邊坡穩定與坍方研討會
論文專集

中國工程師學會
中國土木水利工程學會
台灣台北
中華民國六十八年
四月二日至四日

邊坡穩定與坍方研討會
論文專集

PROCEEDINGS OF SEMINAR ON
SLOPE STABILITY AND LANDSLIDES

中華民國六十八年四月二日至四日
台灣 台北
2-4 April, 1979
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中國工程師學會
中國土木水利工程學會
Chinese Institute of Engineers
Chinese Institute of Civil and Hydraulic Engineering

序

近二十餘年來中華民國在台灣地區的經濟發展迅速，各種建設更是領先地加速推動；加以平地面積有限，人口密度逐漸提高，因此山區土地之開發乃爲政府既定的重要政策。由於山地公共建設之安危以及山坡地之開發，其所帶來的土壤工程問題如邊坡之穩定與坍方之處理，隧道工程之計劃，以及土壤基礎與環境安全等問題，不僅對我們工程師是一種用武的機會，也是工程技術的挑戰，同時對國家的土地利用計劃與建設政策也有深透的影響。

近年來，世界各國對土壤工程及岩石力學等已有相當突破性的發展，爲了國際科技的交流以及加速我們的國家建設，我們認爲有必要邀請國內外的土壤工程專家有機會來相互討論交換意見，因此中國工程師學會與中國土木水利工程學會特別聯合擧辦一次邊坡穩定坍方處理爲主題的研討會。

這次研討會於今年四月二日至四日在台北市擧行，特別邀請了國內外九位專家作專題演講及主持討論。參加的人數達三百餘位，在會議期間參加人員發言踴躍，討論熱烈，與會者均認爲是一次成功的研討會。

我們爲了使中國工程師們都能分享這次研討會的成果，特將幾位專家的演講論文出版專集。

本專集得以順利出版，我們必須對專題演講者的貢獻，各位主持人以及亞新工程顧問公司莫若楫博士及其同仁的辛勞，致以謝忱

中 國 工 程 師 學 會 理事長朱　書　麟
中國土木水利工程學會 理事長 王　章　清

中華民國六十八年十二月

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目　　錄
TABLE OF CONTENTS

六十八年邊坡穩定與坍方研討會
1979 Seminar on Slope Stability and Landslides

A PROBLEM-ORIENTED CLASSIFICATION OF SOILS FOR SLOPE STABILITY ANALYSIS

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SUMMARY The reliability of a stability analysis is much influenced by the type of soil under investigation and the groundwater regime affecting the slope. The presentation concentrates on the first consideration by putting forward a classification of soils based on factors that should be recognized when undertaking stability analyses. Distinctions are made between natural soils and processed soils, between coarse-grained and fine-grained soils, between saturated and unsaturated soils, between contractant and dilatant soils, and between intact and fissured soils. The dominant concerns associated with each member in the classification are identified and illustrated in a series of case histories. The selection of the appropriate Factor of Safety is dependent upon a number of factors that vary with soil type. The paper concludes by summarizing the considerations that enter into the choice of the design Factor of Safety.

INTRODUCTION

In Geotechnical Engineering one proceeds from the characterization of the site and materials, through analysis and design to arrive at engineering solutions that are much influenced by judgement and experience. In so doing, the Geotechnical Engineer must address a seemingly bewildering array of materials ranging from loose sands and soft clays on the one hand to hard jointed crystalline rocks on the other. Through all of this, he is assisted by the unifying factors that soil and rock behaviour are best expressed in terms of the concept of effective stress, that a major portion of the mechanical resistance of soils and rocks is frictional, and that the structure of soil and rock have an important influence on the mechanical and hydraulic behaviour of soil and rock masses.

As a result of the range and complexity of materials considered in Geotechnical Engineering, there is widespread agreement among practitioners that it is inappropriate to standardize exploration and design criteria, particularly for problems such as slope stability. Therefore, practices vary greatly and even the same Geotechnical Engineer will likely use different Factors of Safety in design for different materials. This is both confusing to the student or infrequent practitioner and untidy for regulatory agencies who are often more at ease with standardized design procedures and criteria.

Restricting the discussion to problems of slope stability, it is entirely appropriate for design Factors of Safety to vary from site to site and from material to material. However, it is difficult to document precisely how the Factor of Safety should vary since this will always be influenced by specifics of the site and subjectivity of the designer. One of the major factors influencing a designer is his perception of the reliability with which the properties of the soil, particularly the strength, can be determined. In order to illustrate the validity of variations in the Factor of Safety and at the same time provide some guidance to major variables influencing its choice, a classification of soils has been developed that is based on the dominant factors affecting the behaviour and utilization of soils in problems involving slope stability. This classification with illustrative examples is presented in the subsequent sections and is followed by a summary of factors to be considered in the judicious selection of the Factor of Safety.

PROBLEM ORIENTED CLASSIFICATION

The first distinction made is between natural and processed soils, see Figure 1. In the case of processed soils the engineer has considerable control over the behaviour of the soil because he can in many instances select its source and, within constraints to be discussed, he can choose methods of placing the soil which will result in the requisite behaviour. This is not so for natural soils. Here the engineer must generally deal with the soil as he finds it in nature. Moreover, he must devise procedures to determine the soil properties as they are in-situ. Engineering with natural soils is intrinsically less reliable than working with processed soils because of the need to decipher the geological setting of the natural deposit, undertake borings and either perform in-situ tests or obtain samples of sufficient quality to permit material characterization in the laboratory. The problems of site investigation, except possibly the search for borrow areas, and the need to obtain undisturbed samples are not considerations associated with the utilization of processed soils.

PROCESSED SOILS

As illustrated in Figure 2, two different classes of processed soils can be recognized in engineering practice. The first contains the materials normally used in embankment fill construction, while the second refers to the materials encountered in mine and mineral waste disposal. The major distinction being made here is that when dealing with embankment fill material, the engineer has considerable choice over the origin of the material and over how he chooses to process it, i.e., placement moisture content, rolling, vibratory compaction, etc.

A Problem Oriented Classification of Soils

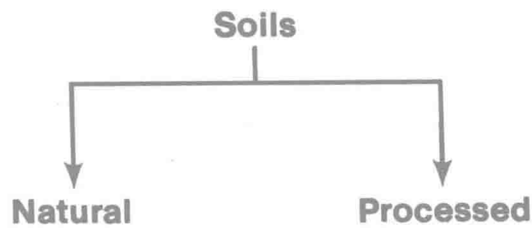

Fig. 1 Basic Classification

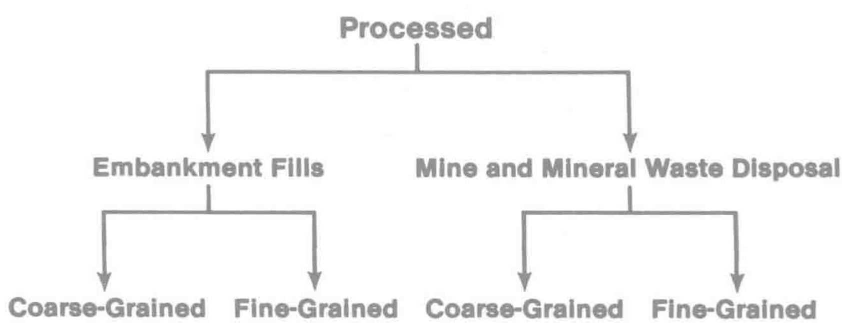

Fig. 2 Classification of Processed Soils

Embankment fill materials can further be classified according to whether they are coarse or fine-grained. The mechanical properties of coarse-grained embankment fills are readily determined for all practical purposes and problems of stability will not arise if they are well-compacted. In the case of fine-grained materials, attention must be given to the development of pore pressures during placement and its influence on stability. However, fine-grained compacted soils have been much studied and their strength properties are well understood. Design with fine-grained compacted soils has progressed to the stage where there is even increasing confidence in predicting deformations. This is not to imply that instability in fine-grained compacted soils has been eliminated. Figure 3 illustrates a catastrophic mud avalanche in Hong Kong in 1976 that resulted in 18 deaths (Morgenstern 1978). The avalanche was triggered by intense rains that lead to the failure of a steep fill embankment. Failure resulted from the development of seepage conditions within a wetted zone as water penetrated the face of the slope. Upon failure, the fill contracted, pore pressures were generated, the fill lost strength, and converted to a mud avalanche. There was evidence, as illustrated by the layering parallel to the slope in Figure 4, that the fill had been left in a loose state as a result of end-tipping. Proper compaction would readily eliminate the hazards to public safety of such conditions.

FIG. 1 VIEW OF CATASTROPHIC MUD AVALANCHE OF 25 AUGUST 1976 AT SAU MAU PING
(COURTESY OF THE SOUTH CHINA MORNING POST LTD HONG KONG)

Fig. 3 Failure of Embankment

Plate 10 Landslide III showing shallow depth of slide and layering parallel to slope

Fig. 4 Loose End-Dumped Material

In the case of processed soils derived as mine and mineral waste, the engineer has no control over the origin and characteristics of the soil but instead is obliged to handle it as it is produced. Moreover, there are usually more stringent economic restraints imposed upon his selection of disposal methods. Often these restraints are complicated by environmental considerations.

A distinction between coarse and fine-grained soils is also appropriate here. Coarse-grained waste, unless it breaks down into clayey material is generally strong and the major problems are seepage control. Problems of instability are usually restricted to the foundations. Fine-grained waste can remain in a weak metastable condition for very long periods of time and its disposal presents special problems.

The classical forms of tailings dams are illustrated in Figure 5. The upstream method requires the least amount of coarse material but generally results in a weaker structure than the downstream method of construction. However, if material has to be imported for a downstream design, large incremental costs are generated. This illustrates some of the compromises that are characteristic of problems associated with the disposal of mine and mineral waste. Further discussion is given by Mittal and Morgenstern (1977).

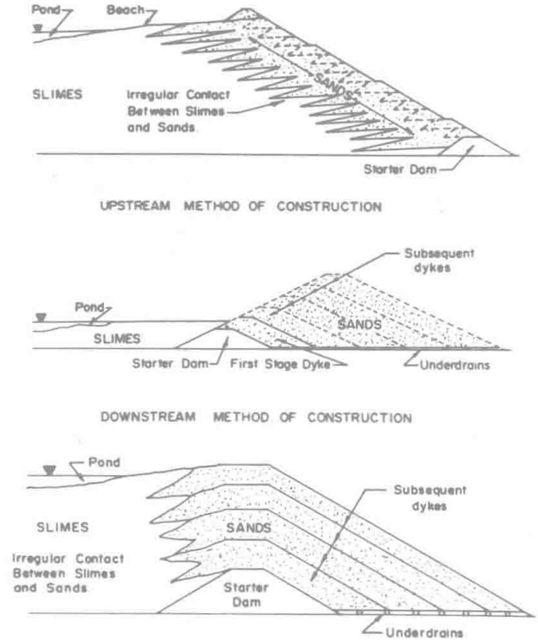

Fig. 5 Typical Design Sections of Tailings Dams

It is often the case that much more time is available to construct embankments for mine and mineral waste disposal than for conventional water-retaining structures. This facilitates a more flexible design procedure and, if the work is properly instrumented and subjected to on-going evaluation of performance, can result in optimized use of soil characteristics that would not otherwise be possible. Figure 6 shows a large tailings dam, about 90 m high, constructed by hydraulic fill methods, in part over a thick bed of normally consolidated alluvial clay. If this had been intended as a conventional earth dam, to be constructed in only a few years, the site would likely have been discarded. More details are given by Mittal and Hardy (1977).

NATURAL SOILS

As noted earlier, the problems of soil characterization differ substantially when dealing with natural soils. Complex groundwater regimes are encountered, properties can vary rapidly over short distances, and both in-situ and laboratory based test procedures yield at best only approximations to the soil behaviour in-situ. Figure 7 suggests that there is a difference in kind depending upon whether the natural soil is coarse or fine-grained.

Fig. 6 Tar Island Tailings Dyke, Alberta

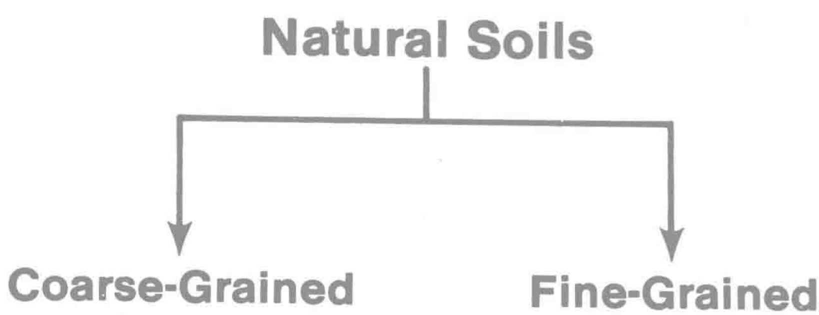

Fig. 7 Classification of Natural Soils

COARSE-GRAINED NATURAL SOILS

Traditionally, coarse-grained soils are further classified according to density into loose or dense materials. Recent studies have revealed that a third class of materials exists that have been called locked sands (Dusseault and Morgenstern, 1979). This three-fold subdivision is given in Figure 8.

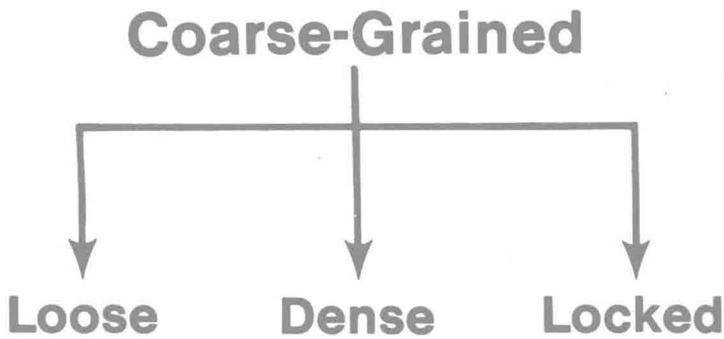

Fig. 8 Classification of Coarse-Grained Natural Soils

Dense coarse-grained natural soils are invariably strong and stability problems are rare. When they occur they are usually associated with some weaker defect within the sand or with blocked seepage such as often arises in slopes in interbedded deposits. Loose coarse-grained deposits are disposed to liquefaction either of a spontaneous or earthquake induced nature. Flow slides result. The mechanisms leading to such slides are well understood although they remain difficult to predict.

Locked sands are sands that have been subjected to load for considerable time and have been exposed to certain diagenetic processes that result in an interlocked texture, see Figure 9. They are uncemented but the interlock creates enhanced dilatancy characteristics and very high angles of shearing resistance at low effective stresses. The failure envelope of locked sands is markedly curved due to particle rupture with suppressed dilatancy at higher effective stresses. This has the effect of reducing the frictional resistance but yielding an apparent cohesion with increasing normal stresses.

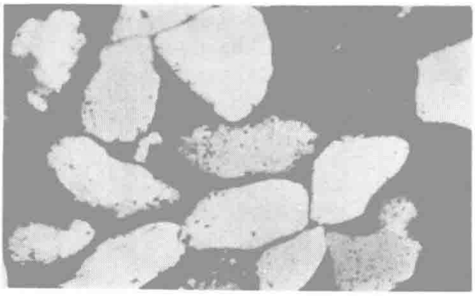

Plate 2 Swan River Sandstone Fabric, X260.
Diagenetic texture is not as well developed as in the St. Peter Sandstone

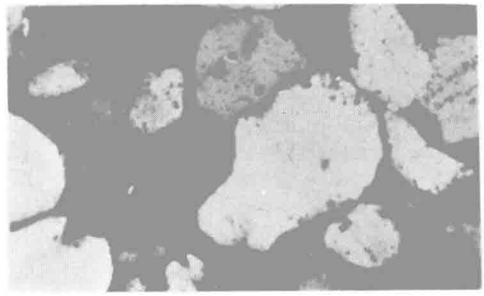

Plate 3 McMurray Formation Fabric, X360.
Similar fabric to the Swan River Sandstone.

Fig. 9 Locked Sands

Locked sands are excellent geotechnical materials. Natural slopes in them are steep, one can often tunnel unsupported in locked sands, and foundation deformations will be small if the fabric is not disrupted. To make efficient use of locked sands it is important to anticipate their occurrence and design site investigation procedures that minimize disturbance of the interlocked texture.

FINE-GRAINED NATURAL SOILS

In the case of fine-grained natural soils, it is suggested that the next major distinction is whether the soil is saturated or only partly saturated, see Figure 10. For saturated soils, regardless of whether stability is being assessed under drained or undrained conditions, the concept of effective stress is clear and the factors affecting changes in pore pressure are reasonably well understood. This is not so for partly saturated soils.

For partly saturated soils, it is generally acknowledged that the suction in the soil is a dominant variable but it is still a matter of research to decide how it relates to the concept of effective stress. Fredlund and Morgenstern (1976) indicate recent work. Of more practical concern, is the recognition that the suction within a partly saturated soil and hence its resistance to shear is influenced by the moisture budget at the surface of the ground. In the case of fully saturated soils, the pore pressure distribution in a natural slope is governed by classical laws of steady seepage and if pore pressures are not known with accuracy it is usually because geological