1997

Risk assessment of sloping land using GIS-based mapping

Phil N. Flentje
University of Wollongong, pflentje@uow.edu.au

Robin N. Chowdhury
University of Wollongong, robin@uow.edu.au

Abstract

In this paper, attention is drawn to GIS-based techniques for mapping and risk assessment for slopes and landslides. The authors focus on an approach developed recently for mapping of geology and slope stability in the Northern Illawarra (or the Northern Suburbs of Greater Wollongong Area) in New South Wales, Australia. The use of databases of geology and land instability and use of other GIS-based information relevant to sloping land for the development of a valid hazard and risk assessment procedure is explored. The developed approach will be applicable to other sloping areas and, in particular, urban areas both nationally and internationally.

Keywords

sloping, assessment, land, mapping, risk, gis

Disciplines

Engineering | Science and Technology Studies

Publication Details

Flentje, P. N. & Chowdhury, R. N. (1997). Risk assessment of sloping land using GIS-based mapping. 2nd Pan-American Symposium on Landslides and hte 2nd Brazilian Conference on Stability of Natural Slopes (pp. 1-7). ABMS.

RISK ASSESSMENT OF SLOPING LAND USING GIS-BASED MAPPING

Comment [MSL1]:

Phil Flentje[1] and Robin Chowdhury[2]
Department of Civil & Mining Engineering
University of Wollongong, NSW, Australia 2522
Phone: 61-42-213037
Fax: 61-42-213238
E-mail: robin_chowdhury@uow.edu.au

Comment [MSL2]: PhD Student and **Head of Department

[1] PhD student
[2] Head of Department

ABSTRACT: In this paper, attention is drawn to GIS-based techniques for mapping and risk assessment for slopes and landslides. The authors focus on an approach developed recently for mapping of geology and slope stability in the Northern Illawarra (or the Northern Suburbs of Greater Wollongong Area) in New South Wales, Australia. The use of databases of geology and land instability and use of other GIS-based information relevant to sloping land for the development of a valid hazard and risk assessment procedure is explored. The developed approach will be applicable to other sloping areas and, in particular, urban areas both nationally and internationally.

1. INTRODUCTION

The stability of natural slopes is influenced by geographical, geomorphological, geological, geotechnical and hydrological factors. Over the last fifty years or more, a great deal of research has been carried out in many countries to understand the fundamental causes and mechanisms of slope instability. Methods of geological and geotechnical modelling and analysis have been developed to understand landslides which have occurred and to predict future instability. The roles of triggering factors such as deforestation, development, rainfall and earthquakes have been explored. It is now acknowledged widely that accurate prediction of slope stability is often difficult due to uncertainties concerning geological details, geotechnical properties as well as triggering factors. Processes of progressive failure are widely recognised to be important but are poorly understood. Accordingly, it is considered much more sensible to develop and use methods of hazard and risk assessment in preference to predictive techniques.

Hazard and risk assessment approaches can be qualitative or quantitative or a combination of the two. The extent to which both types of methods can be developed successfully depends on the availability, extent and quality of geological, geotechnical and observational data. It also depends on how well the input data are validated and analysed. However, the most important step is the development of a comprehensive framework for hazard and risk assessment as discussed briefly below.

2. A COMPREHENSIVE FRAMEWORK

The development of a comprehensive framework for the assessment of hazard and risk must take into consideration the requirements of simplicity and flexibility. Unless the developed system or framework is simple, its validation will not be easy. Flexibility is necessary because the required effort and cost have to match the seriousness of the hazard, the vulnerability of the elements at risk as well as the size or importance of a project. Flexibility is also important because hazard and risk often vary with time and, therefore, the developed system or framework should allow for the future updating of its component parts or elements. An appreciation of the dynamics of hazard and risk requires consideration of changing boundaries of identified landslide areas and of other high hazard areas. This can only be done on the basis of a valid observational approach. However, for all areas, whether of high or low hazard, consideration must be given to the mechanisms of progressive failure. The importance of progressive action and progressive failure in geotechnical engineering and especially in the development of slope instability is well known. However, these mechanisms and processes are often poorly understood and few methods of geological and geotechnical analysis include consideration of their effects.

It is also important to define hazard and risk in an appropriate and consistent manner. In the past literature of risk assessment and management there have been significant inconsistencies. This applies to the many and varied applications of risk in a wide range of activities and disciplines where risk assessment and management are regarded as important.

In this respect the development of a 1995 Standard on Risk Management in Australia and New Zealand is to be welcomed (AS/NZS 4360: 1995). In addition to definitions and terminology, it deals with the requirements for risk management and various elements in such a process including identification, analysis, assessment, treatment, monitoring and review.

Some geotechnical engineers use the terms 'risk' and 'hazard' interchangeably. Such erroneous practices must cease and, in respect of landslides, good progress has been made with respect to definitions and terminology (Varnes 1984, WPL/WL1 1990 and 1995, Turner and Schuster, 1996). There is a general acceptance that the term 'hazard' indicates the probability of occurrence of an event. More accurately it reflects both the 'magnitude' and the 'probability' and may be regarded as their product. Risk reflects both the 'hazard' of an event and its 'consequences'. It has been proposed that specific risk be regarded as the product of the 'hazard' and the 'vulnerability' of the elements at risk. Total risk is the product of 'specific risk' and the 'elements at risk'.

3. THE GREATER WOLLONGONG PROJECT

A pilot project concerning slope stability has been nearly completed and it covers the Northern suburbs of the city of Greater Wollongong within the State of New South Wales (also called the Wollongong City Council Area or WCC Area). Accurate mapping using a Geographical Information System (GIS) package has been an essential feature of this pilot project. The basic methodology has been discussed by Chowdhury and Flentje (1996) with particular reference to computer modelling of the geology on the basis of a comprehensive borehole database and other relevant information. Geological field mapping and inference as well as the mapping of areas of land instability are also covered in that paper. The accurate maps of geology and landslide areas are called the Geotechnical Landscape Map Series.

The techniques used in the preparation of these GIS based maps has further been discussed by Flentje and Chowdhury (1996) including the mapping of major geological discontinuities or faults. Particular attention has been given to the validation of borehole data, and of field mapping including faults and other discontinuities. The potential use of the Geotechnical Landscape Map Series for planning and management of land use has also been addressed. The use of these maps for decision-making has been considered by Chowdhury and Flentje (1997) with particular reference to the Land Instability Database including the example of a site data record form. A wide range of data and information (56 fields) has been recorded for 319 sites of slope instability on a computer using the MS Access database computer package. As a result of this research project 43 of the 319 sites have been clearly identified and mapped for the first time.

4. CONTINUING WORK

As a result of the pilot project, the potential for developing a comprehensive hazard and risk assessment procedure has been greatly enhanced. A number of sites have been monitored (including the recording of piezometer and inclinometer readings) to develop an important resource base of well-documented case studies. Stability studies are being carried out on selected sites. Rainfall data is being analysed in innovative ways. In the following sections selected details of some aspects of the research are now presented.

5. SPATIAL RELATIONSHIPS

GIS-based mapping allows important spatial relationships to be explored on a statistical basis. For example, it is known on a qualitative basis that sites, in the WCC area referred to earlier, underlain by particular geological units (e.g. Stanwell Park Claystone and Wombarra Claystone) are likely to suffer significant instability in comparison to sites underlain by other geological units. The use of a GIS allows a quantitative evaluation of such relationships. Again, the assessment of risk based on the identified hazards (which may have been assessed qualitatively or quantitatively) is facilitated. The use of GIS for topographic and land-use mapping by the Wollongong City Council and now, as part of the pilot project, for mapping of geology and land instability, means that the relationships between topography, land-use, geology and land instability can be explored on a quantitative basis. This process can, of course, be extended to identification of elements at risk and assessments of their vulnerability. Such assessments will then facilitate the assessment of both specific and total risk.

For the whole of the study area (81^2 km) covered by the pilot project, some spatial statistics are shown in Fig. 1. For one of the thirty-one (31) map sheets (Map G11, which covers a total area of 7.5 km^2 including 3.4 km^2 of the study area) which together comprise the study area, the same type of information is presented in Fig. 2.

The Bulgo Sandstone (Rnb), at over 100m in thickness makes up for over one half of the total thickness of the Narrabeen Group of rocks. As can be seen in Fig. 1, areas underlain by the Bulgo Sandstone comprise nearly 20% of the whole subject area (31 map sheets), and of this area approximately 3% is affected by land instability. In contrast, the underlying Stanwell Park Clayston (Rnsp) subcrops below only 7% of the total subject area, and 10% of this subcrop area is affected by land instability. For both units, the area affected by land instability is approximately 0.6% of the total subject area. Clearly the claystone interval represents a higher hazard of land instability.

Similar information for a single map sheet (No. 11) is shown in Fig. 2. It shows that the stratigraphic features known as the Bulgo Sandstone, the Stanwell Park Claystone and the Wombarra Claystone (Rnn) each cover a relatively large proportion of the map sheet area and also have high percentages of their subcrop areas affected by land instability. This figure (Fig. 2) provides quantitative evidence for the known fact that some claystone subcrops are associated with significant known instability of relevant sites.

This information is of immense value for assessment of hazard and risk at sites whether such sites are currently sliding or not.

6. TYPICAL CASE STUDY

An example of the monitoring of subsurface movements using inclinometers is the site which has a numerical Site Reference Code known as 064.0 and is located in Map Sheet G11. As revealed by periodic observations, the subsurface movement is a block type movement (Fig. 3) with a well-defined shear surface located at a depth of 7.5m in borehole 3. The average rate of movement over the period March 1989 to March 1992 has been 51mm per year.

Most of the cases of significant instability in the study area are related to rainfall. Quantitative relationships are being explored, for particular sites, between the magnitude of antecedent rainfall on the one hand and rates of movement on the other.

The cumulative movement, for each of two inclinometer locations, is compared with daily rainfall and various periods of daily rolling antecedent rainfall in Fig. 4. Some general conclusions can be drawn from this figure. The quantity and duration of antecedent rainfall are, of course, important. No systematic published research has so far been devoted to exploring critical periods and magnitudes of antecedent rainfall as these are related to the occurrence of land instability. Some landslides occur as a result of high intensity - short duration rainstorms but there are others which occur as a consequence of medium intensity - long duration events. Innovative ways of exploring such relationships are at present being developed.

7. OTHER IMPORTANT ELEMENTS IN HAZARD AND RISK ASSESSMENT

Only some elements of a comprehensive system have been considered above, namely, accurate maps of geology and landslides, complete information concerning each site of instability arranged in a number of information fields, spatial relationships within a statistical framework, monitoring of sites for movement and analysis of rainfall-movement relationships.

There are other important elements to a comprehensive system such as stability studies using established geotechnical/geological models and innovative models which can deal with observational information and important mechanisms of landslide occurrence and development including progressive failure.

There are many uncertainties concerning hazard of slope instability. These include the natural variability of geological materials, the limited nature of information concerning discontinuities, and the assumptions made in the development of geological and geotechnical models. There are also systematic uncertainties including bias arising out of testing techniques and the limited number of boreholes and geotechnical tests. Consequently, it is necessary to develop probabilistic models including models of failure progression probability (Chowdhury et al, 1987, Chowdhury, 1992). System reliability approaches can also prove to be useful (Chowdhury and Xu, 1994). Due to space limitations, these topics can not be covered in this paper. However, it is now important to consider the essential features of a comprehensive system.

8. THE REQUIREMENTS OF A COMPLETE SYSTEM

An integrated system of hazard assessment is envisaged so that three main types of assessment can be made. These are: (a) qualitative assessment, (b) semi-quantitative assessment, and (c) fully quantitative assessment. These three types of assessment are consistent with the Risk Standard referred to in the beginning of this paper (AS/NZS 4360: 1995).

The selection of the type of approach will depend on a number of considerations including (a) the importance and magnitude of a project, (b) the type and magnitude of failure which can occur, (c) the consequences of failure, (d) the quality and quantity of information and relevant data available for making a hazard and risk assessment.

A qualitative hazard and risk assessment may be made on the basis of accurate maps of geology and land instability and/or other information based on site inspections, reports on previous projects and other past experience if such information is available. A semi-quantitative assessment would include statistical and empirical relationships in addition to the use of accurate maps of geology and landslides. It would also include simple slope stability analyses and limited use of relevant observational data such as pore water pressures and subsurface movements.

A fully quantitative approach would include detailed stability analyses based on high quality geotechnical data, detailed analysis of reliable observational information, assessment of the role of progressive failure, and relationship of the probability of sliding with trigger factors such as rainfall. It would also include consideration of long-term changes in stability and the updating of hazard and risk assessment based on increased and/or better information.

9. CONCLUSIONS

Reference has been made to a comprehensive system for assessment of hazard and risk which is under development at the University of Wollongong. A pilot study concerned with the development of GIS-based maps of geology and landslides has been nearly completed. Innovative techniques are being developed to study statistical relationships between landslide occurrence and geology, location, rainfall and other relevant factors. A number of sites are being monitored and detailed analysis of case studies is being planned. A GIS based computer model mapping geology has been completed and successfully validated.

Examples of some of these activities have been provided in this paper. The main features of the comprehensive system for hazard and risk assessment have been outlined and examples of types of assessment have been provided.

10. REFERENCES

AS/NZS:4360 (1995). Risk Management, Australia/New Zealand Standard, 32pp.

Chowdhury, R.N. (1992). Simulation of risk of progressive slope failure, Canadian Geotechnical Journal, 29 (1), 94-102.

Chowdhury, R.N. and Flentje, P.N. (1996). Geological and land instability mapping using a GIS package as a building block for the development of a risk assessment procedure, Proc. ISL-1996, Trondheim, Norway, 177-182.

Chowdhury, R.N. and Flentje, P.N. (1997). Relevance of mapping for slope stability in the Greater Wollongong area of New South Wales, Australia. Proc. Int. Symp. Geology and the Environment (IAEG), Athens Greece.

Chowdhury, R.N., Tang, W.H. and Sidi, I. (1987). Reliability model of progressive slope failure. Geotechnique, 37, 467-481.

Chowdhury, R.N. and Xu, D.W. (1994). Slope system reliability with general slip surfaces, soils and foundations. 34 (3), 99-105.

Flentje, P. and Cowdhury, R.N. (1996). Preparation and validation of digital maps of geology and slope instability. Proc. 8th Intl. Conf. Field Workshop on landslides (8th ICFL), Madrid, Spain, 343-351.

Turner, A.K. and Schuster, R.L. (1996). Editors 'Landslides - investigation and mitigation' Special Report 247, TRB, NRC, USA, 675pp.

Varnes, D.J. (1984). Landslide hazard zonation, a review of principles and practice. Natural Hazards, 3, UNESCO, 61p.

WP/WLI (1990). International Geotechnical Societies UNESCO Working Party on world landslide inventory - Cruden, D.M. Chairman. A suggested method for reporting a landslide. Bulletin IAEG, 41, 5-12.

WP/WLI (2995). International union of geological sciences working group on landslides. A suggested method for describing the rate of movement of a landslide. Bulletin of the Intl. Assoc. Of Eng. Geol., 52, 75-78.