THE THEORETICAL & PRACTICAL ASPECTS OF LAND STABILITY CLASSIFICATION

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The Theoretical and Practical Aspects of Land Stability Classification

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SUMMARY. The relevance and accuracy of various theoretical concepts and practical procedures adopted in the assessment of the stability of land, is discussed in a manner suited for direct comprehension by non-specialist Engineers. The necessity for the detailed understanding of the site Geological and Environmental processes is emphasised, and guidelines for the undertaking of Land Stability Assessments are presented. Finally, Land Stability Classification systems are suggested for both "Regional" and "Specific Project" type of assessments.

1 INTRODUCTION

Mankind today has a desire to build relatively permanent structures for his place of abode. The system of private land ownership, combined with a fast-growing population, has caused a very large demand for residential land. Consequently, land sub-division has taken place in areas not always suited to conventional Urban Development. It has been the experience of the author that most land instability in residential sub-divisions, is caused by development groups acting without an appreciation of the possible consequences of their actions.

Although the examination of the stability of natural slopes has been major field for scientific endeavour over a considerable number of years, the majority of "State of the Art" reporters (Refs. 6, 8,11,12 & 13), have concluded that we are still largely unable to precisely determine the state of stability of a particular site. Consequently, the various theoretical and practical aspects of land stability classification have been brought together so that the probability approach to the classification process might be more fully understood.

2 NATURAL SETTING

The recognition of areas prone to instability, or actively undergoing movement, requires a detailed understanding of the nature of earth movements. Earth movements occur in a number of ways, and include such phenomena as earthquakes, subsidences, and landslides; however the discussion of the nature and causes of such events is beyond the scope of this paper, and Refs. 3,6,11,12 & 14, are suggested for further study. Suffice to say that, the assessment of actual or potential earth movements at a particular site embraces a number of scientific disciplines such as geology, botany, & hydrology. Whilst it should be obvious that the accuracy with which the scientific base data is collected will greatly influence the correctness of a stability assessment, there are far too many examples of inaccurate data collection that have given rise to a poor evaluation of land stability.

The Frank Slide in Alberta Canada, is an example of how the poor understanding of site geology can lead investigators to be very confused as to the causes of instability. This slide involved approximately 90 million tonnes of rock which moved down the East face of Turtle Mountain, across the entrance of the Frank Mine, the Crowsnest River, the southern end of the town of Frank, the main road from the East, and the Canadaan Pacific Mainline through Crowsnest Pass. The rock mass continued up the opposite side of the valley before coming to rest 120m above the valley floor. The slide event lasted 100s. Immediately after the slide in 1903, an inspection was made by McConnell and Brock and their report was issued a month later. Subsequently a commission was appointed (Daly et al 1912) to investigate the possibility of further movements. The report of this commission has appeared in many recent texts (Refs. 7,12 & 14), and in these texts various theories are advanced as to the possible failure modes. Due to the nature of the failure modes proposed, i.e. failure across joint planes rather than along bedding or joint planes, considerable controversy has surrounded the cause of the slide. It is extremely unfortunate that these recent texts overlooked the geological work undertaken in 1913 (J.D.McKenzie), 1932 (MacKay), & 1933 (Allan) which all indicated that the geology of the area was quite different from that assumed by the commission under Daly in 1912. This later geological work indicated that Turtle Mountain was in reality an anticline, and that failure would have taken place along the bedding planes. It is hoped that the careful investigation of Cruden & Krahn (Ref. 2) will give an impetus to theoretical investigators to carefully check their field data.

Whilst similar geological conditions will generally give rise to similar movements, it is important to recognise that the nature and form of earth movement at a particular site is dependant upon the detailed geological situation. It is considered therefore that the Natural Site Setting, i.e. geology, topography, botany & climate, must be accurately determined before the stability of a particular piece of land can be assessed.

3 THEORETICAL CONCEPTS

(a) Failure Mechanisms

Many Engineers involved in the design process for Urban Development unfortunately do not have an adequate appreciation of the geological processes which cause the instability of land, and as a consequence many developments in Urban areas have been subject to landslip. In the past there has been too much emphasis on theoretical approaches which are not related to the physical field conditions, and consequently undue credence has been placed upon the results of the theoretical analyses.

It is disturbing that so many technical articles are still published using terminologies such as "The Classical Cylindrical Form" when referring to natural slope failures, because Cylindrical Failures are extremely rare occurrences. The necessary condition for a cylindrical slide is homogeneous material, and such materials do not generally occur on natural slopes. There is a great deal of field evidence to suggest that it is the natural planes of weakness within the soil or rock mass that determines the failure surface, and such planes are usually far from circular. Stability analyses, based upon "Cylindrical Form of Slide", must therefore be treated with the utmost caution.

Any stability assessment analysis requires the determination of potential failure planes and the evaluation of the forces causing and resisting failure. Because of the difficulty in determining failure planes and the forces upon them, the interpretation of these analyses often give rise to considerable divergences of opinion. It is considered that stability analyses should be undertaken using a variety of computational assumptions and procedures, so that an insight may be gained into the failure mechanisms which are possible at the site. Field evidence of these failure modes should then be sought and the stability assessment related to field observations in the immediate vicinity.

(b) Mathematical Models

Recent literature on the stability of natural slopes, has placed considerable emphasis on theoretical concepts such as "Residual Friction", "Progressive Failure" etc., and such concepts are extremely important to the proper understanding of possible failure mechanisms; however, unless the applicability of the concept is established beyond conjecture at each site, any resultant conclusions as to the site stability will be misleading.

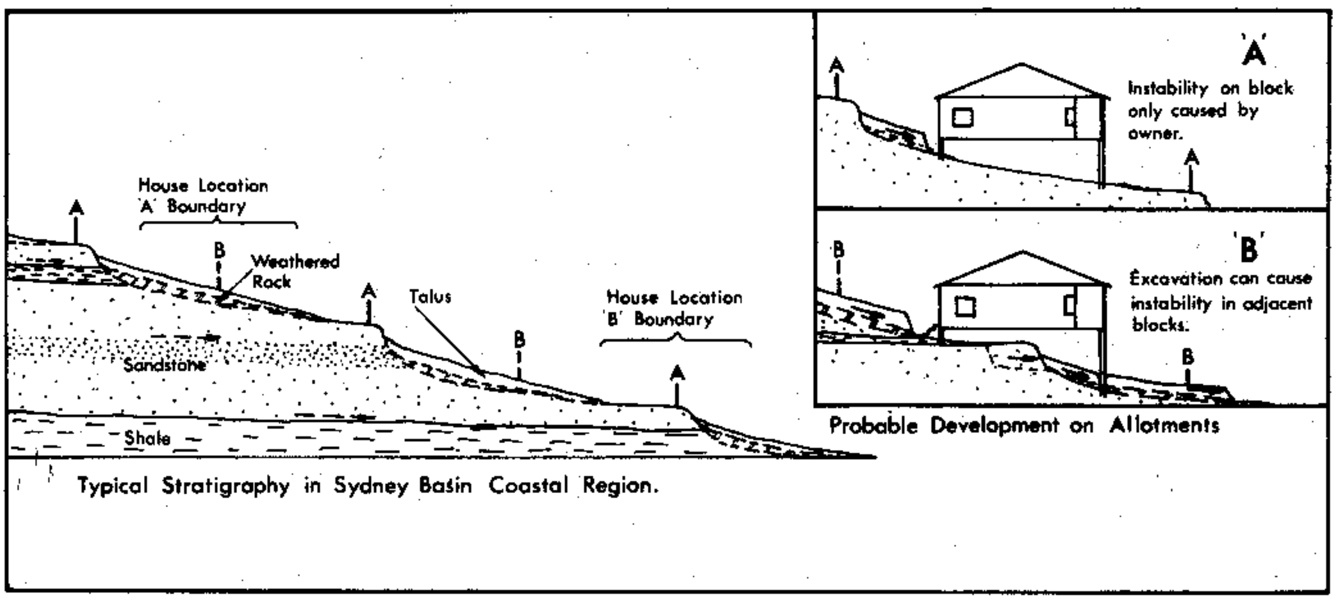
For example, many statements on the stability of the Talus material in the Sydney Basin, have depended upon a "Residual Friction" failure concept, in spite of inconclusive laboratory test programs. It should be recognised that Talus is generally a lightly over-consolidated to normally-consolidated material, and would not normally exhibit "Residual Friction", (Refs. 9 & 10). The use therefore of a "Residual Friction" concept with Talus would have to be treated with suspicion.

Again, the validity of the "Effective Stress Principle" depends upon individual soil particles being sensibly inert during changes in stress. Because Civil Engineering structures generally only cause small changes in soil or rock stress level, the fact that individual soil particles are not always inert has not caused many problems. However, the excavations undertaken in sloping land subdivisions often cause radical changes in the stress level of the near surface materials. In such cases it may be necessary to take into account the possible variation in particle size, and structure, as a result of the change in stress level.

(c) Planning

It should be recognised that not all property owners will be aware of the technical problems associated with sloping land development, and so may undertake projects which can create instability in an otherwise stable area. In view of this, it is considered that any developments planned in sloping areas should ensure that an unwise action on the part of one owner, does not cause problems for other owners. The planning requirements will naturally be unique to each geographical area, but will need to embody special provisions to minimise the alteration to water movement patterns, and the changes in soil and/or rock stress.

Generally, the steeper the slope the shallower the excavation for roads and houses ought to be. It is considered that the present practice of constructing wide suburban streets in hillside areas is a major factor in the development of instability in such areas, and consequently it is essential that planning schemes embody a provision for the variation in road formation width with steepness of hillside. Again, the allotment size and location needs to be related to the detailed local geology; in some areas the simple provision of large allotments will be sufficient to prevent problems between adjacent property owners as a result of land instability, whereas in other areas the allotment boundaries must be precisely determined by the outcropping geology. Fig. No.1 has been prepared to



Typical Stratigraphy in Sydney Basin Coastal Region.

Probable Development on Allotments

Figure 1

demonstrate the likely consequences of poor positioning of allotment boundaries in relation to the site geology. The boundary positions marked "A" are considered to have less potential problems than the boundary positions marked "B".

Further, since the actual subsurface conditions can never be determined in advance with absolute precision, the planning scheme must make allowance for future variations to the scheme as more information is revealed.

4 COLLECTION OF DATA

In the assessment of the stability of land, it should be recognised that the assessment will be an opinion based upon data obtained from the site, and as this data is only a sample of the available site information, the opinion will only be as good as the quality of the site sample. Further, the degree to which the probable earth movement mode is understood, will depend upon the care and accuracy with which the base-data is established.

Adamson (Ref. 1), has prepared some useful comments on the manner of undertaking geological investigations, however there are some aspects which are particularly relevant to land stability assessment. The flow chart presented in Figure 2 is an example of how a typical "Project Type" stability assessment would be undertaken. Some of the items referred to in the flow chart are briefly discussed hereunder.

(a) Air Photo Interpretation

Before any assessment can be made of an area, a proper base plan is required. However some difficulty is often encountered in establishing the proper scale and contour interval for the base plan. If the region is first examined from the aerial view, then it is usually possible to establish areas for intensive study. This procedure permits considerable economies to be achieved in the preparation of base plans, as small scale maps will generally suffice for a large proportion of the area, with a large scale being only used over a limited area. Some useful comments on Air Photo interpretation are contained in Ref. 3, however, the procedure of working from the "whole" to the "detail" cannot be too strongly emphasised, because proper appreciation of the site natural setting is usually only gained by observation of the "whole". Further, old slips and vegetation changes are often only apparent in Aerial Photographs.

(b) Geobotanical Mapping

In view of the fact that it is not usually possible for data to be assembled over a lengthy period, a study of the site vegetation can yield much information about subsurface conditions and the movements that have occurred, and are occuring, at the site.

Many writers have pointed to observations on shape of trees as indicators of ground movement (Ref. 3,6,7 & 14); however it should be recognised that many other facts can be established from the vegetation. Many species are tolerant of widely varying subsurface conditions, however others will only thrive under particular soil conditions. Such species are therefore particularly good indicators of water-logged soil, heavy clays, shaley clays etc. Also dead or dying trees are often the result of root suffocation caused by filling or slide debris, and can therefore indicate topographic changes in the very recent past.

Geobotanical mapping is thus an important phase of the data collection because it often provides data not available from other sources. The geobotanical map needs to be prepared in a manner that will provide the requisite specific data, and this can be achieved by plotting those plants and trees that require particular subsoil conditions to thrive; species tolerant to wide ranging sub-soil conditions should be simply "listed".

(c) Site Geology

Prior to any subsurface investigations, a surface geological map should be prepared, based upon the outcrop geology, published sources and the geobotanical map. It is unfortunate that in recent years there has been a growth towards undertaking subsurface investigations such as seismic surveys, drilling, and trenching, prior to the detailed surface mapping. The surface geological map will usually indicate where subsurface work is most needed for either exploration or verification of interpreted features. Further, because most earth movements occur on "planes of weakness" it is essential to collect as much data as possible about these planes, including statistically meaningful observations on the spacing and extent of discontinuities within each rock and/or soil unit.

When the geological map is completed, it is important that the Geologist interprets his findings to the Engineer. Unfortunately, many first rate

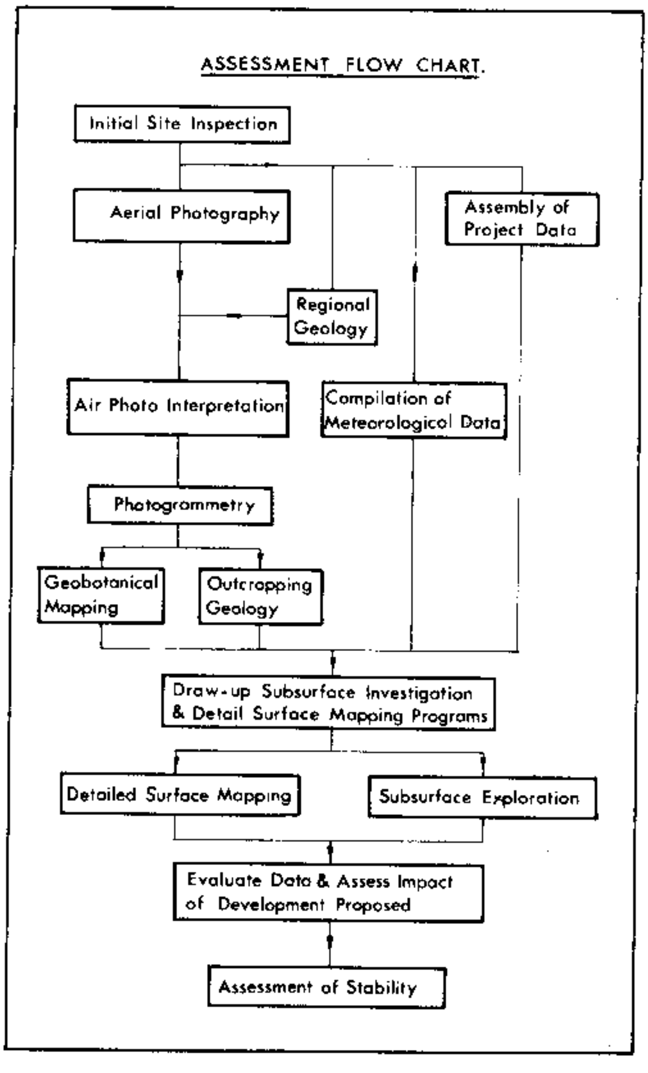


Figure 2

geological plans are little used by Engineers, because the significance of many of the documented features is not fully understood. The determination of the engineering significance is usually the most difficult phase of the project, and is often best accomplished by the Geologist and Engineer working in close collaboration.

5 STABILITY CLASSIFICATION OF LAND

The purposes of any investigation into land stability can be outlined as:-

(i) To assess the stability of the natural slope.

(ii) To assess to what extent the stability of the slope will be altered by the development proposed.

There is however, a further requirement placed upon those who assess the stability of land for Urban Development:-

(iii) To isolate those areas in which the improper actions of the "ill-advised" or "uninformed", could have extensive detrimental effects on the surrounding countryside.

In view of the remarks made so far in this paper, it can be seen that a most detailed understanding is required of the site geological and environmental factors, before an accurate assessment can be made of the land stability. As it is clearly not feasible, nor economically desirable, to fully investigate all potential Urban areas; two levels of land stability classification are required to separate those areas of land obviously requiring further detailed study, from the areas in which conventional sub-division practice may proceed without special restrictions. It is thought that this separation of areas should take place at the Town Planning stage, so that all the related socio-economic factors inherent in hillside development can also be considered. If the communities interests are best served by permitting development in areas requiring large scale detailed geotechnical studies, then the economic consequences are properly evaluated at the appropriate time.

Table I sets out a Regional Land Stability Classification scheme which is thought to be suitable for Town Planning purposes. The scheme embodies the "Extent of Investigation Required" principle, whilst providing specific land use catagories that could be applied to a Town Plan.

TABLE I - REGIONAL LAND STABILITY CLASSIFICATION
- for urban development -

CATEGORY	DEFINITION
1.	Stable Land - no land instability evident or likely
2.	Essentially Stable Land - some small areas of land instability. Most of the land may be safely utilised provided that adequate care is exercised in the nature and form of development. Detailed investigation required before development is undertaken.
3.	Less Stable Land - thorough investigation required before any development.
4.	Essentially Unstable Land - development of area, only after the most thorough assessment of area stability.

The "Extent of Investigation Required" type of classification, whilst being satisfactory for Town Planning purposes, has little practical application to a specific project. However, to be more specific the project type of classification system will need to take into account:-

(i) The extent to which geological processes occuring at the site are understood.

(ii) The extent to which theoretical and mathematical models explain the observed phenomena.

(iii) The nature and type of development to be undertaken.

(iv) The degree of development control that can be exercised after the major engineering works are completed.

A proposed "Project" type of land stability classification system is given in Table II, which uses the term "Degree of Confidence in Stability" because all the preceding matters are based upon sampling and probability. To be consistant therefore, the classification must be expressed in terms which are related to the scientific base data, that

TABLE II - PROJECT LAND STABILITY CLASSIFICATION
- for urban development.

Degree of Confidence in Stability	Usual Interpretation	Movements Expected	Development Restrictions
HIGH	Stable Land	None	No special requirements.
MEDIUM	Essentially Stable Land	Some minor movements can be expected if development undertaken without due regard for landform.	Building and any development subject to special requirements, including detailed appraisal of the effect of development on the land stability prior to development approval.
LOW	Generally Unstable Land	Localised landslips may occur in some areas during or after extreme climatic conditions.	No private development permitted, unless area, or parts thereof, can be re-rated after an intensive geological survey of the area. Public utilities should have the stability of the structure, as affected by the probable land movement properly investigated.
VERY LOW	Unstable	Areas of known active landslides, extensive land movements anticipated.	

is, in terms of confidence limits. Further, since the susceptibility to movement is a major consideration in urban development, it appears reasonable to relate the classification of an area to the nature of the expected movements.

During the course of field observations to classify land into stability zones, it must be borne in mind that stable areas can be made unstable by the actions of the "ill-advised" or "uninformed". It is therefore necessary to clearly differentiate those areas in which usual sub-divisional practice may be followed, from those areas in which special engineering and building techniques may be required. Also, in common with most other aspects of Urban Development, the real control over development is excercised by the Local Government Authority; such control can generally only be exercised effectively at the time of sub-divisional and building approval. In view of the fact that by giving permission to build or develop, Local Authorities tend to incur a non-specific legal or moral obligation, it is considered that these Authorities should only permit residential development in "Stable" areas. Further, such Authorities should ensure that the development is undertaken in such a way that the land susceptibility to movement is not increased; i.e. the land is not rendered "Unstable".

6 CONCLUSION

When the natural geological processes occuring in a given area are properly understood, it then is possible to classify the area into zones of similar stability, and to ascertain the stability of an area for a particular project; always provided that careful field observational procedures are diligently followed, and there is ample field evidence for the theoretical models.

The nature of the classification process inherently involves a degree of uncertainty, because every site will always have some unique features that will not be apparent to even the most skilled observer. The term "Degree of Confidence in the Stability" provides a measure of this uncertainty.

The classification of land into areas of similar susceptibility to movement could greatly assist Town Planners and Local Authorities to overcome some of the existing problems of landslip in Urban areas, and possibly prevent the development of landslip in developments in the future. The "two-stage" classification system outlined in this paper is considered to provide a suitable system.

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