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Techniques of Landslide Control using Drainage

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SUMMARY This paper discusses the initiation and mechanisms by which landslides and earthflows occur,and gives typical details and examples of drainage control methods. The paper concludes that a great number of landslides are controllable by correctly installed drainage, however the drains must be located in such a way that the only risk in design is a "Geotechnical Risk".

1 INTRODUCTION

The control of landslides and the related problems of earth slumps and flows, have concerned Engineers for many years. Numerous papers and texts have attempted to relate the theories of Soil and Rock Mechanics to the analysis of particular landslides, however there are few specific guidelines concerning the design of suitable control measures.

The geological sciences have treated landslides quite extensively, but their treatment has mainly been associated with the nature and mechanics of particular major mass movements, whereas the Engineer is plagued by a large number of minor mass movements in cuts and embankments which endanger engineering structures. It is also the Engineer who is usually charged with the responsibility of undertaking suitable remedial measures, and this activity frequently requires the expenditure of large amounts of money. Whilst money can often be made available at the time of the disaster, when the crisis has passed there is usually a reluctance to expend further sums to achieve final control and future prevention. It is the authors opinion that considerable sums of money could be saved if more resources were devoted to the 'prevention' of landslides, and implementation of control during non-critical periods.

The classification of landslip phenomena, and analysis of landslides is beyond the scope of this paper; the reader is referred to (refs. 4 & 10) for further discussion of these matters.

2 INITIATION OF LANDSLIDES

The movement of water down a hillslope usually has a very significant, and sometimes dramatic affect upon the stability of cuts and embankments. The manner in which water exerts its influence however, varies with the topography and geological conditions. Suffice to say that the movement of ground and surface waters influence the landsliding processes by causing a reduction in strength of the site materials, and increasing the disturbing forces.

Although not all landslides are caused by water, the vast majority of landslides are triggered by prolonged heavy rainfall. Whilst the control of water will not always prevent a landslide, it can often reduce the damage caused by a particular slide. The main theme of this paper is therefore the control of water: other landslide control methods (e.g. retaining walls, earthworks etc.)are not discussed.

3 LANDSLIDE MECHANISMS

Before any remedial works that have a high probability of success can be undertaken, the detailed mechanism by which the landslide is occurring must be properly understood. This requires a detailed understanding of the subsurface geological conditions, water flow patterns (both surface and sub-surface) and the exact cause of the slide. As the collection and analysis of the data necessary to properly understand a given landslide mechanism usually takes a considerable time, it is often necessary to implement some immediate control works based upon general principles. These works usually involve drainage and small scale earthworks, and are outlined later in the paper.

In this paper the term "geological conditions" includes unconsolidated materials, as well as in-situ rocks.

Many authors have attempted to solve landslide problems on the basis of mathematical models that require considerable simplification and idealisation, of the site geological conditions. As a result most of the analytical tools available are only applicable to situations where the on-site materials can be idealised satisfactorily. Unfortunately nature does not generally supply such materials, and usually actual conditions unite to defy mathematics, also it is usually the very detailed matters of geology that cause a particular landslide. Theoretical procedures are therefore mainly useful for comparing equally idealised situations and should not be considered as giving a definitive answer.

The fundamental mechanisms of landslides have been classified by Varnes (Ref.9) however, it is proposed here to concentrate simply on semi-rotational and flow-type movements because it is these movements that appear to be the most important to practising Engineers. These two mechanisms are presented in Fig.Nos. 1(a) & (b), and can usually be fairly effectively controlled by drainage. The basic control methods for both types of movements are:

- diversion of surface water from slide areas
- prevention of infiltration of surface waters
- relief of water pressures within the slide
- earthworks to increase stability.

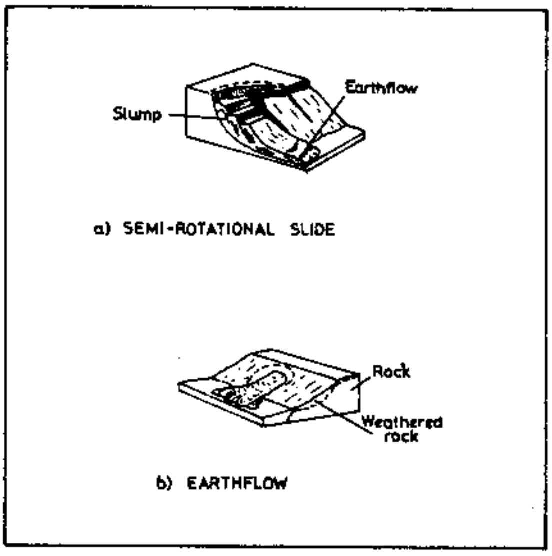

Figure No. 1 – Landslide Mechanisms (after Varnes, Ref. 9)

However, in the case of earthflows, additional works are often necessary such as:

- entire removal of the flow material
- internal drainage of the flow material
- establishment of vegetation with a high suction potential.

For these drainage works to be successfully located and implemented, the sources of the water causing, or aggravating, the 'slide' must be identified.

4 SOURCES OF GROUNDWATER

It is important to recognise that most groundwater originally comes from atmospheric precipitation. When rain reaches the ground, part of it flows away as surface run-off and part of it infiltrates into the soil. Some of this sub-surface water is held in the pores of the soil near the surface, but most of it then joins a body of groundwater which lies in the saturated zone of the sub-soil, or flows along soil and/or rock discontinuities.

In soil, water generally flows at the base of the porous topsoil and at changes in soil strata. A very common interface is on top of a residual soil. The ground can also be charged by water from tides, sewers, stormwater pipes, septic tanks and leaking water mains. In rock, water generally flows through structural discontinuities (joints, fissures, bedding planes, etc.), and emanates where the rock outcrops on slopes or under the surficial soil overlying hillsides. These points of efflux are sometimes quite localised, and therefore are termed 'springs'. When the efflux zone is more general, creeks are frequently located there, as a response to the constant supply of sub-surface water.

The velocity of flow of groundwater is proportional to the driving head, and permeability of the soil. Groundwater flows rapidly through steeply sloping beds of coarse gravel and sand, whereas the movement of groundwater through compact, homogeneous clay is extremely slow. Clay soils of this kind are therefore very difficult, if not impossible, to drain.

Figure No.2 illustrates a simplified portion of the hydrological cycle, and how geological structures can influence the flow of groundwater from one area to another. The time for water to travel through the ground from its point of impact, to its point of efflux may be very long because the rate at which water flows through the ground is dependent upon the nature of the ground, the openness of any joints or fissures in the rock, and the porosity of the intact rock substance. In general terms, water will always find the easiest path through a rock mass, and sometimes this means that water travels upwards.

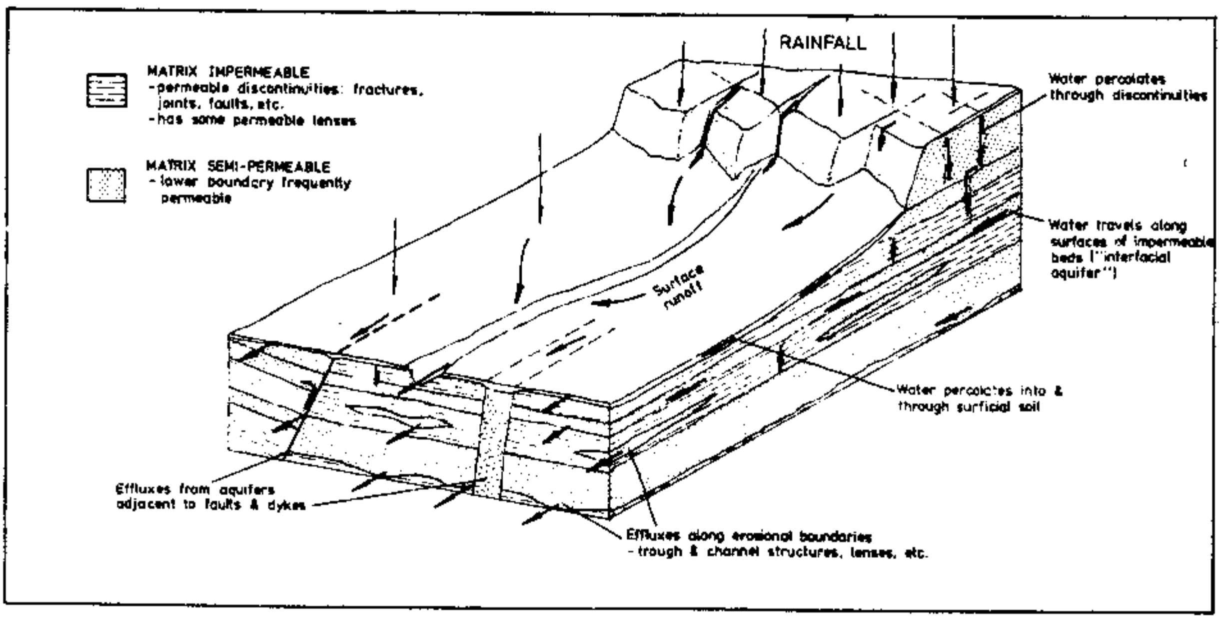

Figure No.2 Geological Control of Groundwater Flow

Engineers usually define the path along which underground water travels as an aquifer, although the strict geological definition of an aquifer is:

" a Stratum or Zone below the surface of the earth capable of producing water as from the well."

When dealing with landslides we must recognise that aquifers are often extremely localised, sometimes about one millimetre thick and only a few metres in extent. Alternatively, the aquifer maybe several metres thick, and extend for several thousand of metres. However, the size of the aquifer is not usually the dominant factor, it is usually the water pressure that provides the force necessary to initiate the slide. It should be clear therefore that a detailed geological picture must be established before constructing any drainage system. To be effective, drains must be located so that they tap, and relieve, the water source.

The collection of the geological data to provide an adequate picture of a given landslide, requires a great deal of painstaking work over a considerable amount of time, and must be undertaken by properly qualified and experienced geotechnical personnel. It has been the authors experience that a geotechnical 'team' (comprising Surveyors, Engineers, Geologists and Botanists), must be used to obtain quick and accurate results. When the location of the various groundwater sources have been identified, and the probable mechanism of the slide understood, only then is it possible to select the type of drainage system applicable to a particular situation. This selection process always involves a degree of uncertainty, however the greatest chance of success will be had if the geological picture (or model) is well established.

5 METHODS OF DRAINAGE

Water affects the stability of slopes by:

- saturation of the soil, perhaps even creating a fluid situation
- developing internal pressures within the soil mass
- reducing the soil/rock shear strength along potential failure planes.

Reduction in the water content of a given soil is therefore clearly desirable, if control over the slide is to be achieved. Surface drainage is normally undertaken first, followed (where applicable) by sub-surface drainage. The general principles of how this is undertaken are outlined in the following paragraphs:

a) Surface Drainage

Surface drainage is always a first in the control of a given landslide area. It is important that the stormwater is captured above the slide area, and diverted safely around the slide area. If the slide is of extremely large proportions, then it may also be necessary to capture surface water on the slide, and divert this water off, and away from the slide.

Surface water should always be prevented from infiltrating into the slide material. Typically slide areas are very disturbed, and have many open cracks, fissures etc., which permit the entry of surface water; it is therefore often necessary to cover them with plastic sheeting, or to fill them with an impervious material, to prevent water infiltration into the slide itself. If the cracks are widening rapidly, covering of the cracks and fissures is generally to be preferred.

The various methods of surface water control are well covered in many standard texts (e.g. refs. 7, 8 & 9), however the drainage of sub-surface waters is usually much more difficult. Suffice to point out the necessity for flexibility in pipes, drain linings etc., in areas prone to earth movement. The choice of a particular kind of surface drainage system will also be influenced by the nature of the soil, the water source, and the volume of water to be drained.

b) Sub-surface Drainage

The type of drain to be used will depend upon:

- the nature of the groundwater, its pressure and expected flowrate
- the soil and rock types
- the depth of aquifer(s), and the macroporosity of region
- the type of slide or flow,

and the drain should embody the following design criteria:

- the base of the drain must be in a stable material (i.e. below the slip plane)
- the drain must be able to be maintained
- the drain must intersect aquifers which are contributing to the instability
- the construction techniques must be practicable without undue risk
- it should be of sufficient permeability to remove sub-surface waters and/or pressures, whilst not permitting soil particles to enter and "clog-up" the drain.

It should be recognised that a particular drainage system can often take a long time to become effective. In addition the formulae produced for calculating the discharge of sub-surface drains, may not be reliable because of the enormous variations in the detailed geological conditions at a particular site. Detailed discussion of sub-surface drainage is included in the next section.

6 SUBSURFACE DRAINAGE SYSTEMS

There are three generally recognised systems of sub-surface drainage:

a) Near surface Interceptor Drains.

b) Inclined Drains (often termed 'Horizontal').

c) Drainage Wells.

In addition, a planned revegetation program should also be considered a valid sub-surface drainage technique.

a) Near-Surface Intercepting Drains

These drains are most suitable for draining discrete near surface aquifers, and are so arranged that they tap a specific water source. Their invert should always be located below the aquifer in a stable material. They are usually uneconomic (and/or impractical) below 5m, and in their design, several points should be noted:

- subsoil pipes are surrounded by a 'designed' filter material to minimise particle migration into the drain, and to prevent blockage of the subsoil pipes
- the near surface backfill should comprise a relatively impervious material
- the drains are provided with access points to permit routine maintenance flushing
- standpipes are installed to check whether any part of a drain becomes blocked.

Spalding (Ref.6) discusses in detail the drain filter requirements, and largely concludes that a coarse 'concrete' sand is generally suitable for draining the silty and clayey soils that are so often associated with landslides. The authors concur with this view, except where the object of the drain is simply piezometric pressure relief, with little attendant water flow. Figure 4(b) indicates the authors detail for such a situation.

The drains can only work satisfactorily if the drain is located in a soil which is 'drainable'. (Ref. Fig. No.3). The typical landslide materials (clays,silts etc.) cannot therefore be stabilised with simple interceptor drains, unless the drains intersect more porous sandy bands.

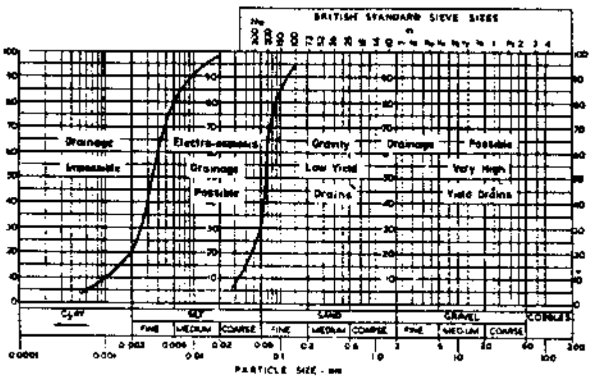

Figure No. 3 - Drainability of Soils

(after Glossop & Skempton Ref.3)

Further, where drains are required to pass through unsaturated soils, it should be recognised that in this type of soil, the drain can have the entirely opposite affect to that intended (i.e. the drain will provide a free water source to saturate the soil). This point is often not recognised by Engineers, but it is the fundamental principal involved in household absorption trenches.

Construction of the drains in unstable areas can also be extremely hazardous as the design will usually require the undercutting of the landslide failure plane. Careful analysis of this problem should always be undertaken prior to construction of the drain.

Some typical details of various types of drains that have been found to be successful are indicated in Fig.No's 4(a) and 4(b). The details should not be regarded as comprehensive,but they do indicate some essential design features. The backfill around the pipe is usually referred to as a 'filter', and the particle size distribution of this material must be related to the size of holes or slots in the pipe, as well as the soil it is designed to protect.

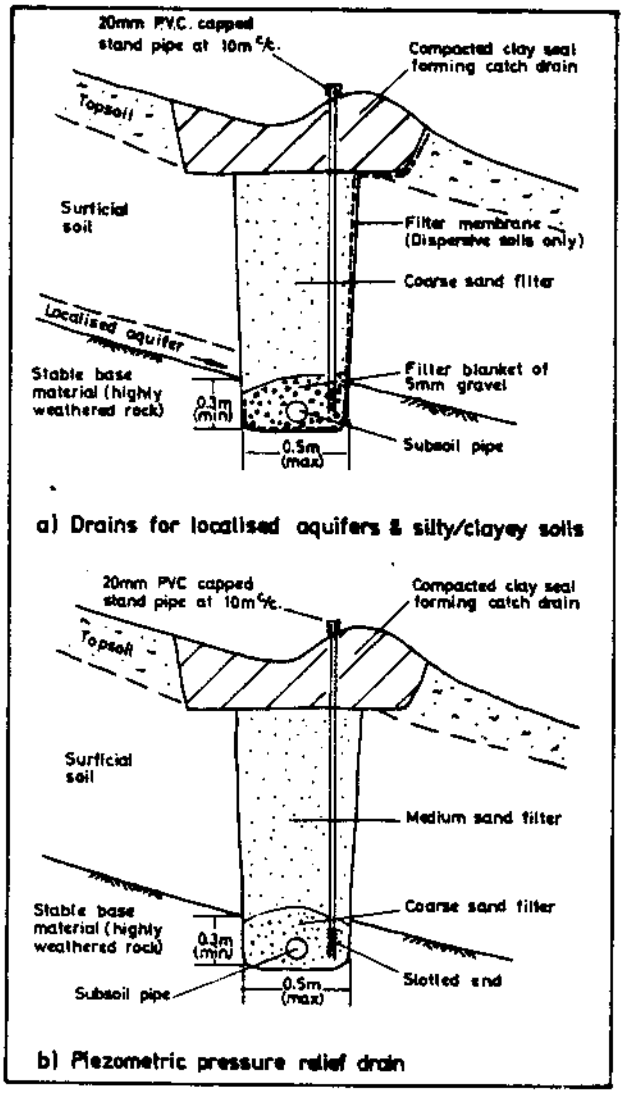

Figure No.4 - Typical Interceptor Drains

b) Inclined Drains

These drains are useful for intersecting a deep aquifer which is not accessible from the surface, or when the landslide is occurring in a detrital material. Consideration should also be given in the design to the drainability of the soil, and the possibility of damage to the drain by subsequent movements of the sliding earth mass. The drains are normally installed by a boring technique, and permanent gravity drainage is usually effected by the installation of a slotted pipe.

Prior to installation of inclined drains, it is essential to fully understand the detailed site structural geological conditions, and to ensure that the drains are orientated to intersect a maximum number of geological discontinuities. The pit (or other location) for siting of the drilling rig often poses significant difficulties, and must be properly investigated and established to be safe before placing operating personnel in it.

A number of drainage installations of this type have been unsuccessful, and it has been the author's experience that the lack of success can be mainly attributed to:

- drains not penetrating permeable and/or drainable strata.
- shearing of drain where it intersects the slide failure surface
- drains being installed where other methods of control are applicable.

The majority of the above situations could be corrected by the adherance to the following design criteria:

- the drain must be inclined at an angle of at least 3 degrees to the horizontal
- slots should be provided in the inserted pipe only where it is anticipated that aquifers and/or drainable materials exist (this is to minimise the clogging of the drain)
- the inserted pipe must be installed prior to removal of the borehole drill casing
- drilling fluids (e.g. Bentonite Muds) should not be used
- moderate to low drill water pressures should be used, and decreased to as low as practical in the vicinity of landslide slip plane.

Details of a typical installation is indicated in Fig.No.5.

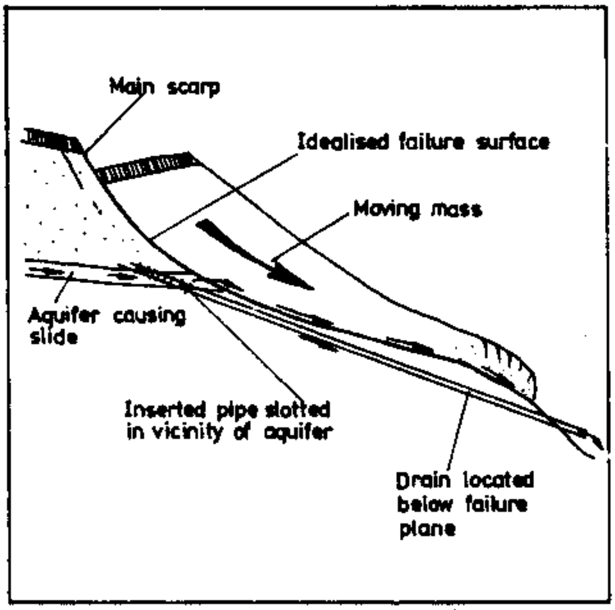

Figure No.5 Typical Inclined Drains

c) Drainage Wells

Wells are often used to obtain immediate control over a sliding mass, whilst investigating the source of the water more thoroughly, and preparing designs for a more permanent installation. Drainage wells often encounter artesian pressures, and therefore considerable care should be taken when drilling such holes, to accurately record the level at which the groundwater is first encountered as well as the various standing water levels. Wells are of several types:

- gravity drainage wells (using simple pumps or venturi eductors)
- vacuum wells
- electro-osmotic wells

The last two types mentioned should only be installed after the most thorough geotechnical investigation, and are therefore not discussed here. Some typical details of gravity wells are given in Fig.No.6, and the salient design features of the wells being:

- the casing is surrounded by a gravel or other 'designed' filter to minimise particle migration into the well
- where possible the well is made sufficiently large to permit subsequent interception for gravity drainage of the well at a later date
- the well encounters specific aquifers.

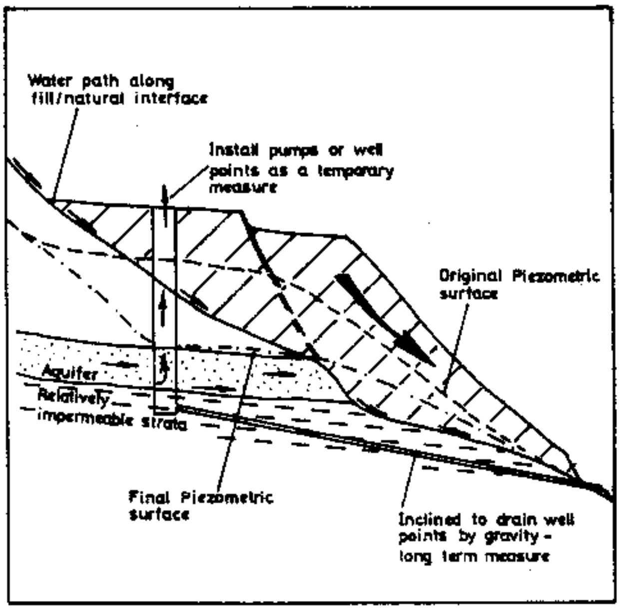

Figure No.6 - Typical Gravity Drainage Well

7 EXAMPLES OF INSTALLATIONS

The various details put forward in this paper have been installed at several locations in N.S.W. These installations have resulted in either complete, or partial control of the landsliding movement. A brief description of several such installations and their effectiveness is set out below:

a) Fill & Talus Slide near Bulli N.S.W.

The widening of the roadway of Bulli Pass, near Devil's elbow in 1950 initiated substantial movement. The movements that have occurred since that time have been directly related to prolonged rainfall. The original road alignment filled-in and diverted a natural watercourse, subsequently the original drainage paths under the fill re-established themselves, although with reduced porosity. This has led to the development of large hydrostatic pressures in the drainage paths and caused a general movement of the entire Road Fill/ Natural Talus material. The largest movements have been recorded when the hydrostatic pressures are the highest (i.e. after prolonged rainfall). This mechanism of failure is schematically represented in Figure No.7, and is fairly common in the Illawarra Region where road fills have been placed over watercourses.

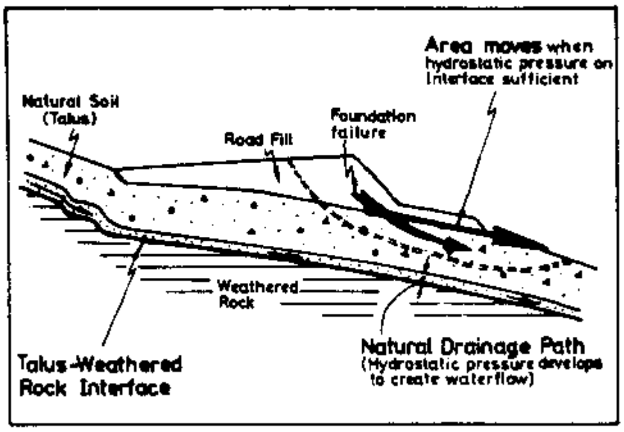

Figure No.7 - Slide Mechanism Devils Elbow (near Bulli N.S.W.)

In addition to this failure mechanism, the regional alterations to groundwater and creek patterns near to the road fill caused a gradual deterioration in the strength of the talus as a foundation material. As a result, the foundation material became too weak to support the overlying fill. The remedial measures proposed for this slide therefore consisted of:

- release of the excess hydrostatic pressures in the Talus-weathered Rock "Interface Aquifer" by constructing an interceptor drain
- drainage, and channelling to a safe location, of sub-surface waterflows that cause fill foundation saturation
- reducing the degree of saturation of the downhill fill foundation area, by clearing out the creeks in the area.

To date the effectiveness of the remedial measures planned cannot be gauged, as they are yet to be fully implemented.

b) Landslide near Bowral N.S.W.

Early in 1976, prolonged rainfall caused substantial cracking and damage to a Mushroom Factory near Bowral N.S.W. Immediately adjacent to the factory a municipal reservoir also showed signs of distress, and an extensive landslide was activated that threatened to completely demolish a small residence and a block of four flats. The general site arrangement is indicated in Fig.No.8. The slide was considered to have been caused by:

- residential sub-division, and construction of major civil engineering works across an old landslide
- leakage from the municipal reservoir
- several springs emanating from the underlying rocks.

With the close co-operation of all parties, very prompt corrective action was implemented at the site. The works were undertaken in the following order:

- diversion of seepages from slip area
- reduction of sub-surface water pressures by the excavation of several pits, and gravity drainage
- drainage of various springs
- site earthworks
- revegetation

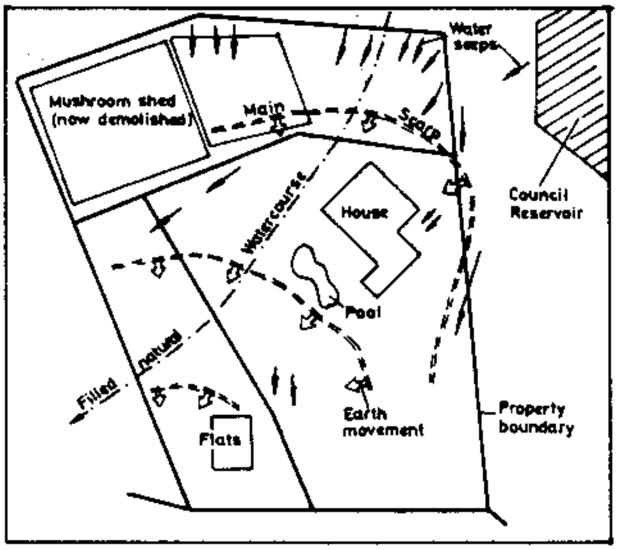

Figure No.8 - Bowral Landslip Mechanism

The various works undertaken are schematically represented on Fig.No.9, and have proved successful so far in spite of periods of prolonged rainfall.

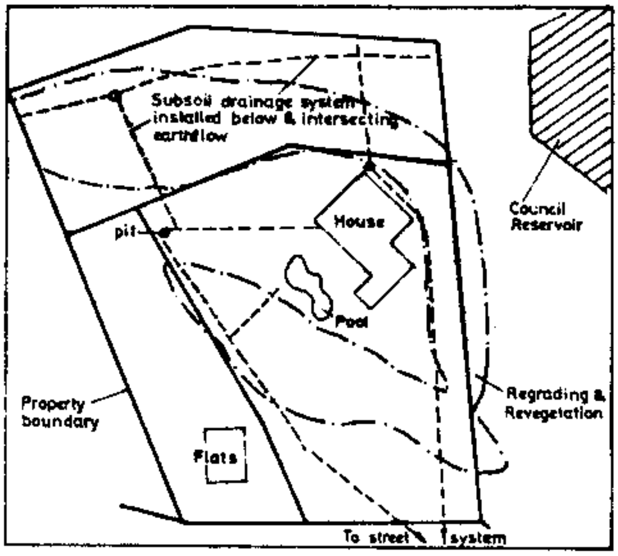

Figure No.9 - Bowral Landslip Remedial Works

c) Rapid Earth Flow near Umina N.S.W.

In March 1976, prolonged heavy rainfall caused the collapse of a very steep excavation behind a domestic residence in Umina N.S.W. Whilst it was clear from the outset that the excavation originally undertaken was most unwise, nevertheless, it is an example of how an unsafe situation can exist for a number of years and that the final trigger for failure is prolonged rainfall.

As the earthflow was extremely rapid almost becoming a debris avalanche, initial control efforts were directed to:

- diversion of stormwater from slide area
- dewatering of the "toe".

After a measure of control of the slip was obtained, various earthworks and other civil engineering works were undertaken. The site works undertaken are indicated in Fig.No. 10 (b).

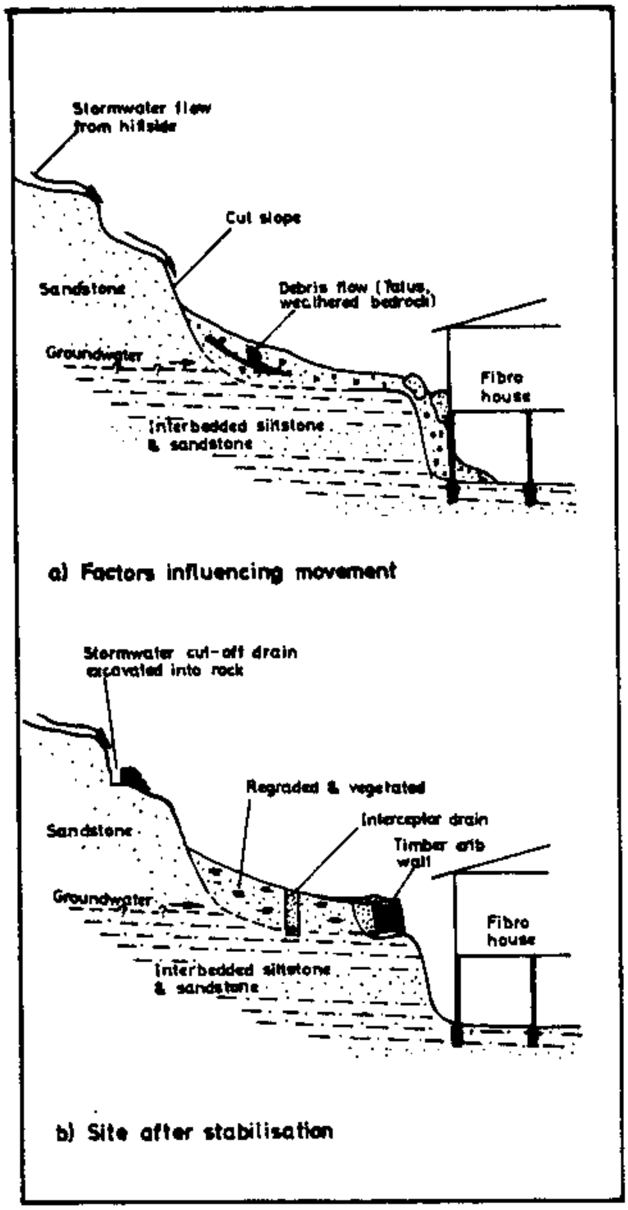

Figure No.10 - Umina Earthflow

d) Failure of Rail Embankment near Macksville N.S.W.

The main northern rail line at Newee Creek (near Macksville N.S.W.)was constructed in 1932, and following track up-grading in the mid 1950's to accept heavier loadings, failures of the embankment were noted. The general arrangement of the embankment is indicated in Fig.No.11.

The failure that occurred was mainly caused by the build up of excessive pore water pressures, in an organic clayey-sand layer at the base of the embankment. These excessive pore pressures were of a transient type, and represented a 100% change in the state of stress at the base of the embankment due to the low embankment height. Permanent drainage of the material could not be arranged because of the very small difference between sea level and the embankment base, and the frequent flooding of the area. The remedial measures therefore comprised lowering of the regional water table during normal seasons, and the provision of an isolating drainage system to protect the embankment during flooding. The installation is still being carried out, but the stormwater and other control measures already undertaken have managed to substantially arrest the embankment movement.

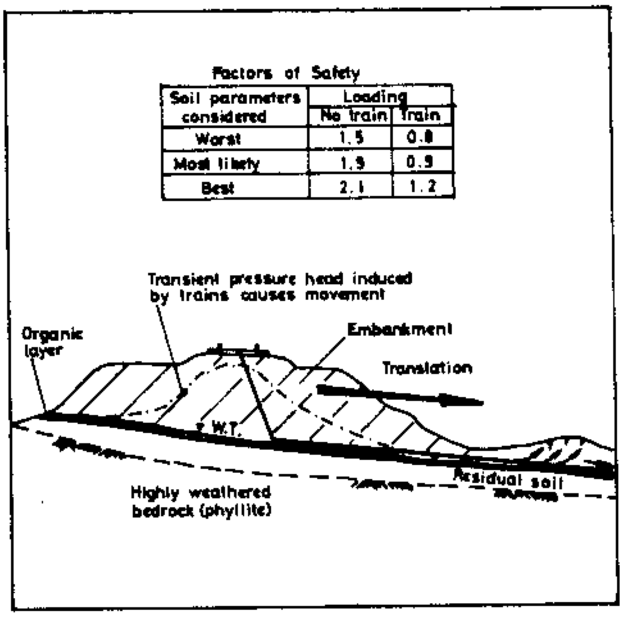

Figure No.11 - Newee Creek Failure Mechanism

8 CONCLUSION

Control over many types of landslides and flows are possible by the correct installation of suitable drainage works.

The effectiveness of sub-surface drains(widely used in landslide control) is a function of the design details, which must include the precise location of the drain. Research has provided the requisite data for the design of satisfactory drains given:

- the sources of the water
- the nature of the materials to be drained.

Both of these matters can only be established by the determination of a satisfactory geological model for the site. It is in this determination that there is an inherent "Geotechnical Risk". Success of a given drainage installation therefore depends upon reducing the "Geotechnical Risk" to an acceptable level. This can only be done by undertaking a detailed Geotechnical Study prior to drain construction.

9 ACKNOWLEDGEMENTS

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