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Landslide risk assessment - development of a hazard consequence approach

Abstract

Several Landslide Hazard and Risk Assessment methods have been developed and used in the State of New South Wales (NSW), Australia. The Rail Services Australia Geotechnical Services and the Roads and Traffic Authority of NSW have each developed Risk Assessment procedures suitable to their own specific needs. A generic risk management methodology is presented in the Australian Standard/New Zealand Standard (AS/NZS) 4360:1995. An approach similar to the (AS/NZS) 4360:1995 Risk Management Standard has been applied by a NSW State Emergency Services geotechnical team (which included one of the writers) to 191 problem sites in the Wollongong Area, following a major rainstorm event in August 1998, (GTR, 1998). The writers at the University of Wollongong (UOW) are developing a more comprehensive hazardconsequence approach. This has required careful and precise definitions of the terms and parameters being used. It is the writers' intention that this will lead to effective, efficient and consistent assessments of hazard and risk. Field Data Sheets based on the stated concepts are being developed and tested at several field sites. The formalisation of field data collection will provide a good mechanism for consistent data capture. Data collected in this manner is most suited for management in a database environment.

Keywords

risk, development, hazard, consequence, approach, landslide, assessment

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ABSTRACT: Several Landslide Hazard and Risk Assessment methods have been developed and used in the State of New South Wales (NSW), Australia. The Rail Services Australia Geotechnical Services and the Roads and Traffic Authority of NSW have each developed Risk Assessment procedures suitable to their own specific needs. A generic risk management methodology is presented in the Australian Standard/New Zealand Standard (AS/NZS) 4360:1995. An approach similar to the (AS/NZS) 4360:1995 Risk Management Standard has been applied by a NSW State Emergency Services geotechnical team (which included one of the writers) to 191 problem sites in the Wollongong Area, following a major rainstorm event in August 1998, (GTR, 1998). The writers at the University of Wollongong (UOW) are developing a more comprehensive hazard-consequence approach. This has required careful and precise definitions of the terms and parameters being used. It is the writers' intention that this will lead to effective, efficient and consistent assessments of hazard and risk. Field Data Sheets based on the stated concepts are being developed and tested at several field sites. The formalisation of field data collection will provide a good mechanism for consistent data capture. Data collected in this manner is most suited for management in a database environment.

1 INTRODUCTION

A study of the available hazard and risk assessment methods and procedures indicates that different levels or stages of risk assessment could be carried out depending on the available data. The greater the quantity of available data and the better its quality, the greater the objectivity and accuracy of the assessment achieved.

Comprehensive geotechnical investigations and subsurface monitoring are costly and such expenditure may or may not be required or economically justified. On the other hand, site inspections with some mapping are comparatively cost effective as essential preliminary tools for the decision making process.

At present, risk assessment methods are described as 'Qualitative', 'Semi-quantitative' and 'Quantitative' in relation to the degree of subjective judgement involved in making the assessment. In most cases, 'Qualitative' assessment is the pre-requisite assessment for justification of further more rigorous 'Semi-quantitative' or 'Quantitative' assessments.

It is generally recognised that there is a need for further improvements in achieving effective and efficient hazard and risk evaluation. In order to achieve a consistent outcome it is desirable to develop systematic procedures for field data collection and analysis. The following procedures will be very useful in this regard:

- Reducing the level of subjective assessments or, at the very least, clearly identifying the subjective component of the assessment
- Defining the terms precisely and clearly, so that there is no ambiguity in assessment or interpretation
- Development of approaches that are more quantitative in format and output

A comprehensive set of 'Field Data Sheets' based on the above concept are being developed and have reached the stage where Field Guide/Data Collection Sheets for the hazard assessment of natural slopes have been finalised. A trial hazard assessment test on natural slopes has been carried out on selected sites in the Wollongong area (South Coast, NSW, Australia). The next stage is the use of these procedures at problem sites on the North Coast Railway Line between Coffs Harbour and Grafton

Area of NSW, Australia.

The scope of this paper does not include the assessments of magnitude and frequency of landslide triggering events such as rainstorms. This aspect has been covered in recent work (Chowdhury & Flentje, 1998 and Flentje & Chowdhury, 1999). Preliminary or stage I hazard and risk assessment discussed in this paper does not therefore include the insight gained from analysis of rainfall data. However, such insight is extremely valuable and often essential for more detailed hazard and risk assessment.

2 QUALITATIVE RISK ASSESSMENT METHODS

The Australian Geomechanics Society (Walker et al, 1985) has developed a geotechnical risk assessment procedure associated with hillside development. The Rail Services Australia Geotechnical Services (RSA), Roads and Traffic Authority of NSW (RTA), and a Sydney based Consulting firm have developed risk assessment methods for their

2.1 Qualitative Risk Analysis Matrix (AS/NZS 4360:1995)

An example was appended to the Australian New Zealand Standard (Table 1) for a qualitative risk analysis matrix together with example descriptions of the qualitative measures of 'Likelihood' and 'Consequences'. This particular example and the Standard as a whole does not directly or indirectly refer to landslide hazard and risk assessment. However, the approach can be useful for such an application. A similar approach has been applied by a team of two engineers and one geologist to 191 problem sites in the Wollongong Local Government Area following the major storm event of August 1998 (GTR, 1998).

The risk assessment values may be expressed as an alpha-numeric combination such as A5, B2, E3, C1 etc. These combinations are defined as 'high risk', 'significant risk', 'moderate risk' and 'low risk' respectively as shown in Table 1. This type of assessment requires considerable judgement from an experienced geotechnical engineer or engineering geologist to interpret the levels of 'Likelihood' and 'Consequence' that are assessed primarily from a

Table 1. Qualitative Risk Assessment Matrix – Level of Risk (AS/NZS 4369:1995)

Likelihood	Consequence				
	Insignificant - 1	Minor - 2	Moderate - 3	Major - 4	Catastrophic - 5
A - Almost certain	S	S	H	H	H
B - Likely	M	S	S	H	H
C - Moderate	L	M	S	H	H
D - Unlikely	L	L	M	S	H
E - Rare	L	L	M	S	S

H = high risk: detailed research and management planning required at senior levels

S = significant risk: senior management attention needed

M = moderate risk: management responsibility must be specified

L = low risk: manage by routine procedures

respective needs.

The Australian Geomechanics Society method arrives at risk assessment directly. However, the other methods qualitatively assess the probability of landsliding (hazard) and separately assess the damage and/or loss of life (consequence). Based on these assessments of hazard and consequence, risk is determined and expressed in several categories. A further step is taken in the RTA method where numerical weighting is used in probability assessment of slope failure or landsliding. Some further details of these methods are described and discussed below.

visual site inspection. In defining consequence, examples pertaining to injury or loss of life, economic loss and extent of toxic contamination are provided in the example in AS/NZS 4360:1995. However, the terms used for the qualitative measures in the AS/NZS 4360:1995 tables, such as 'in most circumstances' and 'at some time' are not well defined. It is also important to note that the landsliding processes and related phenomena are not specifically considered in this Standard. This is further justification for the work undertaken by the writers as reported in this paper.

2.2 Rail Services Australia Geotechnical Services (RSA) approach for Risk Assessment and Hazard Management

The RSA Geotechnical Services (1997) have developed a Risk Assessment and Hazard Management Guideline. Using this guide, the RSA

The estimates of 'Probability' and 'Consequence' are a subjective evaluation or qualitative assessment taking into consideration the geotechnical features of the site, the topography, track alignment, operating requirements and maintenance practices (RSA, 1997). Hence this method also requires judgement

Table 2. Risk Assessment Matrix, RSA (1997)

	PROBABILITY of event affecting the track, in the short term (12 months). Assessment is necessary of probability of event occurring and affecting the track			
CONSEQUENCE of the event affecting the track	HIGH (H) Event is anticipated	MODERATE (M) Event is probable	LOW (L) Event is probable but not expected	VERY LOW Event is possible
Extreme (E) - loss of life expected - extensive damage and disruption	1	2	3 Priority 3	4
Severe (S) - loss of life is possible, not expected - appreciable damage and disruption	2	3 Priority 1	4 Priority 1	5
Moderate (M) - loss of life or serious injury not expected - minor damage to structures and facilities	3 Priority 1	4 Priority 2	5	
Minor	4	5		

have completed risk assessments concerning 1200 Geotechnical Problem Sites situated on approximately 4500km of railway line within the state of NSW, Australia. The problem sites have subsequently been categorised by the writers as 'Slips', 'Cuttings', 'Embankments' and 'Poor Performance of the Track Formation'.

The RSA risk assessment approach also uses a matrix consisting of (a) Consequence and (b) Probability, of an event affecting the track in the short term (12months). 'Consequence' of an event affecting the track is qualitatively assessed in terms of 'extreme', 'severe', 'moderate' and 'minor'. "Probability" of event affecting the track is also qualitatively expressed as 'high', 'moderate', 'low' and 'very low'. Risk category value is then quantitatively expressed between 1 and 5 in relation to the ranks of 'Consequence' and 'Probability' as shown in Table 2. A priority ranking for category 3 and 4 has been established because of the large variety and number of problems normally assessed in this category (Table 2).

of experienced geotechnical engineers or engineering geologists. Examples of geotechnical risk assessment for rail operation, and the definitions of risk category and consequences resulting from geotechnical events are also given. However, the 'Probability' assessment is based entirely on the engineering/geological judgement of an experienced professional.

2.3 Road and Traffic Authority of New South Wales (RTA) Guide to a Slope Risk Rating System

The RTA (1994) introduced a systematic slope risk rating system guide for in-house application. Following considerable field application and performance assessment a revised guide was issued in 1995. The Slope Risk Rating is assigned on the basis of qualitative levels of an Instability Assessment and the severity of the Consequences of slope failure. Two levels of reporting are included in the risk assessment procedure, firstly the Slope Instability Score Sheet and secondly, the Slope Risk

Table 3. RTA Slope Risk Rating

		Consequence				
		VH	H	M	L	VL
Instability Class based on Instability Score	VH	1	1	2	3	4
	H	1	1	2	3	4
	M	2	2	3	4	5
	L	3	3	4	5	5
	VL	3	3	4	5	5

VH = Very High

H = High

M = Medium

L = Low

VL = Very Low

Rating Report.

The Slope Risk Rating (Table 3) is designed to establish an order of priority that adequately reflects the need for geotechnical investigation and remedial or preventive action. The potential for and the consequences of slope failure are qualitatively determined by an instability assessment and a consequence assessment respectively, and the process of assessment requires experience, knowledge and includes a fair degree of subjectivity (RTA, 1995).

The RTA risk assessment approach takes the process of slope instability assessment a step further by adopting a scoring technique. The classification of slope instability assessment is based on field observations of thirteen components, each with a numerical weighting (score) recorded on the slope instability score sheets. The score assigned to each component is recorded either as a single value or as the cumulative sum of the individual scores assigned to the features. The instability score (I.S) which is the sum of the individual scores assigned to each component of a slope is qualitatively represented as an Instability Class as shown in column 1, Table 3.

The score sheet also includes the following information: (a) nature of the slope (cut, fill or natural), and (b) material type (rock or soil), where separate consideration and scoring are given for 'rock slope' and 'soil/fill slope'. This type of instability assessment by numerical weighting utilising scoring sheets contributes to consistent and repeatable assessments.

3 DEVELOPMENT OF FIELD INSPECTION DATA SHEETS AT THE UNIVERSITY OF WOLLONGONG (UOW)

3.1 Introduction

The first requirement in carrying out a risk assessment is that the hazard has to be identified and assessed. The first step of any hazard assessment will be a thorough field inspection. An efficient and reliable risk assessment requires the accurate identification of hazard and the probability of its occurrence. A comprehensive field inspection and site study is also essential for determining the consequences of failure. Hence it is important to develop field inspection guide lines which will facilitate consistent assessments by means of minimising the need for subjective judgement and the unreliability that is associated with inconsistent procedures.

Field checklists that are of value in producing such field inspection guidelines have been proposed by, among others, Hutchinson (1995), Cruden & Varnes (1996), Turner & McGuffey (1996), the RSA (1997) and Fell & Hartford (1997).

3.2 Present Status

With the above concepts in mind, a series of field sheets for systematic data collection have been designed and developed. These are particularly useful for initial site inspection when carrying out qualitative hazard and risk assessment. The field sheets also serve as a checklist for inspecting any particular site. The main advantage of these sheets is that a consistent assessment is facilitated.

Table 4. Probability rating chart

SCORE	PROBABILITY	DESCRIPTION	ANNUAL PROBABILITY
≥100	Very High	The event is expected and will occur in most circumstances.	>0.2 (within 5years)
80 - <100	High	There is a high probability that the event may occur in the short term or will be easily activated by adverse conditions.	0.2 - >0.02 (within 5 to 50years)
60 - <80	Medium	The event is probable and may occur within medium to long term.	0.02 - >0.002 (within 50 to 500years)
40 - <60	Low	The event is not expected, but could occur under extreme adverse conditions within extended long term period.	0.002 - >0.0002 (within 500 to 5000years)
<40	Very Low	The event is possible but may occur only in exceptional circumstances and adverse condition.	>0.0002 (greater than 5000years)

The field data sheets comprise of the following;

- Field inspection sheets for Hazard Assessment of (1) Natural slopes, 2) Embankments and Side-Fills, (3) Rock cuttings and (4) Soil cuttings
- Field inspection sheets for Consequence Assessment for (1) Railway Lines, (2) Roads, (3) Gas Pipelines and Electrical Power Lines, (4) Sewer and Tele-Communication Lines, (5) Water Conduits and Water Storage, (6) Buildings, (7) Lands, (8) Human casualty/fatality (transport and/or open space) and (9) Human casualty/fatality (buildings)
- Risk assessment data sheet including recommendations to attach appropriate site plans and/or sketch drawings. Such sketches are very useful in identifying, describing and highlighting problem areas, and are essential when communicating assessments to others.

Field inspection sheets for Hazard Assessments for Natural Slopes have been fully developed at this stage but are not included in this paper due to space limitations. A weighting technique is used which recognises the research findings of several previous workers such as Stevenson (1977), Vecchia (1978), Sinclair (1992), Anbalagan (1992), Chang (1992), RTA (1995) and Kumar et al (1996).

The seven influencing factors for slope performance considered are (1) site history, (2) landslide indicators, (3) bedrock geology type and landslide material type (e.g. rock or soil) and the appropriate geotechnical properties, (4) geologic structures (e.g. adverse bedding plane, faults, and joints), (5) morphological factors such as slope angle, seepage/ground moisture condition, erosion

and vegetation, (6) preventative or remedial works installed and their performance, and (7) adverse human impact. Point scores are give to the above mentioned factors and the probability/hazard rating is determined according to the total score using Table 4.

4 TRIAL HAZARD ASSESSMENT ON SELECTED SITES, WOLLONGONG AREA

A preliminary trial hazard assessment was carried out on the 6 selected sites in the Wollongong area to test the applicability of the new field inspection sheets for hazard assessment of natural slopes. Hazard and risk assessments were also made using the other four methods (e.g. AS/NZS, GTR, RSA & RTA). Two professionals with very different levels of experience in the slope instability field (i.e. inexperience and extensive experience) carried out the trials. The results are tabulated in Tables 5 and 6 for the experienced professional and the inexperienced professional respectively.

5 DISCUSSION

All the methods compared in Tables 6 and 7 are based on the probability (hazard) - consequence matrix approach. Assessment by the AGS approach is not included in these tables because that approach considers risk directly and not in terms of its two main components, the hazard and the consequence. The results indicate that the assessments for probability (and, therefore, hazard) can be

Table 5. Hazard assessments results derived from 5 qualitative methods on 6 selected sites by an experienced professional.

Site Number	AS/NZS Probability	GTR (1998) Probability	RSA Probability	RTA Instability Class	UOW Probability
1	unlikely	unlikely	Very Low	High	Medium
2	moderate	likely	High	Very High	High
3	moderate	likely	High	Very High	High
4	likely	almost certain	High	Very High	Very High
5	moderate	likely	High	Very High	High
6	moderate	almost certain	High	Very High	Very High

Table 6. Hazard assessments results derived from 6 qualitative methods on 6 selected sites by an inexperienced professional.

Site Number	AS/NZS Probability	GTR (1998) Probability	RSA Probability	RTA Instability Class	UOW Probability
1	unlikely	moderate	Moderate	Medium	Medium
2	moderate	likely	Moderate	Very High	High
3	moderate	moderate	Moderate	Very High	High
4	almost certain	almost certain	High	High	Very High
5	moderate	likely	Moderate	Very High	High
6	moderate	likely	Moderate	High	Very High

significantly different depending on the individual assessment method used. For example, in Table 6 for site 2, the probability is assessed as moderate or likely or high or very high and this is indeed a very significant variation that justifies the need for a more comprehensive method.

Turning now to the UOW comprehensive method, there are no significant differences between the assessments made by the experienced and inexperienced professionals for each of the 6 sites (compare column 6 in each of Tables 6 and 7). Similarly, there are few significant differences with the assessments by the RTA method for each of the six sites. On the other hand, the differences between their respective assessments are greater using the other less comprehensive methods

Another interesting point is that the AGS method results in the risk category 'Very High' for all the six sites. This is because these are all landslide sites, each of which is included in a Land Instability Database of the Northern Illawarra (Flentje, 1998). While each site has a history of movement, some are currently active whilst others are currently inactive. While the assessments by the RTA and UOW methods are consistent with these sites being landslides, only the UOW method captures the differences in the future hazard of landsliding between the different sites.

Thus the initial use of the UOW method at these 6 sites clearly justifies the development and utilisation of comprehensive field data sheets and it is expected that the method will also be vindicated for consequence assessments that have so far not been completed

6 CONCLUSIONS

Several qualitative hazard and risk assessment methods and approaches have been studied and their main features outlined in this paper. Each of these approaches has been used successfully in the context for which they were developed and within the agencies that developed them for particular applications. Yet it should be recognised that each method has both its merits and limitations. The AGS approach, for instance, has the merit of simplicity but it requires an experienced geotechnical engineer to make an assessment and the use of considerable subjective judgement. Hazard and consequence are not separated. Moreover, it is not possible to distinguish the level of risk between different sites, each with a previous history of instability.

Methods which consider a probability (hazard) - consequence matrix approach allow systematic assessment of risk and are, therefore, more valuable.

Such methods may vary from those that are mainly qualitative to those that are increasingly quantitative.

Consistency of assessments requires that careful thought be given to influencing factors for slope stability, the weight to be given to each factor, and the way in which data on each is recorded during site inspections for hazard and risk assessment. Effort must also be made to have clear and unambiguous definitions for the terms used.

In this paper, the UOW approach has been introduced briefly and the need for the development of data sheets for hazard, consequence and risk assessments has been highlighted. The method has been used on six sites as a trial for hazard assessment and other methods have also been used for comparison.

Based on this limited field application, reliable, consistent and repeatable assessments are obtained. There is remarkable correspondence between the assessments of an experienced and an inexperienced professional, which is not achieved when other methods are used by the same pair.

7 REFERENCES

- Anbalagan, R., 1992. Terrain Evaluation and Landslide Hazard Zonation for Environmental Regeneration and Land Use Planning in Mountainous Terrain. Proceedings of the Sixth International Symposium, David H. Bell (ed.), Christchurch, New Zealand, A. A. Balkema, Rotterdam, Vol. 2., pp. 861-868.
- AS/NZS, 1995. Standards Association of Australia/New Zealand. Australian Standard/New Zealand Standard 4360:1995. Risk Management.
- Chang, S.C., 1992. The Simprecise Mapping and Evaluation System for Engineering Geological and Landslide Hazard Zonation. Proceedings of the Sixth International Symposium, David H. Bell (ed.), Christchurch, New Zealand, A. A. Balkema, Rotterdam, Vol. 2., pp. 905-910.
- Chowdhury, R. N. & Flentje, P. N., 1998. Effective Urban Landslide Hazard Assessment. Eighth Congress of the International Association of Engineering Geology and the Environment, A Global View from the Pacific Rim. September 21-25, Vancouver, British Columbia, Vol. 2., pp. 871-878.
- Cruden D. M. & Varnes D. J., 1996. Landslide Types and Process. Landslide Investigation and Mitigation, Special Report 247, Transportation Research Board, National Research Council, Turner A.K. & Schuster R.L.(eds.), National Academy Press, Washington D.C., pp. 36 - 75.
- Fell .R., 1994. Landslide Risk Assessment and Acceptable Risk. Canadian Geotechnical Journal, Vol. 31, pp. 261 - 272.
- Fell R. & Hartford D., 1997. Landslide risk management. Landslide Risk Assessment, Cruden & Fell (eds.), Balkema, Rotterdam, pp. 51 - 109.
- Flentje, P.N. 1998. Computer Based Landslide Hazard and Risk Assessment (Northern Illawarra Region of New South Wales, Australia). Doctor of Philosophy Thesis, University of Wollongong, New South Wales, Australia. Unpublished, 525p.
- Flentje, P.N. & Chowdhury, R. N., 1999. Quantitative Landslide Hazard Assessment in an Urban Area. Proceedings of the Eighth Australian New Zealand Conference on Geomechanics. Editor: Dr. Nihal Vitharana. February 15-17, Hobart, Tasmania. Institution of Engineers, Australia, Vol. 1., pp. 115-120.
- GTR, 1998. A report concerning Hazard and Risk associated with sites identified after the August 1998 rainstorm in Wollongong, NSW, Australia. Report commissioned by Wollongong City Council Emergency Services Department. Confidential report prepared by a Geotechnical Team including one of the authors. Unpublished report.
- Hutchinson, J. N., 1995. Landslide Hazard Assessment. Proceeding of the Sixth International Symposium on Landslides, Christchurch, New Zealand, Volume 3, pp. 1805 - 1841.
- Kumar, K., Tolia, D.S. & Kumar Satish, 1996. Landslide Hazard Evaluation in a part of Himalaya. Proceedings of the Seventh International Symposium on Landslides, Kaare Senneset (ed.), Trodheim, Norway, A. A. Balkema, Rotterdam, Vol. 1, pp. 239-244.
- RTA, 1995. Roads and Traffic Authority of New South Wales, Geotechnical Engineering Unit (Scientific Services Branch, Technical Services Directorate), September. Guide to a Slope Risk Rating System, unpublished report.
- RSA, 1997. Rail Services Australia, Railway Geotechnical Services, August. Geotechnical Risk to Rail Operations - NSW, unpublished report.
- Sinclair, T.J.E., 1992. SCARR: A Slope Condition and Risk Rating. Proceedings of the Sixth International Symposium, David H. Bell (ed.), Christchurch, New Zealand, A. A. Balkema, Rotterdam, Vol. 2., pp. 1057-1064.
- Stevenson, P.C., 1977. An Empirical Method for the Evaluation of Relative Landslide Risk. International Association Engineering Geology Bulletin, Vol. 16, pp. 69-72.
- Turner A.K. & McGuffey V. C., 1996. Landslide Types and Process. Landslide Investigation and

- Mitigation, Special Report 247, Transportation Research Board, Turner A.K. & Schuster R.L.(eds.), National Research Council, National Academy Press, Washington D.C., pp 121 - 128.
- Vecchia, O., 1978. A Simple Terrain Index for the Stability of Hillsides Scarps. In: J.D. Geddes (ed.). Large ground Movements and Structures. New York/Toronto, John Wiley, pp. 449 - 461.
- Walker, B.F., Dale, M., Fell, R., Jeffrey, A., Leventhal, A., McMahon, M., Mostyn, G., and Phillips, A., 1985. Geotechnical Risk Associated with Hillside Development. In Australian Geomechanics News, No. 10, December 1985, pp. 29-35.