THEME 3

Assessment of the effectiveness of corrective measures in relation to geological conditions and types of slope movements

Experiences with corrective measures applied to slope movements

Evaluation de l'efficacité des mesures de stabilisation par rapport aux conditions géologiques et aux types des mouvements du terrain

Expériences acquises par l'exécution des mesures de la stabilisation

General report / Rapport général

ASSESSMENT OF THE EFFECTIVENESS OF CORRECTIVE MEASURES IN RELATION TO GEOLOGICAL CONDITIONS AND TYPES OF SLOPE MOVEMENT

EVALUATION DE L'EFFICACITÉ DES MESURES DE STABILISATION PAR RAPPORT AUX CONDITIONS GÉOLOGIQUES ET AUX TYPES DES MOUVEMENTS DU TERRAIN

HUTCHINSON J.N., Imperial College of Science and Technology, London, United Kingdom*

Summary:

The General Report consists of three parts. In Part 1, the various types of corrective measures are briefly reviewed. Attention is then concentrated on the two, most used measures; modification of the slope profile by excavation and filling, and drainage. An analysis is made of the optimum positioning of corrective cuts or fills, making use of the influence line concept, borrowed from structural engineering. In this way a neutral point, neutral line and neutral zone are defined for circular and non-circular landslides and for various values of B with respect to the applied change in total stress. Drainage is then discussed in more detail, with particular attention being given to horizontal drains and to trench (and counterfort) drains. Performance data for trench drains in the U.K. are then reviewed and analysed. From this a tentative basis for design is developed.

In Part 2 the papers contributed to Theme 3 of the Symposium are reviewed. The clogging of drainage systems by siltation or by geochemical effects, is also discussed. Finally, in Part 3, some suggestions are made as to the desirable directions of future research. An extensive list of references is provided.

Résumé:

Le Rapport Général se compose de trois parties. Dans la première partie les différentes mesures de stabilisation sont brièvement examinées. L'attention est ensuite portée sur les deux mesures les plus courantes: la modification du profil de la pente par excavation et remblayage et par drainage. Une analyse est faite de l'emplacement optimal des tranchées ou des remblais de stabilisation qui utilise le concept de la ligne d'influence emprunté au génie structural. De cette manière un point neutre, une ligne neutre et une zone neutre sont définis pour les glissements de terrain circulaires et non-circulaires ainsi que pour des valeurs diverses de B en tenant compte du changement apporté à la tension totale. Le drainage est ensuite discuté de façon plus approfondie en insistant plus spécialement sur les drains horizontaux et les drains tranchés (et contreforts) en particulier. Les résultats d'essais sur l'utilisation de drains tranchés dans le Royaume Uni sont présentées et analysées. A partir de ces données une tentative de mise au point de drains tranchés est développée.

Dans la deuxième partie les contributions écrites du Sujet 3 sont discutées, ainsi que le colmatage des systèmes de drainage par dépôt de limon et par effets géochimiques. Enfin, dans la troisième partie sont présentées des suggestions sur l'orientation à donner aux futurs projets de recherches. Une liste détaillée de références est donnée.

* Imperial College of Science and Technology, Department of Civil Engineering, Prince Consort Road, South Kensington, London SW7 2BU
Introduction

In view of its context, this General Report concentrates on the stabilization of slopes consisting of soils and rocks in their natural state, in either natural slopes or cuttings, and excludes ones that comprise chiefly fills.

The theme chosen by the Organising Committee is a good one. It directs our attention specifically towards the assessment of the efficacy of stabilization measures, which a reading of the literature shows to have been a matter largely neglected hitherto. This situation has doubtless arisen partly from a natural desire to close the file on a job and partly from the reluctance of the client or owner to accept continuing expenditure on long-term monitoring.

In accordance with the wishes of the Organising Committee, the General Report consists of three parts. The first reviews the main aspects of the theme in the light of the present state of knowledge, the second evaluates the contribution of the submitted papers while in the third, suggestions are made as to the nature of the still unsolved problems and the direction of future research.

1. Review

General


The main methods of stabilization used are summarised briefly below. They may be employed singly or in combination.

1. Excavation & filling

a/ Excavate at toe until stability is attained: a crude method which relies on stimulating retrogression of the slide until its average slope is sufficiently gentle to be readily maintained. Large quantities of excavation are generally involved. The classic application of the method is in the Culebra reach of the Gaillard Cut on the Panama Canal /Lutton & Banks, 1970/.

b/ Remove and replace slipped material: either wholly by free-draining material /Symons, 1970/ or, more economically, by recompacted slip debris provided with drains /Newman, 1890, Duncan, 1971/. The method is obviously applicable only to slips of modest size. A variant of this method is to destroy pre-existing shear surfaces at shallow depths by digging out, remoulding and recompacting the excavated material /Weeks, 1970/.

c/ Excavate to unload slope: either by a general flattening, with or without berms /Baker & Marshall, 1958, Brooks, 1969/, or locally at the head of a slide /Peck & Ireland, 1953; Lutton & Banks, 1970/. As discussed later, it is important that such excavations are correctly positioned.

d/ Filling to load slope: generally by means of berms, possibly combined with other gravity structures, such as a gabion or reinforced earth walls, at its toe /Viner-Brady, 1955; Brooks, 1969, Early & Skempton, 1972; Záru-ba & Mencl, 1976/. Again the correct positioning of stabilising fills is of great importance, as is their proper drainage. The disturbing effects of embankments that have, unavoidably, to be placed in pre-existing shear surfaces can be reduced by the use of light-weight fills, such as fly-ash.

2. Drainage

/Cedergren, 1967, 1975, Rat, 1976/

a/ Lead away surface water: this should generally be done immediately /Záru-ba & Mencl, 1969/.

b/ Prevent the build-up of water in tension cracks: this should also be attended to straight away /East, 1974/. Attempts to seal such cracks against surface inflow usually fail, as any seal will tend to be broken by the slightest further movement. It is better, therefore, to make arrangements to drain cracks.

c/ Blanket slope with free-draining material, with filters as necessary: This combines measure 1 /d/ with drainage /Root, 1958/ and is particularly effective in the case of slopes exposed to rapid drawdown /Skempton, 1946, Finzi & Nicolai, 1961; Cedergren, 1967, Klingel et al. 1974/.

d/ Trench drains: these are generally narrow* and aligned directly downslope /Early & Skempton, 1972/, thus largely avoiding the risk of reactivating the landslide being treated. They are sometimes supplementecl by shallower drains laid in a chevron or herring-bone pattern /Duvivier, 1940/. An earlier version of the trench drain is the counterfort drain. In this the invert is located in firm ground beneath the slip surface so that, in addition to reducing ground-water pressures, the drains also provide some mechanical support /Gregory, 1844, Collin, 1846/. Open or gravel-filled drain trenches running cross-slope are sometimes built above the crest of a slip or slope, when they are usually termed interceptor or cut-off drains /Toms & Bartlett, 1972, Smith, 1964/. Shallow ones merely intercept surface run-off; deeper ones are intended to intercept ground-water flowing towards the slope. A deep cut-off trench, extended downwards by drain holes into a drainage gallery, was constructed at the head of the colluvial slope being stabilized at Wescott /DP Appolinario et al., 1976/. Care must be taken to avoid siting cut-off drains so that they could act as a tension crack in any future landslide.

e/ Horizontal drains: usually drilled into a slope on a slightly rising gradient and provided with perforated or porous liner /Smith & Stafford, 1957, Root, 1958, Robinson, 1967, Henke, 1968, Nonveiller, 1970, East, 1974, Tong & Maher, 1975; Brandl, 1976/. The maximum practicable length of such drains is generally around 100 m, though one 231 m long is reported by Záru-ba & Mencl /1976/. Lengths of up to about 60 m are more common. In slides of large scale, horizontal drains can be used to advantage in conjunction with vertical drainage shafts /Nat. Conf. Landslide Control, 1972/, with trench drains /La Rochelle et al., 1976/, or with galleries /see 2f below/. In cold climates it may be necessary to prevent the outlets of horizontal drains from freezing /Goldier, 1971/.

f/ Galleries: expensive, but can be appropriate to use in the treatment of very large slides /Viner-Brady, 1955; Kezd, 1969; National Conf. Landslide Control, 1972, Rico et al., 1976/. Supplementary drainage borings can be made through the sides, floor or roof of the galleries as required /Taniguchi & Watari, 1965; Rodriguez et al., 1967, Záru-ba & Mencl, 1969, Hoek & Bray, 1974, Nilsen & Lien, 1976/. For galleries running parallel to the slope face, Sharp /1970/ has made a study of the optimum locations for various ratios of horizontal to vertical permeability, using a variable resistance analogue.

g/ Vertical drains: these may discharge by gravity through horizontal drains or add /well-drains/ /Seaton, 1938; Palmer et al. 1950; Sherrell, 1971; Rat, 1976/, by siphoning, within the normal limitation of depth /Root, 1958/, or by automatically activated pump /National Conf. Landslide Control, 1972; Hoek & Bray, 1974/. Alternatively, the water may be blown out of the wells at intervals by compressed air. Under favourable hydrogeological conditions it is sometimes feasible to discharge downwards into an underlying aquifer at lower piezometric pressure /Barrett, 1955; Wilson, 1961/. In some cases, however, such measures have led to fresh stability problems associated with the under-draining stratum /Záru-ba & Mencl, 1969; Lefebvre & Lafluer, 1976/. Vertical drains may also be used as relief wells, discharging upwards, to lessen artesian ground-water pressures at depth. The use of sand drains in this way, to stabilize a slope of quick clay, is described by Hold /1961/.

* Wider drains, in which a bulldozer can operate, are used in the U.S. /Root, 1958/.