Effective urban landslide hazard assessment

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

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

Publication Details
Effective urban landslide hazard assessment

Abstract
Landslide hazard assessment is a vitally important component of any strategy for the management of risk of instability in hilly areas. Within many urban areas, reactivation of landslides is an important component of risk. Yet, most qualitative approaches do not differentiate between the hazard of individual landslides. Two quantitative approaches are introduced in this paper both of which utilise GIS-based accurate maps of geology and landslip as well as a landslide database. The first method is based on historical recurrence of individual landslides. The second method is based on monitoring of subsurface shear movements, and their relationships to rainfall. Both methods can provide reliable information on hazard. Hazard ranking based on the first method has been validated in the Greater Wollongong area of the State of New South Wales in Australia. This paper does not address the potential hazard associated with sites which are recognised to be stable with no known history of instability.

Keywords
assessment, landslide, urban, hazard, effective

Disciplines
Engineering | Science and Technology Studies

Publication Details

This conference paper is available at Research Online: http://ro.uow.edu.au/eispapers/1781
Effective Urban Landslide Hazard Assessment

Robin Chowdhury and Phil Flentje
Department of Civil, Mining and Environmental Engineering
University of Wollongong, Australia

ABSTRACT: Landslide hazard assessment is a vitally important component of any strategy for the management of risk of instability in hilly areas. Within many urban areas, reactivation of landslides is an important component of risk. Yet, most qualitative approaches do not differentiate between the hazard of individual landslides. Two quantitative approaches are introduced in this paper both of which utilise GIS-based accurate maps of geology and landslip as well as a landslide database. The first method is based on historical recurrence of individual landslides. The second method is based on monitoring of subsurface shear movements, and their relationships to rainfall. Both methods can provide reliable information on hazard. Hazard ranking based on the first method has been validated in the Greater Wollongong area of the State of New South Wales in Australia. This paper does not address the potential hazard associated with sites which are recognised to be stable with no known history of instability.

1 INTRODUCTION

Urbanisation of natural sloping areas often worsens existing instability and may lead to the development of new sites of instability. Effective methods and techniques for hazard and risk assessment of landsliding are essential for the planning of future physical developments and for the management of existing slope instability problems. This paper addresses hazard assessment for existing areas of instability which may reactivate during periods of high rainfall.

Reliable geological and geotechnical information is needed to gain a good understanding of the causes and mechanisms of instability and to facilitate the development of models for slope stability analysis.

The preparation of detailed and reliable maps of geology and existing landslides is an important first step for the development of a hazard and risk assessment system.

The Wollongong City Council is responsible for the planning and development of land in the Wollongong Local Government Area (LGA). The Council has made use of geology and land instability maps first developed about 25 years ago. New maps have now been developed as part of a research project partly supported by the Council. A computer-based approach has been adopted for accuracy, speed and flexibility in mapping. A Geographical Information System (GIS) package with associated facilities was made available by the Council for assistance with parts of this project. These accurate maps are an important element of a proposed system for landslide hazard assessment. The second important element is a comprehensive landslide database which has been developed on the basis of reliable and diverse sources of information.

2 SLOW-MOVING LANDSLIDES

Many of the significant sites of existing instability are characterised by colluvium overlying claystone or sandstone bedrock and the movement occurs along non-circular slip-surfaces. Based on definitions proposed by the Working Party on the World Landslide Inventory (1993), the rates of movement are often slow, very slow or extremely slow as shown in Table 1. Even such slow movements often result in significant damage to houses and infrastructure. Renewal of movements or
The acceleration of continuing movements is often associated with prolonged or intense rainfall. However, urbanisation of these hilly areas over the last 100 years has been a key factor in the development of slope instability including first-time landslides as well as the reactivation of existing landslides. The number of reported annual landslide occurrences since 1880 is shown in Figure 1.
Several high-rainfall years since 1950 have been associated with significant increase in the number of landslides. Moreover, the increasing overall trend appears to support the view that urbanisation leads to a significant increase in slope instability. One must also recognise the role of progressive failure and pore pressure equilibration after major alterations to ground profile and drainage resulting from deforestation, excavation, filling, construction and other types of disturbance.

Extremely slow rates of movement are imperceptible to the naked eye and it is not surprising that development of hilly areas and construction of houses continues in spite of damage to houses and other property in the past. Experience and research leads to the inescapable conclusion that there is significant potential for future damage to houses and property. Moreover, such damage, however isolated and infrequent, can also result in significant loss of market values for even those properties not yet damaged by landslip. Therefore, an important part of landslide hazard management in an urban area should be directed to landslides areas which may appear to be dormant or inactive or which may show very slow rates of movement. Consequently, the authors have proposed a risk management procedure which incorporates an observational approach and utilises a comprehensive landslide database in combination with the accurate GIS-based maps to which reference was made earlier. It should be noted that assessment of hazard is just one part of the risk management procedure. However, it is the most important part and must be reliable and based on a sound and repeatable methodology.

Two approaches have been used to quantify hazard in relation to existing landslides and these are discussed below. There is, of course, another very important aspect of this continuing research project and that relates to the consideration of potential hazard of new landslides which may occur in the study area in the future. Discussion of this major aspect of research is outside the scope of the present paper.

The development of a borehole database, the GIS-based Geotechnical Landscape Map Series and a landslide inventory have been discussed earlier by Flentje and Chowdhury (1996) and Chowdhury and Flentje (1998). In those publications reference has also been made to spatial analysis of GIS data such as the percentage areas affected by landslides related to the underlying bedrock lithology.

3 ASSESSMENT OF HAZARD

Previous Qualitative Approaches

In the past 'hazard' was assessed only qualitatively. This assessment was based on geological and landslip maps originally prepared for the Wollongong City Council by Bowman (1972). Detailed maps of some specific areas were also prepared from time to time. However, the characterisation of 'hazard' continued to be based on subjective judgement with descriptive terms being used. For example, all existing landslides were given the same zoning and were obviously classified as the sites with the highest hazard. There was no differentiation between these sites even on a qualitative basis. Subsequently the Australian Geomechanics Society also proposed a qualitative approach and a descriptive classification (Walker et al, 1985). This approach also characterised existing landslide areas as having the highest hazard with no method for differentiation between them.

Quantitative Approach

As part of the research carried out by the authors at the University of Wollongong, hazard has been quantified in several ways based on historical data and the observational method. It should be recognised that absolute values of hazard are difficult, if not impossible, to determine. However, quantitative hazard values and a hazard ranking has been achieved. Moreover, the use of a quantitative approach still allows a descriptive classification of hazard. However, such a classification will obviously be more reliable and will allow clear differentiation between various landslide areas.

'Hazard' may be defined as the temporal probability, P, of landsliding or it may be defined as the product of magnitude, M, and probability, P. Both alternative definitions have been used in the research carried out at the University of Wollongong. The magnitude has been taken as the volume of a landslide mass which is moving. For convenience of calculation, the logarithm of volume has been used in computing the hazard using this definition.
4 QUANTIFICATION OF HAZARD BASED ON HISTORICAL DATA

The first reported landslide movement in the study area occurred in 1887 and the most recent recorded in the Landslide Database was in 1996. Thus the Landslide Database covers a period of 109 years. Based on the record of recurrences of any particular landslide an average frequency of landsliding has been calculated for that landslide. These average frequencies have been calculated for all of the 328 identified landslides or sites of instability. The calculated average frequency, would in some cases, be only an approximation since some recurrences may not have been reported for those sites. It will be an underestimate (unconservative) for such cases.

The minimum frequency of 1/109 = 0.009 has been assigned to those sites which have no record of recurrence during the historical period. If the absence of recurrence data for such sites is due to lack of reporting, this frequency is a lower bound (an error on the unconservative side). On the other hand, if the landslide has really been inactive, it is an upper bound (an error on the conservative side) because the landslide may have moved many years before the year 1887 considered here as the start of the historical period.

Data concerning the top 20 sites ranked in order of decreasing hazard are shown in Table 2. For simplicity the average frequency of occurrence has been taken as the probability of occurrence. The ranks of frequency and volume have been shown separately, the hazard having been defined for this table as the product of volume and average frequency.

Validation

The above approach was a relatively simple and straightforward solution to the problem of differentiating between the hazard associated with existing landslide sites. Therefore, the validation of the approach was of considerable interest during this research. The Landslide Database includes information concerning damage to life and property including houses damaged or destroyed. The database shows that a total of 60 houses have been damaged and a further 29 have been destroyed by landsliding. Study of the database in conjunction with the hazard ranks shown in Table 1 reveals that:

- The highest (hazard) ranked 3% of the landslides caused 62% of the house destruction
- The highest (hazard) ranked 3% of the landslides caused 52% of the house damage

<table>
<thead>
<tr>
<th>Hazard Rank</th>
<th>Hazard Value</th>
<th>SRC</th>
<th>Probability used</th>
<th>Probability Rank</th>
<th>Log Volume</th>
<th>Volume Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.448</td>
<td>113.0</td>
<td>0.092</td>
<td>1</td>
<td>4.888</td>
<td>21</td>
</tr>
<tr>
<td>2</td>
<td>0.372</td>
<td>63.0</td>
<td>0.073</td>
<td>3</td>
<td>5.072</td>
<td>13</td>
</tr>
<tr>
<td>3</td>
<td>0.370</td>
<td>65.0</td>
<td>0.080</td>
<td>2</td>
<td>4.626</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>0.354</td>
<td>153.0</td>
<td>0.064</td>
<td>4</td>
<td>5.516</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>0.318</td>
<td>26.0</td>
<td>0.055</td>
<td>8</td>
<td>5.775</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>0.306</td>
<td>20.0</td>
<td>0.055</td>
<td>8</td>
<td>5.533</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>0.297</td>
<td>37.0</td>
<td>0.055</td>
<td>8</td>
<td>5.403</td>
<td>7</td>
</tr>
<tr>
<td>8</td>
<td>0.295</td>
<td>134.0</td>
<td>0.055</td>
<td>8</td>
<td>5.352</td>
<td>9</td>
</tr>
<tr>
<td>9</td>
<td>0.268</td>
<td>77.0</td>
<td>0.050</td>
<td>16</td>
<td>5.367</td>
<td>8</td>
</tr>
<tr>
<td>10</td>
<td>0.268</td>
<td>57.0</td>
<td>0.064</td>
<td>4</td>
<td>4.176</td>
<td>90</td>
</tr>
<tr>
<td>11</td>
<td>0.267</td>
<td>14.0</td>
<td>0.055</td>
<td>8</td>
<td>4.856</td>
<td>24</td>
</tr>
<tr>
<td>12</td>
<td>0.263</td>
<td>145.0</td>
<td>0.046</td>
<td>17</td>
<td>5.727</td>
<td>2</td>
</tr>
<tr>
<td>13</td>
<td>0.248</td>
<td>122.0</td>
<td>0.055</td>
<td>8</td>
<td>4.509</td>
<td>49</td>
</tr>
<tr>
<td>14</td>
<td>0.244</td>
<td>59.0</td>
<td>0.064</td>
<td>4</td>
<td>3.792</td>
<td>162</td>
</tr>
<tr>
<td>15</td>
<td>0.237</td>
<td>141.0</td>
<td>0.046</td>
<td>17</td>
<td>5.165</td>
<td>11</td>
</tr>
<tr>
<td>16</td>
<td>0.234</td>
<td>64.0</td>
<td>0.055</td>
<td>8</td>
<td>4.250</td>
<td>77</td>
</tr>
<tr>
<td>17</td>
<td>0.232</td>
<td>124.0</td>
<td>0.064</td>
<td>4</td>
<td>3.612</td>
<td>190</td>
</tr>
<tr>
<td>18</td>
<td>0.231</td>
<td>60.0</td>
<td>0.055</td>
<td>8</td>
<td>4.204</td>
<td>84</td>
</tr>
<tr>
<td>19</td>
<td>0.204</td>
<td>24.0</td>
<td>0.037</td>
<td>22</td>
<td>5.569</td>
<td>4</td>
</tr>
<tr>
<td>20</td>
<td>0.195</td>
<td>104.0</td>
<td>0.046</td>
<td>17</td>
<td>4.253</td>
<td>76</td>
</tr>
</tbody>
</table>

Table 2. Hazard table for the 20 highest hazard ranked sites in the study area
Based on the above correlation, the simple methodology worked well in spite of the fact that some landslide recurrences may not have been reported. It is also understandable that many instances of landslide damage to houses, especially minor damage are often not reported. Owners do not wish the values of their respective properties to fall and, therefore, tend not to report minor damage. This tendency is reinforced by the fact that insurance against landslide damage is generally unavailable.

5 HAZARD ASSESSMENT BASED ON MONITORED MOVEMENTS

An alternative approach, far more elaborate and sophisticated than the one based on historical recurrences, has also been developed during this research. This approach is based on the monitoring and analysis of subsurface shear movements at individual sites where inclinometers have been installed in boreholes.

There are two main elements in this approach. Firstly, rainfall analysis is carried out. Apart from daily rainfalls, cumulative totals are plotted against time considering different periods of antecedent rainfall, e.g. 7 day, 30 day, 60 day, 90 day and 120 day periods (Fig. 2). In the past, no systematic analysis of the relationship between rainfall and landslide movement had been carried out and different periods of antecedent rainfall have been considered significant by different engineers or research workers. Therefore, the above approach proved to be useful in understanding the effects of prolonged rainfall when compared with records of subsurface shear movement.

The second important element in this approach relates to the analysis of the data concerning subsurface shear movement determined from the monitoring and analysis of inclinometer data (Fig. 3). It is important to define 'failure' from these rates of shear curves. Once this has been done, the antecedent rainfall curves can be compared to the rate of shear curves and conclusions drawn about the rainfall-movement relationship. 'Failure' was defined, in this study, where the inclinometer data indicated peak rates of displacements, and/or where disruptive surface movements were reported.

An innovative approach has been developed to represent the various rainfall curves. The antecedent percentage exceedance time (ARPET) for any magnitude of antecedent rainfall was calculated for the historical period. The ARPET values were then plotted against the antecedent rainfall in mm. (Fig. 4). Based on shear movement data, lines such as A and B (running across the different ARPET curves) can be plotted. Line A represents the upper bound of rainfall magnitudes below which landslide movement is unlikely. Line B represents the lower bound of rainfall magnitudes associated with 'failure'. The region between A and B represents rainfalls which are likely to cause renewal of movements or acceleration of continuing movements but not 'failure'.

Lines such as A and B may be drawn considering whole or part of the study area with a number of instrumented sites. Such lines may also be drawn for a single site.

A single ARPET curve for 90 day antecedent rainfall was considered to be significant on the basis of the shear movement data for site 064 (Fig. 5). On
that site the point representing the upper bound of movements unlikely to cause instability is shown as X. The point which shows the rainfall level associated with 'failure' is shown as Y.

The ARPET values facilitate the calculation of probability of occurrence and therefore, the hazard associated with the particular landslide. Thus the hazard values based on the two methods can be compared. Comprehensive discussion of the ARPET approach is not given here because of space limitations. These details will be reported in another

Figure 3. Inclinometer monitoring history (cumulative displacement and rate of shear) for a landslide in Scarborough, Site 64, with daily rainfall histogram and antecedent rainfall curves
5 CONCLUSIONS

Assessment of landslide hazard in hilly urban areas has immense importance in risk management. Existing landslides often cause significant damage to property and reduce values of adjacent properties. Thus assessment of hazard of these existing landslides should assume a high priority in any strategy for risk management. Two practical and reliable approaches have been presented in this paper. One is based on historical record of landslide recurrences and its application is straightforward. The results of hazard ranking for the study area have been validated. The other approach is based on monitoring and analysis of subsurface shear movements and their relationship to rainfall. Hazard ranking for all landslides has not been done on the basis of this method because only a few of the 328 sites of instability are instrumented. Yet this method enables hazards of individual sites to be assessed on a reliable and accurate basis.

REFERENCES


