for the determination of volume of rock.

Water Absorption

It is defined as ratio of weight of water (Ww) absorbed by the rock specimen (expressed in percentage) to its oven dry weight of rock (W):

$$A = \frac{Ww * 100}{W}$$

Void Ratio (e)

It is the ratio of volume of voids (Vv) to the volume of solids (Vs) of the rock:

$$e = \frac{Vv}{Vs}$$

Porosity (n)

It is defined as ratio of volume of voids (Vv) to the volume of rock (V),

$$n = \frac{Vv}{V}$$

Water content, $w = \frac{Mw*100}{Ms}$, Degree of saturation, $Sr = \frac{Vw*100}{Vv}$

Porosity, $n = \frac{Vw*100}{V}$, Void ratio, $e = \frac{Vv}{V'}$ Bulk density (ρ), $KN/m^3 = \frac{M}{V}$

Relative density (Specific Gravity), $d = \frac{\rho}{\rho w}$, Dry density ρ_d $KN/m^3 = \frac{M}{V}$

Saturated density, $\rho_{sat,}$ $KN/m^3 = \frac{Ms + Vv}{V} \rho$ w, Unit weight, $\nu = \rho / g$

Where, V = Vs+Vv

Void Ratio and Porosity values are calculated by computation with the help of following equations:

$$e = \frac{G^*Dw}{D} - 1, \quad n = 1 - \left(\frac{D}{G^*Dw}\right)^*100$$

where, D = Density of rock, G = Sp. Gravity of rock, and Dw = Density of water

There is following relationship between the void ratio and the porosity

$$a = \frac{n}{1-n} \quad \text{and} \quad n = \frac{e}{1+e}$$

Usually porosity is expressed in percentage of the total volume and depends upon the grain size, shape and kind of cementing/interlocking material. The presence of voids/pores affects the strength properties of rock.

Uniaxial Compressive Strength (UCS)

This method of test is intended to measure the Uniaxial Compressive Strength (UCS) of a rock sample of regular geometry. The test is meant for strength classification and characterisation of intact rock. It should be noted that sample for Uniaxial Compressive strength should be adjacent to joint surface. The specimen may be in the shape of cylinder i.e. core (preferably Nx size) or Cube. In case of cylindrical sample, the length(l) to diameter(d) ratio should be 2.5 - 3. Here, the load is applied in only one direction and the compressive strength is defined as the load per unit area at failure and is expressed in MN/m^2 or kg/cm^2 .

Point Load Strength

This test is intended as a method for measuring the strength of rock specimen in the field using portable equipment. Specimen in the form of either rock core (the Diametral and Axial test) or of irregular lumps (the Irregular lump) are broken by applying a concentrated load using a pair of conical platens. A Point Load Strength Index $IS_{(50)}$ is obtained which may be used for rock strength classification. Alternatively, this method is also practiced in laboratory.

The point load strength index (Is) is calculated as below:

$$Is = \frac{P}{D^2} \text{ in } MN/m^2 \text{ or } kg/cm^2,$$

Where P is the failure load and D is the distance between the two platens. A median value of Is is identified by systematically deleting the highest and the lowest values. For cores other than 50 mm dia the size correction to point load strength index value is corrected to $Is_{(50)}$ using the size correction chart.

Shear Parameters

Shear Strength Parameters of the material prone to potential instability are characterised by its cohesion and friction angle. These are determined by sophisticated laboratory or in-situ test in which all the characteristics of the in situ test behaviour of the rock discontinuity are reproduced as accurately as possible. A number of shear machines both for test in laboratory and in field (portable) are available which are designed to take samples of sizes 10 cm x 10 cm to as large as 30 cm x 40 cm. The loading rate is variable over a very wide range and normal and shear displacements can be monitored continuously during the test.

Direct Shear Test

The test determines peak and residual shear strength as a function of normal stress to shear stress. The test specimen is so inclined with respect to rock mass and its direction of mounting in the shear box as to shear plane coincides with the discontinuity plane. The shear strength determination is preferably done on at least five specimens with normal stress in each case. Shear and normal stresses are computed as:

Normal stress $\sigma_\eta = \rho_s/A$
Shear stress, $\tau = \rho_\eta/A$
Where ρ_s = total shear force; ρ_η = total normal force

A = area of shear surface overlap (corrected to account for shear displacement)

Conclusion

It is needless to emphasise that significance of index properties and geomechanical parameters in the study of slope stability analysis has got every relevance. Therefore, the field geologists are advised to utilise these parameters in studying and analysing the problems of instability of slope.

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References

Manual on Rock Mechanics, Central Board of Irrigation and Power, 1988.

Compendium of Indian Standards on Soil Engineering Part 1, Bureau of Indian Standards 1987.

Hoek, E. & Bray, J. (1981) : Rock Slope Engineering.