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EARTH RETAINING STRUCTURES IN AREAS OF LANDSLIDE

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SUMMARY

This paper describes the implications of the Australian Standard on Earth Retaining Structures for retaining wall design in areas of landslip, and provides a technical discussion of the various forms of structures that are appropriate for use in landslip areas. Some comments are also made on the recognition of landslip situations, the geotechnical information needed to enable appropriate wall design, the various types of wall suited for hillside & landslide situations and the use of rock bolts & anchors. The paper also includes some examples of inappropriate wall construction.

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INTRODUCTION

In areas of potential landslide, landslip & rockfall, the design of retaining structures poses considerable difficulties for structural and civil engineers, with the mechanism of slope instability usually dominating the form of structure that can be adopted. Also, as the forces which affect retaining structures in areas of potential landslide, landslip & rockfall are usually considerably different from those calculated by conventional earth pressure theories, the establishment of the loads upon such structures is difficult.

As a consequence, many engineers are daunted by the task of preparing an appropriate design for an earth retaining structure in hillside and / or landslide areas. Alternatively, some engineers fail to recognise the need for a special analysis, and as a consequence prepare a design for a completely inappropriate structure; this can then give rise to serious professional issues for the design engineer.

This paper has thus been prepared to provide some guidelines to engineers undertaking the task of designing an earth retaining structure in an area of potential landslide hazard, as well as providing information on some details that may be of assistance to practising engineers.

Thus, this paper will now traverse the following issues:

1. Recognition of Landslip Hazard.
2. Relevant matters in AS 4678 – Earth Retaining Structures.
3. Retaining Walls for Landslide Areas.
4. Comments on Particular Wall Details.

RECOGNITION OF LANDSLIP AND GEOTECHNICAL HAZARDS

As a prerequisite to the design of an earth retaining structure in an area of potential landslide hazard is the recognition of the potential for landsliding, it is very important for the design engineer have an understanding of the mechanism, or potential mechanisms of instability where the retaining structure is required.

In this regard, the following matters are usually important to the design engineer:

1. The Terms Landslip & Landslide.
2. The Susceptibility of an Area to Landslide.
3. Mechanisms & Indicators of Instability.

1. The Terms Landslip & Landslide

Whilst the engineering community at large uses a variety of terms to describe soil and rock instability, the geotechnical community now uses the term "landslide" to describe a range of ground movements which include:

a) Landslip & Soil Creep.

b) Rockfalls & Coastal Recession.

c) Ground subsidence.

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The geotechnical community has done this to establish a logical framework in the 'risk management' of landsliding and other geotechnical processes, which has been formalised in the latest publication of the Australian Geomechanics Society in 2007.

It is also convenient to think of a landslide as being a relatively large movement of the ground, in contrast to a landslip which is a relatively small movement that may often be described as an excavation slump, batter failure, etc.

Whilst there are a number of large landslides along the east coast of Australia, experience has shown that most landslides are caused by human development, and relate to excavations, land clearing, the emplacement of fill on wet and soggy ground, etc.

2. Susceptibility of an Area to Landslide

Whilst the identification of the susceptibility of an area to landslide is necessarily an expert geotechnical matter, there are a number of indicators to the ordinary engineer that can provide guidance as to whether an area is susceptible to landslide. These indicators usually relate to the site slope, presence of fill, wet ground and / or weak underlying geological strata.

A design engineer can also gain assistance in the assessment of whether the site is a possibly subject to landsliding by reference to the hazard zoning maps prepared by a Local Council; in this regard, most Local Councils now have maps illustrating the various hazards in their area, whether these maps including flood, bushfire and geotechnical hazards.

It is however important to recognise that:

a) The maps only identify the existence of the hazard at a site, and usually do not provide any information on a particular instability mechanisms operating at the site.

b) These maps are often have limited accuracy, and may well not cover the area within which the retaining structure is proposed.

As such, it is the design engineer's responsibility to consider the potential for land instability at a particular site and make a judgement as to the precautions that he needs to take to produce an effective design. Such precautions may include the obtaining of specialist advice from a geotechnical engineer.

Another hazard that an engineer needs to be concerned about is the effect of ground subsidence, and the particular form of subsidence that arises from mining. However comments on design methods in mine subsidence areas are not included in this paper.

3. Mechanisms & Indicators of Instability

Although it is not intended in this paper to provide an exhaustive discussion of the various indicators of instability, there are a number of items that the average experienced engineer should be able to recognise as posing a significant stability issue. It is however important in any hillside situation for the designer of a retaining structure to seek advice from geotechnical personnel, and to seek this advice before site earthworks are undertaken.

Perhaps the most obvious indicator of a potential for instability is steeply sloping ground and / or ground which obviously becomes wet. Thus, where the site slopes are fairly steep [i.e. in excess of 15°], or where there is lots of seepage and weak rock materials such as claystones and shales, instability may be present.

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Another common indicator of potential for instability is the site vegetation, with tilts on trees, bending of tree trunks, and water loving vegetation [e.g. ferns and moss] are important indicators of the potential for land instability.

Slide: - vegetation ex Gosford

Another issue for the design engineer to consider is the potential for a rockfall to occur from a cliff above the site, or for a boulder to roll and bounce down the hillslope. Whilst these are specialist topics of their own, it is important to note that in the Sydney, Central & South Coast regions of NSW, rockfalls and boulder rolls have occurred on a reasonably regular basis, with typically one significant boulder roll / rockfall occurring annually in each of these areas.

In view of the above, when preparing a design for an earth retaining structure on a hillside slope in the vicinity of steep land and cliffs, it is important during the design process to assess the probability of rockfall and / or boulder roll occurring down the steep slope.

Slide: Boulder roll ex Gosford

RELEVANT MATTERS IN AS 4678 [EARTH RETAINING STRUCTURES]

As any retaining structure designed in Australia will need to comply with the Australian standard on 'Earth Retaining Structures' [viz: AS 4678-2002], it is important for a wall designer to be fully conversant with the Standard. In addition, the Australian Geomechanics Society has published a useful guide on retaining walls [GeoGuide LR06 – Ref: 2], and there are a number of specific comments in the referenced paper:

'Building in Areas of Landslip, Subsidence & Rockfall' [Ref: 3]

Slide

Geoguide only very general and not suitable for landslip situations

Shirley & Ingles Paper provides more information

AS 4678 applicable to walls over 800 mm high

A wall designer would be well advised to consider all of these documents prior to preparing the design for a earth retaining structure in any area potentially subject to landslide, or on hillslope.

It is also noted that the Standard applies to all retaining structures up to 15 m high, including walls as low as 200 mm. The only exemption is for low **'facings'** less than 800 mm high.

In relation to the Australian Standard, the following parts of Section 3 of the Standard are most relevant to the construction of Earth Retaining Structures on hillsides, and within areas potentially subject to landslide:

1. Limit States & Possible Slope Failure Mechanisms.
2. Drainage
3. Effect of Construction on Adjacent Ground

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1. Limit States & Slope Failure Mechanism

In Section 3 of the Standard, a number of 'limit states' are presented for a wall designer to consider in the process of preparing a earth retaining structure design.

Unfortunately, none of the 'limit states' presented deal with the issue of overall slope failure mechanism; as such, a designer needs to determine the potential failure mechanism as a part of the design process. It is also to be noted that:

a) In the majority of hillslopes experiencing instability it is not feasible to design the retaining structure to 'fully support' the load calculated by most stability analyses.

b) The 'earth pressure factor' approach commonly adopted by design engineers is usually not appropriate to hillside situations and areas where there is landsliding.

c) In many situations on a hillside, the excavation will expose a weathered rock material [which is comparatively stable] and an upper soil mantle which is subject to instability.

Slide

Earth Pressure Factor approach usually NOT appropriate

Load on wall determined from Stability Analyses

Safety Factor / Partial Factors

In view of the above, it is common for retaining walls on a hillside to be designed so that they are able to move, with the wall moving down slope at a slow rate that matches the potential for soil slope instability of the hillside. Should such a wall configuration be considered, then it is very important that the wall be of the flexible / ductile type, and that any long term movement of the wall will not create other site problems.

In relation to the partial and load factors suggested in the Standard, the typical hillslope situation is such that the usually recommended partial & load factors are not able to be achieved; as such, when issuing a design it would be prudent for the engineer to put a notation on the drawing as to the actual safety factors embraced by the design.

2. Drainage

As in nearly every case of landsliding, groundwater, seepage and stormwater seem to be involved, the provision of appropriate drainage in association with any earth retaining structure on a hillside, or in an area potentially subject to landsliding is very important.

In this regard, particular attention is drawn to Clause 3.6.2 of the Standard:

> *Clause 3.6.2*
>
> ***Design considerations***
>
> *…. the designer shall consider and allow for at least the following items in the design:*
>
> *a) Existing site ground water conditions and how such conditions are likely to be affected by the construction of the structure.*
>
> *b) Necessity for and specific details of any drainage systems to be provided behind the structure.*
>
> *c) The 'long-term' performance of the drainage system and the necessity for maintenance.*

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In view of the above, it is very important that the designer of the retaining wall not only design the drainage immediately behind and associated with the wall, but also become involved in the drainage arrangements for the site overall.

Slide

Drainage of Paramount Importance

Drainage MUST:

- last for the life of the wall
- be able to be maintained

Drainage both behind the wall & at excavated face

AS 4678 : Diagrams & Appendix Notes

Slide : Northbridge Problems

In addition, as retaining walls are often constructed on steep slopes where there are various forms of site drainage absorption pits, the designer of the retaining wall should also acquaint themselves with the locations of any site drainage / absorption structures on close by, and / or the adjoining land.

3. Effect of Construction on Adjacent Ground

Although it is always important, in hillslope areas it is particularly important that an earth retaining structure designer consider the stability of the adjoining ground, and the possible effects of the proposed construction on the stability of the ground.

In this regard, particular attention is drawn to Clause 3.7 of the Standard, viz:

> *"Consideration shall be given to the possible adverse effect on the adjacent land or structures of the construction of an earth-retaining structure. This is particularly important on sloping ground where any excavation associated with the construction of the retaining wall may induce or reactivate slope instability"*

In passing, it is noted that this clause was introduced into the Standard because of the common practice of design engineers to only concern themselves with the 'completed construction', and to leave the issues of excavation support and the like to the contractor / builder charged with constructing the works. Whilst this may be acceptable where the potential for land instability is not an issue, in an area subject to landsliding [and / or where this hillslope is relatively steep], the wall designer **must involve** themselves in both:

- the process of creating the earth retaining structure, as well as:
- the design of the completed structure,

because the selected form of the completed structure will have a significant effect on the way in which the wall is constructed, as well as the necessary site excavations to enable the construction to proceed.

Slide: Kurrawyba Ave Terrigal

Slide: Gabagong Road

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TYPES OF RETAINING STRUCTURES FOR LANDSLIDE AREAS

Whilst the Australian Geomechanics Society GeoGuide LR06 provides some information on several types of retaining walls, the guide does not traverse the particular requirements for retaining structures on hillslopes and areas subject to landsliding.

As such, as a part of a designer's consideration of the most appropriate type of structure to be adopted at a particular site, the following issues / factors should be considered

1. The Constructability of the Wall, including the speed of construction, and whether the construction can be staged.
2. Whether the wall needs to provide temporary, as well as permanent support to the slope.
3. Whether the wall will need to resist the very substantial forces arising from slope movement, or whether some deformation of the wall can be tolerated.
4. Whether a rigid [viz: not movable] structure is required.

Following a consideration of the above factors, then the range of wall types that may be appropriate to individual situation can be selected.

1. Constructability Issues

In a hillside area, and / or an area subject to slope failure / landsliding, a very important issue is that of ‘Constructability’, which embraces issues such as:

- the speed of construction;
- whether the structure can be built in sections, or stages.

Slide:

Speed of Construction & temporary support

Staged Construction

Design vs. construction condition

In this regard, it is noted that the speed of construction is perhaps the most important because most excavations in soil and weathered are rock able to stand for a short period at relatively steep slopes; whereas they are not likely to be stable at a steep slopes for more than few days or a few weeks.

Thus, if it is possible to construct the wall relatively quickly, then it may well be possible to avoid the installation of temporary support and / or shoring. It is however important to recognise that associated with this 'quick construction' is a need for an effective site drainage so that during the construction processes the excavated soil / weathered rock does not become saturated and as a consequence cause a slope failure.

In addition, in hillslope / landslide areas, the temporary stability of the slope is often defined by the extent of excavations undertaken for the proposed earth retaining structure; as such, a short excavation is usually more stable than an extensive, or long, excavation due to the three-dimensional effects of slope support.

Therefore, it is often preferable to design a wall that is able to be built in short sections in a potentially unstable area, rather than one that has to be built in a single operation.

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Another important issue for an earth retaining structure designer is the question of whether or not the structure will need to be able to provide lateral support to the excavation during the construction process, or whether the structure can be fully completed before it is backfilled and used as an earth retaining structure. In this regard, reinforced concrete block walls are generally inappropriate for construction on hillsides, because the construction processes normally necessitate an extensive construction period with an unsupported excavation behind.

Slide : Walls of Jericho - Terrigal

Slides: Grandview Parade Newport

2. Slope Movement Issues & Wall Loads

Another important consideration in the selection of the appropriate type of earth retaining structure in a landslide area or hillslope is the likely load for which the wall will need to be designed. In this regard, the questions will typically be:

1. Whether the wall will need to be able to support the full soil load coming onto the structure from the hillslope, **or**
2. Whether the wall is able to be designed for a lesser load on the basis that the wall can move somewhat during the structure's life.

Slide:

Wall to resist the full slope force?

Can the wall deform / move without damage?

In the first instance, walls that are required to accept the full soil load are usually major structures that might be constructed with anchors, deep piles, etc. Such walls are nearly always very costly and only used to support major features such as railway embankment fills, major highway excavations, etc.

Slides: 2 x diagrams ex gosford

In addition, if a 'super strong' wall is constructed near the toe of an unstable fill, then the structure is not necessarily successful as the fill can fail and then flow over the 'super strong' wall.

Slide: Ramsay Street, Collaroy

A viable alternative to the use of 'super strong' walls is the use of earth retaining structures which are able to deform / move without significant damage and so accommodate the down slope movement of the surficial soil on a hillslope.

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3. Wall Types for Landslide Areas

In light of the likely loading configurations that come upon an earth retaining structure in a hillslope or landslide situation, typically there are two groups of walls that are suitable for use in such areas:

1. Inflexible Walls.
2. Flexible / Ductile Walls.

Slide:

Inflexible Walls – 'super strong'

Flexible / Ductile Walls

a) Inflexible Walls

In areas where slope movement is expected, inflexible walls typically need to be able to resist very substantial forces arising from the slope movement, with this force usually being at least several times the load applied to the majority of retaining walls. This large force arises from the continued imposition of the load onto the structure as a result of the soil movement down slope, and therefore the build up of passive earth forces upon the wall.

Slide:

Long Time to Construct

Usually need to resist Large Lateral Loads

If wall strong enough, the slope can still fail

Because of the large loads, such walls are typically anchored walls, or walls constructed with a system of piers and anchors and normally only used to restrain the movement of a critical embankments and other structures. These walls also typically take a substantial period to construct and thus normally require an extensive system of temporary support during the construction processes.

These walls could also be described as 'super strong' walls, because of their usual massive structural proportions and high cost.

b) Flexible / Ductile Walls

As noted previously, an alternative to the 'super strong' wall is a flexible / ductile wall which can deform / deflect under load thus reducing the usual design load on the wall. Such structures must however be designed in such a way that they have sufficient capacity to tolerate the predicted deformations arising from the slope movement. As a consequence, these walls normally need to exhibit both flexibility and ductility.

In this regard, it is especially noted that a wall that has a number of joints is not necessarily either flexible or ductile.

For example, whilst segmental concrete block walls have many joints and are very useful in hillside areas, such walls are unable to cope with substantial deformations under load.

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Slide

Flexible / Ductile Walls

Difference between Joints and Flexibility

Separation between walls and structures

It is also important when designing a flexible / ductile wall that a clear and accessible space be always maintained between the earth retaining structure and the particular structure or facility associated with the earth retaining structure. Such a space can also prevent damage to the facility when an inappropriate wall actually fails.

Slide: Tulloona Ave Bowral

In light of the above, experience has shown that the most effective walls for use in hillslope areas, and areas potentially subject to land instability include:

1. Segmental Concrete.
2. Gabion & Crib Walls.
3. Boulder Walls / Revetments.

Slide:
Segmental Concrete
Gabion Walls
Boulder Walls / Revetments
Post & Log walls not suitable

Slide: RTA Gabion Walls - Mt Ousley

In relation to the use of 'post & log' walls, and whilst it is acknowledged that these walls have been extensively used, experience has shown that these walls are generally not suitable for use on hillslope areas where the slope angle exceeds 15° because of the lack of stability of such walls on steeper hillslopes.

PARTICULAR WALL DETAILS

Whilst extensive comment on all of the various details applicable to earth retaining structures are beyond the scope of this paper, some of the more common issues arising with earth retaining construction in hillside areas and areas subject to landsliding are commented on in the following section, with these comments embracing:

1. Footing Construction.
2. Rock Bolts
3. Piered Wall Construction & Ground Anchors.
4. Post & Log Walls.

Slide
Footing Construction
Rock Bolts
Piered Wall Construction & Ground Anchors
Post & Log Walls

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1. Footing Construction

One of the most challenging tasks in constructing a retaining structure on the hillslope or areas subject to landsliding is the construction of an adequate footing system on a suitably stable foundation. Typically, the construction issues that arise include drainage, excavation instability, localised excavation slumping, and deterioration of the foundation strata due to weathering and exposure.

As a consequence, footing systems for retaining walls in hillslope areas and areas subject to landslide need to be simple and able to be rapidly constructed; for preference, reinforced concrete footings are to be avoided as well as footings which require extensive excavation below any excavated platform.

Experience has also indicated that:

a) Where an adequate foundation can be created by the use of mass concrete, or cement stabilised roadbase materials, then the construction of the earth retaining structure normally proceeds with minimal delay and cost overruns.

b) Excavations into weathered bedrock materials below surficial soil materials commonly encounter extensive seepage at the weathered bedrock / surficial soil interface which can of itself create a significant construction issue.

c) Excavations for the footing itself can in fact initiate a failure of the soil the structure is intended to support.

2. Rock Bolts, Piered Walls & Ground Anchors

In many hillside situations designers are often tempted to use earth retaining structures created by the installation of piers which are then supported by anchors and / or rock bolts.

As this form of construction inherently results in a structure which is relatively inflexible, the structure will need to be designed for the very large soil loads that may come upon it. In addition, there are normally concerns about:

- the permanency of the anchors / rock bolts;
- the need for effective corrosion protection to any anchorage system provided.

Thus, whilst these structures are often very effective as temporary earth retaining structures, their use as a permanent walls may generally not be warranted.

Slide

Large load to be resisted on Anchored Walls

Rock Bolt / Anchor Corrosion Protection

Where rock bolts are installed to guard against failure of a localised pieces of rock, and / or protect against a boulder roll down the hillside, then it is always necessary to ensure that the rock bolts / anchors are:

1. Sufficiently deeply embedded & bonded into the ground to provide a secure anchorage.

2. Appropriately protected against long-term corrosion.

Another issue that can arise on hillslopes where anchored walls are used, is a lack of appropriate quality control of the construction, which then leads to failure of the anchors when the full design load comes upon the wall, and consequent failure of the wall.

Slide: Soil Nail Wall failure in Noosa

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3. Post & Log Walls

A very common form of earth retaining structure to be built upon hillsides is the timber 'post & log' form of retaining wall, which has a very high incidence of structural failure. Whilst many of the structural failures can be attributed to poor quality construction, it would appear that many of the failures should be attributed to a lack of understanding of the way in which a post & log retaining wall resists the soil and fill loads upon them. In this regard, the following is noted:

Slide:

Lateral Load resisted by passive pressures

Special anchorages for walls on slopes steeper than 10 to 15°.

Failure of even small wall can cause serious damage.

1. The lateral loads upon the wall are entirely resisted by passive soil pressures against the individual posts.
2. When the slope angle of the ground in front of the post exceeds some 10 to 15°, then the available passive resistance reduces to negligible levels.

Slide: Passive pressure diagram.

3. Unless the post & log is fitted with an especially designed anchorage within the active side of the wall, a wall constructed on the hillslope will normally fail when the design load comes upon the wall. The design condition is also usually achieved during periods of wet weather.
4. If a relatively small post & log retaining wall fails on a steep hillside behind a house, then the resultant soil, water and other debris flow down the slope can lead to serious damage; particulary if the debris impinges on, or enters the house structure.
5. A post & log retaining wall in a backyard on a hillslope should normally be classified as a Class B or Class C structure in accordance with AS 4678, and not as a Class A structure.

As a consequence, post & log retaining walls within residential properties should normally be limited in height to 600 mm, unless a special structural design is performed and the construction itself supervised by an appropriately qualified engineer.

Slides: Valentine & Newport

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CONCLUSION

The undertaking of earth retaining structure design on hillslope areas, and areas that have a potential for landsliding, requires significant expertise in the structural, civil & geotechnical disciplines. In addition, the design processes require a good understanding of slope instability mechanisms and of the interaction between soils, weathered rock and structures.

As such, successful design of earth retaining structures in these areas would normally be a 'team effort' between engineers of relevant expertise.

Slide

Landslip Area Wall Design a Team Effort

Understanding of Slope Stability Mechanisms

Workshop after a break

In addition, the requirements of the Australian Standard on Earth Retaining Structures [viz: AS 4678] impose significant obligations on the designers of retaining structures in areas where soil and slope instability is suspected, as well as requiring special consideration of:

1. The drainage arrangements associated with the earth retaining structure.
2. The possible effects of the proposed construction on nearby and / or adjoining ground.

In light of the above, and whilst it is hoped that this paper will provide a significant aid to designers of earth retaining structures in hillslope areas and areas subject to landsliding, the guidelines presented in this paper should be seen as a ‘progressive step’ in the development of appropriate guidelines for safer earth retaining structures in areas of landslide, subsidence & rockfall.

REFERENCES

1. Standards Australia [July 2003], AS 4678-2002 ‘Earth Retaining Structures’.
2. Australian Geoguide LR6 – Australian Geomechanics Vol 42 No. 1 March 2007.
3. Shirley A F & Ingles O G, ‘Building in Areas of Landslip, Subsidence & Rockfall’ [including hillside building guidelines]. Australian Geomechanics Vol 37 No. 3 June, 2002.