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A SUGGESTED METHOD FOR REPORTING LANDSLIDE CAUSES

PROPOSITION D'UNE MÉTHODE POUR RENDRE COMPTE DES CAUSES DES GLISSEMENTS DE TERRAIN

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Summary

A brief list of landslide causal factors is presented and a format for reporting landslide causes is suggested. They make useful additions to the Landslide Report proposed by the International Geotechnical Societies' UNESCO Working Party on World Landslide Inventory.

Résumé

L'auteur présente une brève liste des causes des glissements de terrain et suggère un système de référence destiné à rendre compte de ces causes. Cette liste et ce système constituent un complément utile au « Compte rendu sur un glissement de terrain » proposé par le Comité de Travail de l'UNESCO pour l'Inventaire mondial des glissements de terrain, établi par les Sociétés Internationales de Géotechnique.

1. Introduction

The International Geotechnical Societies' UNESCO Working Party on World Landslide Inventory (WP/WLI) has been formed from the IAEG's Commission on Landslides and Other Mass Movements, the ISSMFE's Technical Committee on Landslides and nominees of National Groups on the International Society for Rock Mechanics. As a contribution to the International Decade for Natural Disaster Reduction (1990-2000), the Working Party is assisting the establishment of a World Landslide Inventory by suggesting standard terminology for describing landslides. The Working Party has suggested a method for reporting a landslide (WP/WLI, 1990) and for preparing a landslide summary (WP/WLI, 1991). The Party's working definition of a landslide is "The movement of a mass of rock, earth or debris down a slope" (Cruden, 1991).

In August 1989, the Working Party set up Working Groups to suggest methods of classifying the rates of movement of landslides, their causes, their geology, their activity and the distribution of movement within landslides.

When preparing a landslide report for a particular site, it is of primary importance to recognize the conditions that caused the slope to become unstable and the processes that triggered the movement. Only an accurate diagnosis makes it possible to properly understand the landslide mechanisms and to propose effective remedial measures. The great variety of slope movements reflects the diversity of factors that may disturb slope stability (Popescu, 1984).

This report provides an operational approach to the classification of landslide causes for use in reporting historic landslides, as proposed by the Working Party on World Landslide Inventory (1990, 1991). The suggested method is summarized in Tables 1 and 2.

2. Landslide causes and the factor of safety

In every slope there are forces which tend to promote downslope movement and opposing forces which tend to resist movement.

A general definition of the factor of safety, F, of a slope results from comparing the downslope shear stress, τ, with the shear strength, τ_f, of the soil, along an assumed or known rupture surface : $F = \tau_f/\tau$.

Starting from this general definition, Terzaghi (1950) divided landslide causes into external causes which result in an increase of sheraing stress (e.g. geometrical changes, unloading the slope toe, loading the slope crest, shocks and vibrations, drawdown, changes in water regime) and internal causes which result in a decrease of the shearing resistance (e.g. progressive failure, weathering, seepage erosion). However, Varnes (1978) pointed out there are a number of external or internal causes which may be operating either to reduce

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Table 1 : A brief list of landslide causal factors.

1. GROUND CONDITIONS
   1) Plastic weak material
   2) Sensitive material
   3) Collapsible material
   4) Wheathered material
   5) Sheared material
   6) Jointed of fissured material
   7) Adversely oriented mass discontinuities (including bedding, schistosity, cleavage)
   8) Adversely oriented mass discontinuities (including faults, unconformities, flexural shears, sedimentary contacts)
   9) Contrast in permeability and its effects on ground water
   10) Contrast in stiffness (stiff, dense material over plastic materials)
2. GEOMORPHOLOGICAL PROCESSES
   1) Tectonic uplift
   2) Volcanic uplift
   3) Glacial rebound
   4) Fluvial erosion of the slope toe
   5) Wave erosion of the slope toe
   6) Glacial erosion of the slope toe
   7) Erosion of the lateral margins
   8) Subterranean erosion (solution, piping)
   9) Deposition loading the slope crest
   10) Vegetation removal (by erosion, forest fire, drought)
3. PHYSICAL PROCESSES
   1) Intense, short period, rainfall
   2) Rapid melt of deep snow
   3) Prolonged high precipitation
   4) Rapid drawdown following floods, high tides or breaching of natural dams
   5) Earthquake
   6) Volcanic eruption
   7) Breaching of crater lakes
   8) Thawing of permafrost
   9) Freeze and thaw weathering
   10) Shrink and swell weathering of expansive soils
4. MAN-MADE PROCESSES
   1) Excavation of the slope or at its toe
   2) Loading of the slope or at its crest
   3) Drawdown (of reservoirs)
   4) Irrigation
   5) Defective maintenance of drainage system
   6) Water leakage from services (water supplies sewers, stormwater drains)
   7) Vegetation removal (deforestation)
   8) Mining and quarrying (open pits or underground galleries)
   9) Creation of dumps of very loose waste
   10) Artificial vibration (including traffic, pile driving, heavy machinery)

the shearing resistance or to increase the shearing stress. There are also causes affecting simultaneously both terms of the factor of safety ratio.

In order to facilitate a better understanding of landslide causes, reference is made to Figure 1 which shows an example of factor of safety variation as a function of time, for a given slope. Seasonal rainfall and evaporation is reflected in seasonal variations in the factor of safety. Should there be a long-term trend in groundwater levels, or changes in strength due to weathering, these will show as a trend imposed on the seasonal variation. Sudden changes will be due to short-term variation in either the strength of the materials or the forces applied to the slope.

This demonstrates that seldom, if ever, can a landslide be attributed to a single causal factor. The process leading to the development of the slide has its beginning with the formation of the rock itself, when its basic properties are determined and includes all the subsequent events of crustal movement, erosion and weathering (Varnes, 1978).

Table 2 : Landslide Report Section on Landslide Causal Factors. Example for the Hudson Slide (Terzaghi, 1950).

Preparatory causal factors : 4.2, 4.7
Triggering causal factors : 3.3

The computed value of the factor of safety is a clear and simple distinction between stable and unstable slopes. However, from the physical point of view, it is better to visualize slopes existing in one of the following three stages : stable, marginally stable and actively unstable (Crozier, 1986). Stable slopes are those where the margin of stability is sufficiently high to withstand all destabilising forces. Marginally stable slopes are those which will fail at some time in response to the destabilising forces attaining a certain level of activity. Finally, actively unstable slopes are those in which destabilising forces produce continuous or intermittent movement.

The three stability stages provide a useful framework for understanding the causal factors of landslides and classifying them into two groups on the basis of their function (Fig. 1) :

1. Preparatory causal factors which make the slope susceptible to movement without actually initiating it and thereby tending to place the slope in a marginally stable state.

2. Triggering causal factors which initiate movement. These causal factors shift the slope from a marginally stable to an actively unstable state.

A particular causal factor may perform either or both functions, depending on its degree of activity and the margin of stability.

Although it may be possible to identify a single triggering process, an explanation of ultimate causes of a landslide invariably involves a number of preparatory conditions and processes. Based on their temporal variability, the destabilising processes may be grouped into slow changing (e.g. weathering, erosion) and fast changing processes (e.g. earthquake, drawdown). In the search for landslide causes, attention is often focused on those processes within the slope system which provoke the greatest rate of change. Although slow changes act over a long period of time to reduce the resistance/shear stress ratio, often a fast change can be identified as having triggered movement.

3. An operational approach to the classification of landslide causal factors

Because landslide cause assessment is complex and landslides are not always investigated in great detail, it

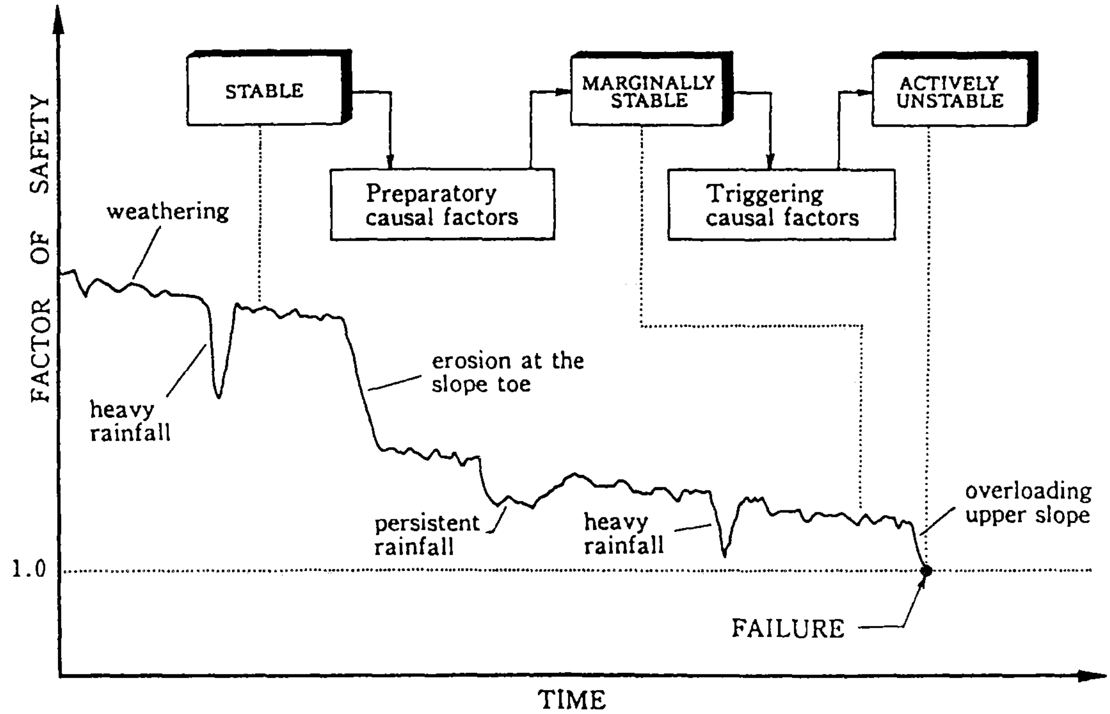

Fig. 1 : An example of changes in the factor of safety with time.

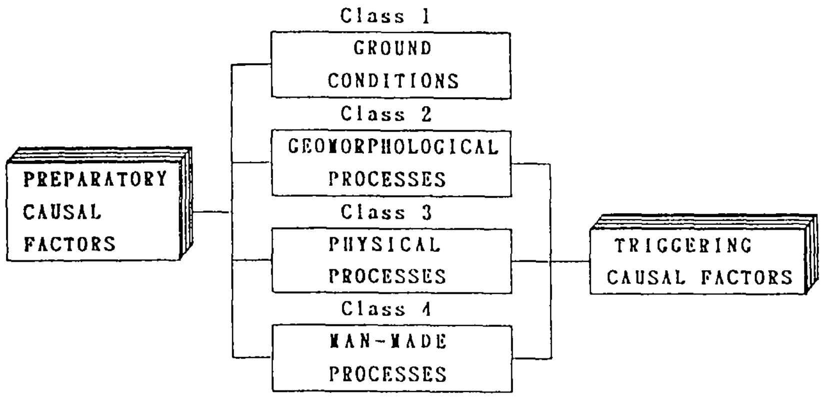

Fig. 2 : Types of causal factors of landslides.

appears reasonable to adopt a simple classification system of landslide causal factors.

When assessing landslide causes it is necessary to make a distinction between ground conditions and processes. Ground conditions are the specification of the slope system, the setting on which a process can act to prepare or trigger a failure (Brunsden, 1979).

The proposed operational approach to classification of landslide causal factors is intended to cover the majority of landslides. It involves the consideration of the available data from a simple site investigation and information furnished by other site observations.

The classification proposed in Figure 2 and Table 1 divides landslide causal factors according to their effect (preparatory or triggering) and their origin (ground conditions and geomorphological, physical or man-made processes). Ground conditions may not have a triggering function, while any ground condition or process may have a preparatory function.

Ground conditions or the material and mass characteristics of the ground, can be mapped on the surface of the landslide and the surrounding ground and explored in the subsurface by drilling, trenching and adits. Mechanical characteristics can be determined by testing.

Geomorphological processes or changes in the morphology of the ground, can be documented by pre-existing maps, aerial photographs, surveys of the landslide, or careful observation over time by the local population.

Physical processes concern the environment and can be documented at the site by instrumentation, such as rainfall gauges, seismographs or piezometers. Careful local observations over time of water wells or damage from earthquakes may be acceptable substitutes. Variations in mechanical properties with distance from the surface may, in some circumstances, indicate changes of these properties with time.

Man-made processes can be documented by site observations and from construction or excavation records at the site. Separate identification of artificial and natural landslides is useful for both administrative and theoretical reasons.

We propose to include a new section on landslide causes in the Landslide Report (WP/WLI, 1990). This section would have two headings, namely "Preparatory causal factors" and "Triggering causal factors". Under each heading there will be a list of causal conditions and processes belonging to each class, which are relevant to the reported landslide (Table 2).

For instance, Terzaghi (1950, p. 105) suggested that among the causes of the Hudson slide of 1915 were "the accumulation of stockpiles of crushed rock, with a total weight of about 25,000 tons along the upper edge of the slope... the deforestation of the outcrops of the gravel or of an adjacent aquifer produced an unprecedented increase of the highest elevation of the water table". These are preparatory causal processes 4.2 and 4.7 in Table 1.

Terzaghi also noted (1950, p. 105) "The Hudson slide was preceded by unusually heavy rainfall". This is triggering process 3.3 in Table 1.

4. Discussion

The need to properly recognize landslide causal conditions and processes in order to understand landslide mechanisms and to propose effective remedial measures is apparent.

The suggested method for reporting landslide causes in the Landslide Report (WP/WLI, 1990), should simplify acquiring and accumulating information.

A brief list of landslide causal factors is proposed in Table 1. Most of them are selected from a larger list in Varnes (1978) and their operation is discussed in references given by Varnes. However, there are some landslide causal processes which are not considered by Varnes, such as the thawing of permafrost slopes (McRoperts, Morgenstern, 1974) or breaching of crater lakes (O'Shea, 1954) which have been inserted in our classification.

We propose that a section on landslide causal factors be included in the Landslide Report (WP/WLI, 1990) as outlined in Table 2. Table 1 would make a useful check list attached to the Landslide Report form.

The structure of the landslide causal factors list (Table 1) and the format of the landslide causal factors report (Table 2) are suggestions which can be modified by discussions from within or without the Working Group. The Working Group welcomes carefully documented proposals for additions or amendments to the Suggested Method.

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