LANDSLIDES

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DIGEST OF PUBLISHED INFORMATION

Landslides cannot possibly occur except on slopes whose inclination is greater than the angle of internal friction For dry and perfectly cohesionless materials the angle of internal friction is fairly identical with the angle of repose For materials with cohesion the term " angle of repose " has no meaning, and for such materials the angle of internal friction could not possibly be determined except by friction tests covering a wide range of pressure Thus far very little is known about this subject, as far as cohesive materials are concerned For materials with miscroscopic grains and very feeble cohesion the angle of internal friction is approximately identical with the angle of repose of the dried material in a loose state, but for fine grained materials no such simple relation exists.

As a rule, the angle of internal friction of cohesive materials seems to be very small, or considerably smaller than the average slope of hillsides in nature For this reason the majority of landslides occur on the slope of deposits of cohesive earth Slides in cohesionless materials can only take place if the angle of internal friction spontaneously drops below the normal value, due to a change in the hydrostatic conditions of the water contained in the voids

The theory of the equilibrium of cohesive materials has advanced to such a point that the factor of safety against sliding can roughly be computed, if the angle of internal friction ϕ and the cohesion (shearing strength under no pressure) C are known. Two different methods of computation can be used The French one is based on the Coulomb-Rankine principles and gives good conception of both the stress conditions and of the shape of the sliding curves. The Swedish method is less scientific, but seems to serve the practical purpose better. No theoretical refinements beyond the existing theories seem to be required.

The open problems consist (a) in roughly estimating in advance the values ϕ and C and (b) in selecting the most efficient methods for stabilizing unstable or moving slopes

(a) The older authors were inclined to assume that landslides very often occur on pre-existing sliding planes and even believed that such sliding planes could be " revived " by lubrication with water Today it is known that pre-existing sliding planes play an insignificant rôle. Everything depends on the values of ϕ and C.

The difficulties one meets when attempting to estimate ϕ and C are manifold, foremost among them being the lack of uniformity of most of the soil deposits, and the fact that the values of both ϕ and C are apt to change as a result of a change in the hydraulic conditions or of a change in the soil structure (arrangement of the soil particles) Thus far the most important organized effort to obtain data for stability calculations was made by the Swedish Geotechnical Commission for the Swedish government railroads It consisted in systematically sampling the suspect sections of the slopes along the railroads and in submitting the soil samples to standardized laboratory tests. Due to lack of previous experience, the amount of time and labor was somewhat out of proportion with the results obtained, particularly inasmuch as the soil tests failed to furnish the data required for reliable soil identification Yet with certain modifications based on broader experience and a deeper insight into the physical nature of friction and cohesion, the Swedish method of attack may lead to a working solution.

(b) Properly selecting the remedies requires above all a knowledge of the causes which underlie the defects Since every landslide is preceded by a state of equilibrium, the start of the movement must be associated with a decrease of ϕ, C or of both, and no such decrease can occur, unless the voids of the soil contain water This fact has been known for a long time However, the conceptions concerning the rôle of the water have changed The older conceptions were based on the idea that the water as such acts as a lubricating agent It is now known that the water cannot possibly act as a lubricant, unless it is "trapped," that means brought under pressure without having an opportunity to escape other than slowly Hence the chief requirement for successfully handling unstable slopes consists in leading the gravitational water out of those strata, in which the water circulates (Ordinary drainage)

In those cases, however, where the unstable section essentially consists of a homogeneous, feebly permeable material, drainage is ineffective. In these cases the slides are primarily due to excessively steep slopes The movement starts with the formation of cracks which serve as water pockets. The remedy consists first of all in computing the admissible slope from the results of a preceding estimate of the values ϕ and C (using the Swedish theoretical procedure) and then to provide ample surface drainage of the ground located behind the crest of the slope.

As soon as the movement starts, the consistency of the moving masses spontaneously drops to a lower value The importance of the decrease in consistency depends on the nature of the soil in a manner which, thus far, is still unknown. If the drop in consistency is small (Pennsylvania slides) the movements can be stopped by placing some obstacles (piles) into the path of the moving masses However, if the drop is important (certain glacial clays and rock flours) it is very difficult to stop the movements In this case it is more economical to keep the slopes from the very beginning within safe limits.

Information about whether or not a suspect mass of earth can be handled by drainage consists in drilling holes through the material to the level of the base of the slope and to observe whether or not there is a free flow of water towards the holes

Facts Established

1. For cohesionless materials the angle of internal friction is approximately identical with the angle of repose For moist cohesive materials there is no "angle of repose" and the angle of repose of dried and powdered cohesive materials has nothing in common with the angle of internal friction of the moist materials (Ref 94 and 99).

2 Distinction should be made between the apparent and the true cohesion of soils The apparent cohesion disappears, if the soil is brought into contact with water, whereby the soil swells The true cohesion is not affected by the presence of water (Ref 99)

3 If limited by a plane sloping at an angle equal to the angle of internal friction, shrinkage cracks have no effect on the stability conditions because in every point of the mass the weight of the earth tends to produce compression (Ref 94)

4 On slopes steeper than the angle of internal friction there is a tendency for the dead weight of the material to produce tensile stresses. Hence in this case the formation of shrinkage cracks involves a decrease in stability (Ref 94)

5 The angle of internal friction of clays is of the order of 14° (Ref 99) or even smaller (Ref 94) Hence on every clay slope steeper than 4 1 or 5 1 the theoretical possibility for slides exists

6 Without the voids of the material being filled with water, there is no possibility for a spontaneous drop either in friction or in cohesion Hence the most important protection measure consists in

draining the gravitational water out of the slope, provided such water is present (Ref 89-92)

7 Water in itself is an antilubricant, tending to increase the friction rather than to reduce it The so-called lubricating effect can only take place if the water is "trapped" (Ref 99)

8 The angle of internal friction of cohesionless materials may spontaneously drop, in the presence of water, to a lower value on account of local settlement In this case the lowering of the friction precedes the slide (Ref 93, 99).

9. The angle of internal friction of cohesive materials may drop on account of merely disturbing the arrangement of the particles In this case the slide precedes the lowering of the internal friction (Ref. 99).

10 The tendency of a slope to slide can frequently be learned from the presence of slide scars, the remnants of ancient landslides. (Landslide topography.) (Ref. 90, 91, 104)

11. When a landslide goes down, rupture should theoretically occur along cylindrical surfaces, the cross-section having the shape of a deformed cycloid (Ref 96, 98)

12. For stability computations the cycloids can be replaced with sufficient accuracy by circular curves (Ref 103)

13 For materials whose consistency is only slightly affected by the soil movement, the movements can be stopped by placing obstacles, as piles or the like, into the path of the moving mass (Ref 102).

14. For materials whose consistency considerably drops as a result of the disturbance, ample prevention measures represent a good investment

STRONG INDICATIONS

1. In very fine-grained soils, the tendency to slide depends, under equal external circumstances, on the character of the soil and its water content. The most unstable soils seem to be those intermediate between typical clays and miscroscopic sands (Feebly plastic, uniform materials)

2 The stability of slopes composed of weathered rock and residual soils seems essentially to depend on the character of the rock, irrespective of the character of the finest soil constituents.

3. In materials where the water freely circulates through cracks, fissures or through veins of sands, drainage seems to represent the most effective method for handling the situation

4. For strata with little or no circulation of gravitational water, drainage seems to fail to produce the desired results. The most effective remedy seems to consist in this case in making the slopes flat and in providing proper surface drainage on the surface beyond the crest of the slopes

5. Artificial fills consisting of chunks of cohesive soils seem to become gradually more homogeneous and to develop a true cohesion of the order of magnitude of 0 2 to 0 3 kg per cm^2

Research in Progress

1. Effect of disturbing the structure of the soil on its consistency and an attempt to correlate the relative importance of this effect with the other soil properties.

2 A study of how Frontard's equations compare with actual experience

3 An analysis of the data on landslides presented by the Swedish geotechnical commission in (Ref 7)

4 A study of individual landslides including description of the slide itself, the topographic, geologic and hydrologic conditions and of the success of the attempted remedies.

Suggested Research

1 An experimental study of the relation which exists between the true cohesion and the internal friction for repeated loading and unloading, for the principal types of soils

2 Development of a tool for determining the internal resistance (cohesion plus internal friction) of fine-grained soils by a torsion test to be performed within the drillhole With such a tool, more satisfactory results would be expected than were obtained by the Swedish investigators

3. A petrographic study of the rock material, obtained from both stable and unstable slopes in Pennsylvania and in West Virginia. The results should be supplemented by a sieve analysis and by accelerated soundness tests (20-hour immersion in sodium sulphate alternating with 4-hour drying at 100° C)

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TOP DRESSING OR DRY MAINTENANCE ROADS

C N Conner
Highway Research Board

The following is a résumé of publications, correspondence, conferences and field inspections. It includes:

General Description, Materials, Construction Methods, Maintenance Methods, Costs and Service.

This type of construction has been used with success.