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An Example of a Qualitative Terminology and Risk Matrix For Use in Landslide Risk Assessments

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Summary: In March 2000, a sub-committee of the Australian Geomechanics Society published a guideline document on landslide risk management entitled "Landslide Risk Management Concepts and Guidelines". Appendix G of this document provides "--- an example of qualitative risk terms which could be used for risk to property". It also explains that "other terms may be used".

This paper provides another example of qualitative terminology and a risk matrix that has been adopted by a local government authority in Sydney, Australia as the standard for stability assessment reports submitted to it for development proposals. It adopts a semi quantitative approach to risk to life but with quantitative boundaries. It is based on the guidelines provided by AGS 2000. This paper sets out the framework adopted in the standard and provides some commentary on it.

INTRODUCTION

One of the principal aims of the paper "Landslide Risk Management Concepts and Guidelines" (Henceforth referred to as AGS 2000) was to provide a general framework for landslide risk management including guidance on the methods which should be used to carry out the risk analysis as well as information on acceptable and tolerable risks for loss of life. Appendix G of the paper provides good guidance for the assessment of risk to property in the form of an example of qualitative terminology for likelihood and a matrix for categorization of risk. Definitions are also given for risk level implications. This paper expands on the example given in Appendix G for its recommended procedure for the assessment of loss of property.

In regard to the assessment of loss of life, the main paper comprising AGS 2000 is firm in its opinion that "Risk for loss of life should be quantified because the risk acceptance criteria used in society for loss of life are quantified". It then makes the recommendation that "the important first stage for the landslide risk assessor is to identify whether loss of life is an issue". The framework presented herein assists with this recommended procedure. Often, once a risk to life is identified it is relatively easy to undertake works or to manage the risk such that the risk to life ceases to be an issue. The writers consider that, in this case, no further analysis may be required. The example given in this paper has been extended to provide a first pass assessment of the risk to life with risk levels consistent with those discussed in AGS 2000.

The scheme described herein is intended to be used for a typical residential development. It can be used as a guide to whether a full quantitative risk analysis is required. This may be the case for marginal residential cases or when more persons are at risk or if more than one event dominates the risk assessment. In June 2003, Pittwater Council, located in the northern beach suburbs of Sydney, Australia, adopted this example as the basis of an Interim Risk Management Policy (the Policy). Submissions for Development Applications and for the issue of Building Certificates for properties that lie within designated geotechnical instability and coastal hazard zones, now are required to comply with this Policy. The Policy allows the assessment of risk levels as per this example and requires compliance with the acceptance criteria of the Policy. These latter criteria have been set by Council following the guidance provided in AGS 2000 and the opinion expressed therein that "--- the decision on risk acceptability (or tolerance) <u>must</u> be made

Figure 1. House on Failed Slope Showing Scaffolding Support and Reinforced Piers

by the client, owner, regulator and those at risk, where they are an identified group". Council recognises that in the instance of property development, where the duty of care is continuous but ownership can change, then it must be the role of the regulator to determine the acceptability (or tolerance) of risk, in order for it to ensure that it has satisfied its duty of care to future owners.

The authors became involved in the formulation of this scheme via interaction on the development of a "Stability Standard" for a group of houses in the Pittwater Shire which required investigation and remedial work as a result of damage from land slippage. Some examples of typical problems that can develop as a result of inappropriate development on landslide prone sites are shown in Figures 1, 2 and 3. One of the aims of the Council in implementing its Policy was to try to prevent re-occurrence of similar inappropriate development in its Shire.

Figure 2. House on Failed Slope Showing Rotated Timber Piers

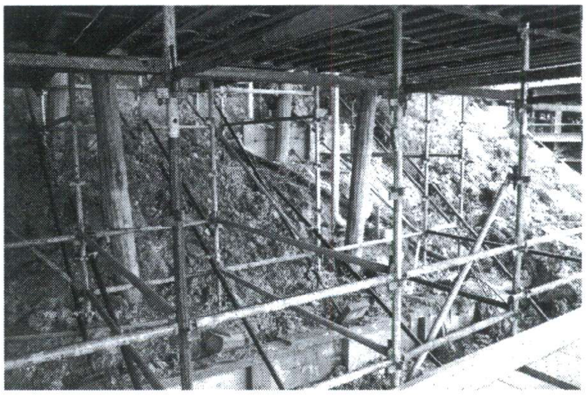

Figure 3. House on Failed Slope Showing Scaffolding Support and Rotated Piers

FRAMEWORK

The framework consists of five tables and associated tolerability and acceptability criteria. These are given in each of the following sections with some discussion of each. It is important to note that whenever practical, the tables should be read from right to left.

QUALITATIVE MEASURES OF LIKELIHOOD

Qualitative measures of likelihood of occurrence of a landslide are given in Table 1. The descriptor refers to the likelihood of the event occurring over the life of the structure and the indicative probability is the approximate annual probability that is associated with that descriptor.

Table 1. Qualitative Measures of Likelihood

Level	Descriptor	Description	Indicative Annual Probability
A	Almost Certain	The event is expected to occur.	$\geq 10^{-1}$
B	Likely	The event will probably occur under adverse conditions.	$\geq 10^{-2}$
C	Possible	The event could occur under adverse conditions.	$\geq 10^{-3}$
D	Unlikely	The event might occur under very adverse circumstances.	$\geq 10^{-4}$
E	Rare	The event is conceivable, but only under exceptional circumstances.	$\geq 10^{-5}$
F	Barely Credible	The event is almost fanciful.	$< 10^{-5}$

The first three columns have been slightly modified from Appendix G. For example, "Not credible" has been changed to "Barely credible", otherwise fanciful cases (e.g. asteroid impact dislodging multiple boulders, etc) would have to be considered.

The numerical probabilities also have been altered to be about one half of an order greater than the indicative values given in Appendix G. The principal reason for this is that substitution of these indicative values into the risk matrix in Table 4 (see following), along with an assumption of an equal distribution for the indicative probability of loss of life in the consequences to life table (see Table 3), gives consistency between the expected annual probability of loss of life and the matrix diagonal positions for tolerable and acceptable risk combinations. The numerical probabilities also are considered to better reflect the descriptions e.g. "Likely" implies an expectation of a result (P>0.5) over the life of the structure. The range applicable to the annual probability for the "Likely" descriptor in Table 1 is 0.1 to 0.01 p.a., which implies between 40% and 99.5% likelihood of the event occurring over a typical 50 year life of structure.

QUALITATIVE MEASURES OF CONSEQUENCES TO PROPERTY

Qualitative measures of consequences to property are given in Table 2.

Table 2. Qualitative Measures of Consequence to Property

Level	Descriptor	Description	Approximate Cost of Damage
1	Catastrophic	Structure(s) completely destroyed or large scale damage requiring major engineering works for stabilisation. Could cause at least one adjacent property major consequence damage.	≥ 100 %.
2	Major	Extensive damage to most of structure, or extending beyond site boundaries requiring significant stabilisation works. Could cause at least one adjacent property medium consequence damage.	≥ 10 %.
3	Medium	Moderate damage to some of structure, or significant part of site requiring large stabilisation works. Could cause at least one adjacent property minor consequence damage.	≥ 1 %.
4	Minor	Limited damage to part of structure, or part of site requiring some reinstatement stabilisation works.	≥ 0.1 %.
5	Insignificant	Little damage.	≥ 0.01 %.

The descriptors in this table are similar to those given in Appendix G, but we have added the approximate cost of damage to both the subject structure and any adjacent property also damaged. In the above table this has been expressed as the cost of the physical damage as a percentage of the improved value of the unaffected land and structure(s) (i.e. the market values). It is the writers' experience that this system which assigns a range of dollar values to each risk category is an important consideration to local government authorities and to property owners, because of the readily assessable commercial implications of the respective damage levels.

What becomes readily apparent to users of this table is that the Medium level consequence will often only represent a modest sum of money. This is a direct result of the ten-fold multiplier between levels and what the writers consider to be the (obvious) choice for the Level 1 consequence as at least equal to the complete loss of the subject structure. Note that the writers consider that the Catastrophic consequence cost could also be greater than 100% in situations where an event completely damages the subject structure and affects an adjoining property (or properties). The writers also consider that the ten-fold division between level boundaries is a realistic representation of the accuracy that can be invoked with this type of assessment. With this in mind therefore, the adoption of the above scale of costs puts into perspective the expectation for the performance of an engineering design implied by the table i.e. in addition to the Medium cost level discussed above, Minor consequence damage for a site is seen to fall below 1% of the cost of the development.

Another advantage of the above method of expressing the cost of damage as a percentage of the cost of the improved value of the unaffected structure(s), is that it allows meaningful discussion about consequences and limits seemingly endless discussion regarding the distinction between "moderate" and "limited". It does not eliminate but reduces and focuses discussion. It also allows the real net present value of the damage to be quantified, and provides an indicator of the cost of the insurance increment or sinking fund required. This is discussed further later in this paper.

QUALITATIVE MEASURES OF CONSEQUENCES TO LIFE

The left hand columns of Table 3 present qualitative measures of consequences to life. The indicative probabilities are for the loss of the life of the person most at risk if the event (landslide) occurs.

Table 3. Qualitative Measures of Consequences to Life

Level	Descriptor	Description	Indicative Vulnerability
1	Catastrophic	Almost Certain Fatality	$\geq 10^{-1}$
2	Major	Likely Fatality	$\geq 10^{-2}$
3	Medium	Possible Fatality	$\geq 10^{-3}$
4	Minor	Unlikely Fatality	$\geq 10^{-4}$
5	Insignificant	Rare Fatality	$< 10^{-4}$

The descriptions and probabilities are new and probably controversial. The authors have tried to be consistent with the quantitative approach recommended in the AGS 2000 paper. The consequence is to the person most at risk and thus leads to acceptance criteria. The term "Indicative Vulnerability" combines the assessor's estimate of vulnerability, exposure and the consequence assessed as fatality.

The descriptors from Table 1 - Qualitative Measures of Likelihood, have been used to describe the different levels of consequence to life and have been assigned the same numerical probability range. The authors intend that this table is best used from right to left i.e. that the respective probabilities covering temporal and spatial exposure and vulnerability are initially quantified into a single consequence value (albeit that this may only be possible in an approximate manner) and that this result is then compared with the qualitative assessment of the likelihood of a fatality i.e. the numerical assessment is given a "reality check".

Alternatively, as a "first pass" assessment in situations where data for use in a quantitative assessment is not readily available and/or is difficult to quantify, the table can be read from left to right. That is, in these situations use of the table is proposed in the same way as the assessed probability of occurrence of a hazardous event is proposed for assessment in the example in Appendix G of AGS 2000. However, as stated earlier, where this preliminary assessment raises the risk to life as an issue, a full quantitative risk analysis should be performed unless risk treatment results in a satisfactory situation.

The above approach can only be applied meaningfully for a single event. Therefore, it is most applicable when a single event dominates the risk assessment. In many situations this will be the case and the method proposed herein can be used. However, in situations where there may be more than one hazard for which the risk to life is an issue, either a more rigorous quantitative approach will be required or it may be that remedial works can be undertaken to reduce the risk levels.

QUALITATIVE RISK ANALYSIS MATRIX

Table 4 provides the qualitative risk matrix intended for use with Tables 1, 2 and 3. The advantages of this matrix are discussed below.

The matrix is similar to that given in Appendix G of the AGS 2000 paper except that it has been modified to remove the dual groups. A spread of risk levels might result from sensitivity analysis or consideration of different events. However, if the likelihood and consequences are well known, then only one risk level results. Further, superimposed on the matrix are diagonals of equal probabilities resulting from the multiplication of the indicative values given in Tables 1 and 3 for likelihood and consequence respectively.

The intention with this table is that risk to property can be obtained by the category level given by the combination of likelihood and consequence, and risk to life can be obtained by the probability value of the diagonal. The superposition shows the consistency of the relationship between the two sets of results along the indicated diagonal of each of the matrix "rectangles". Along the opposite diagonals, there is a change in risk level within each cell of some 2 orders. This shows the large variation possible within each cell of the matrix.

Table 4. Qualitative Risk Analysis Matrix

Likelihood	Consequence to Property or to Life					
	1. Catastrophic	2. Major	3. Medium	4. Minor	5. Insignificant	
		10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}
A - Almost Certain	VH	VH	H	M	M	10^{-6}
B - Likely	VH	VH	H	M	L	10^{-7}
C - Possible	VH	H	M	L	VL	10^{-8}
D - Unlikely	H	M	L	L	VL	10^{-9}
E - Rare	M	L	L	VL	VL	
F - Barely Credible	L	VL	VL	VL	VL	

Notes: 1. The risk matrix has been skewed in favour of consequence.
2. The diagonal lines give indicative (p.a.) risk levels for life.

The choice of the indicative probabilities in Tables 1 and 3 is now seen as being driven by the need to have the consistency between the matrix rectangles of risk level and the diagonals of probability. Other combinations of indicative probability in Tables 1 and 3 are possible. However, the authors have chosen to use the same distribution of probabilities within each table.

The Moderate risk level along the diagonal of the matrix correlates well with an expected risk to life of 10^{-5} per annum, as does the Low risk level with a risk to life of 10^{-6} per annum. Two "mis-matches" occur at cell No's A3 and A4 where H and M risk levels are seen to have probabilities of 10^{-3}p.a. and 10^{-4} p.a. respectively. This was the result of a deliberate choice to make cell A4, a Moderate risk level because of the practical consideration of the implication of a High risk associated with Almost Certain, Minor hazards (such as small cobbles, localized slumps etc falling onto a roadway where an assessed High risk in this cell could result in unnecessary closure of many roads). The High risk in cell A3 was used as an intermediate level between VH in cell A2 and M in cell A4. This example of a matrix skewed in favour of consequence is similar to the example in AS/NZS 4360-1999.

From the table and in terms of the example proposed in this paper it is seen that a Moderate risk to property implies an expected annual cost of damage of between 10^{-4} to 10^{-6} times the value of the property. Many properties in Sydney are now valued in the vicinity of, or in excess of $1,000,000. Thus, the expected annual cost of the event would be between $1 and $100. This can be looked at as the increase in insurance premium required to cover that event. A different way of looking at the cost of this event is that, assuming a real rate of return of 3% p.a., a sinking fund of approximately $30 to $3,000 would be required to meet the cost of this event. It should be noted that in some assessments there will be multiple events that might be considered and that the expected cost of these would often be cumulative.

RISK LEVEL IMPLICATIONS

Table 5 sets out the Implications of the Risk Levels.

The risk level implications are the same as those in Appendix G of AGS 2000, except that the comments "May be accepted", "Usually accepted" and "Acceptable" relating respectively to the Moderate, Low and Very Low risk levels have been deleted. This has been done because, for this example, separate acceptance criteria have been stipulated in the Policy (see following).

Table 5. The Implications of the Risk Levels

	Risk Level	Implications
VH	Very High Risk	Extensive detailed investigation and research, planning and implementation of treatment options essential to reduce risk to acceptable levels: may be too expensive and not practical.
H	High Risk	Detailed investigation, planning and implementation of treatment options required to reduce risk to acceptable levels.
M	Moderate Risk	May require investigation and planning of treatment options. Tolerable provided treatment options are implemented to maintain or reduce risks.
L	Low Risk	Treatment requirements and responsibilities to be defined to maintain or reduce risk.
VL	Very Low Risk	Manage by normal slope maintenance procedures.

ACCEPTANCE CRITERIA

The council has adopted the following acceptance criteria within the Policy.

Acceptable Risk - Acceptable Risk includes the risk to life and the risk to property, both must be considered. The guidance for the establishment of acceptable risk criteria in this Policy has been based on the contents of Section "4.2.1 Property" and "4.2.2 Loss of Life" in AGS 2000. Acceptable Risk for Loss of Life for the person(s) most at risk, per annum is taken as having one order of magnitude smaller than the "Tolerable Risk" for the person most at risk, as given in the table in 4.2.2 of AGS 2000. That is, the "Acceptable Risk" has a probability of 10^{-6} *per annum Loss of Life being the overriding consideration as compared to property loss for developments in Pittwater LGA and "new slopes" being chosen as the criteria because developments generally result in slope disturbance in one form or another. Acceptable Risk for Loss of Property is taken as "Low" as defined in AGS 2000 and Appendix 1 of this Policy. The risk level for Loss of Life or Property can be determined by the quantitative methods outlined in AGS 2000 or by the semi-quantitative methods outlined in Appendix 1 of this Policy. The choice of method is dependent on the availability of information. The risk level for Loss of Property can be determined by the semi-quantitative example by using qualitative terminology given in AGS 2000 or by the qualitative method outlined in Appendix A of this Policy.*

Tolerable Risk -10-5 for the person(s) most at risk, per annum and "Moderate" for property, as defined in AGS 2000 and Appendix 1 of this Policy. The Tolerable Risk criteria is only applicable to sites with structures that have been in existence in their present form for at least 10 years and have demonstrated a performance at a Tolerable Risk level, or better, during that period and there is not a foreseeable reason why this situation should change. Tolerable risk can only be considered as a criterion for the purpose of Building Certificates and under the Orders process.

The Council Interim Policy has set acceptable and tolerable risk levels for loss of life in accordance with the guidance given in AGS 2000 for individual risk i.e. the person most at risk. The Council will accept risk levels for loss of life assessed either by the quantitative methods outlined in AGS 2000 or by the semi-quantitative method described herein.

The Policy differentiates between new developments which must comply with the Acceptable Risk criterion and existing developments which have been subject to a "demonstrated performance at Tolerable Risk level" for a period of at least 10 years, in which case the Tolerable Risk criteria applies. This latter case is available only for the purpose of Building Certificates or works to be carried out under the Orders process. It includes existing slopes or slopes with developments on them. Where a slope or an existing house is to be significantly modified then the Acceptable Risk criterion applies. The one exception exists in the case which the Policy has defined as Minor Development and/or Minor Alteration. These are developments with *"a value of less than $10,000.00 or as determined by Council from time to time every 5 years"*. In this case the Policy requires the geotechnical engineer to determine whether a risk assessment is required, so that even in this case, existing high risk cases can become subject to remedial action.

CLOSURE

The writers have found that the example framework discussed in this paper has allowed them to focus discussion about particular properties on substantive matters and avoid never ending discussion regarding semantics. They consider this to be worthwhile. Others may find the example useful in their practice.

ACKNOWLEDGEMENTS

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REFERENCES

Australian Geomechanics Society Subcommittee (2000) "*Landslide Risk Management Concepts and Guidelines*" Australian Geomechanics, Vol. 35, No 1, March, pp 49-92.

Australian/New Zealand Standard, "*Risk Management. AS/NZS 4360:1999*".

Planning NSW. "Risk Criteria for Land Use Safety Planning. Hazardous Industry Planning Advisory", Paper No. 4, 2nd Edition, 1992.

Pittwater Council, Sydney, Australia. "Interim Geotechnical Risk Management Policy for Pittwater", June 2003.