Generation of qualitative landslide risk maps
- Advances and pit-falls -

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Risk assessment & management

- Triggering factors
- Preparatory factors
- Landslide inventory

- Probability of landsliding
- Runout behavior
- Land use

- Hazard assessment
- Elements at risk
- Vulnerability assessment

- Risk assessment
- Risk management
- Cost-benefit analysis

Dai et al. (2002)
Lecture Overview

- Review of landslide risk assessment
- Steps in risk analysis
- Evaluation of landslide risk
- Acceptable risk
- Risk estimation
  - Qualitative risk analysis
  - Quantitative risk analysis

Landslide risk assessment

- Risk analysis
- Risk evaluation
- Risk management

Risk = f (hazard, elements at risk, vulnerability)

Specific Risk = expected degree of loss to a particular natural process
Varieties of landslide risk

- Distributed landslide risk
  - Providing risk maps that depict the level of risk in terms of fatality/economic loss at different locations of a given region quantitatively or qualitatively

- Site-specific landslide risk
  - Provide a systematic assessment of the hazards and level of risk in terms of fatality (economic loss) at a given site, or a potential landslide
    => acceptable risk levels; evaluation of risk mitigation measures

- Global landslide risk
  - Defining the relative contribution to the total risk
    => reference for landslide risk management; policy making (Dai et al., 2002)

Required steps in risk analysis (1/2)

- **Scope definition**: scope of investigation, aim of study, scale and degree of precision, limits of study area, damage sources, damage types

- **Hazard identification**: recognize, analyse and classify hazardous processes; assess location, areal extent and magnitude of processes; investigate preparatory, triggering and controlling factors; estimate run-out distance, velocity,....

- **Hazard analysis**: determine probability of occurrence, hazard modelling
Required steps in risk analysis (2/2)

- **Consequence analysis**: elements at risk, vulnerability, probability of spatial and temporal impact, probability of seasonal occurrence
- **Risk calculation**: calculate risk using respective formulas

Evaluation of landslide risk

- Combination and parameterization of several different factors
- Definition of those parameters involve different competences and skills
- The three different components of risk (H, E, V), should be defined with different degree of detail depending on requirements, data availability and experiences from experts and scientific communities
- During the risk assessment procedure, a fundamental priority is the *acceptable and tolerable risk* threshold definition
- The acceptable risk definitions permit the discrimination of a list of priority in order to assess mitigation measurements.
Acceptable risk

- Risk from a given hazard can be accepted under the condition that the risks are perfectly understood

Definition by IUGS Working Group on Landslide, Committee on Risk Assessment (1997):

A risk that society is willing to live with so as to secure certain benefits in the confidence that it is being properly controlled, kept under review and further reduced as and when possible

Acceptable risk – General principals

- Incremental risk from a hazard should not be significant compared to everyday life risks
- As low as reasonably practicable (ALARP)
- If possible loss of life is high, risk should be low
- Persons will tolerate higher risks, when they are unable to control/reduce risk due to financial/other limitations
- Higher risks are likely to be tolerated for existing than for planned projects
- Higher risks are likely to be tolerated for naturally occurring hazards than from engineered slopes
- Tolerable risk varies from country to country and within countries (Dai et al., 2002)
Acceptable risk - How to define?

- Top-down?
- Bottom-up?

Acceptable risks are defined – and now?

- Can we get any reliable data within risk analysis?
- Do the results differ depending on various …
  - … process models?
  - … processes (snow avalanche, landslides, floods, etc.)?
  - … risk models?
  - … reference units?
  - … data resolutions?
- Are acceptable risks referring to single or multi-hazards?
- Individual or object risk?
- Spatio-temporal changes of risk acceptance

Changing risk due to different process models

Process model A

Process model B


Spatio-temporal changes of risk acceptance?

Risk estimation

- Qualitatively
- Semi quantitatively
- Quantitatively

Wherever possible, the Risk Estimate should be based on a quantitative analysis, even though the results may be summarized in a qualitative terminology.

(Australien Geomechanics, 2000)

Recommended Methods & Scales

<table>
<thead>
<tr>
<th>Scale</th>
<th>Qualitative methods</th>
<th>Quantitative methods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inventar</td>
<td>Heuristic Analysis</td>
</tr>
<tr>
<td>&lt; 1:10,000</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>1:25,000 – 1:50,000</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>&gt; 1:100,000</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Qualitative risk analysis

- Most simple expression of landslide risk assessment
- Qualitative classification of risk based on expert judgment

Damage propensity:
- Considers only part of the base elements or simply defining them qualitatively or semi-quantitatively
- Typical approach: Overlapping of elements at risk with landslide inventories/susceptibility maps
- Almost all the existing literature and applications on landslide risk assessment can be considered as damage propensity analysis (ARMONIA Project Report, 2005)

Example of qualitative terminology for use in assessing risk to property (1/2)

<table>
<thead>
<tr>
<th>Qualitative Measures of Likelihood</th>
<th>Description</th>
<th>Indicative Annual Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>A ALMOST CERTAIN</td>
<td>The event is expected to occur</td>
<td>( &lt;10^{-2} )</td>
</tr>
<tr>
<td>B LIKELY</td>
<td>The event will probably occur under adverse conditions</td>
<td>( &lt;10^{-3} )</td>
</tr>
<tr>
<td>C POSSIBLE</td>
<td>The event could occur under adverse conditions</td>
<td>( &lt;10^{-4} )</td>
</tr>
<tr>
<td>D UNLIKELY</td>
<td>The event might occur under very adverse circumstances</td>
<td>( &lt;10^{-5} )</td>
</tr>
<tr>
<td>E RARE</td>
<td>The event is conceivable but only under exceptional circumstances.</td>
<td>( &lt;10^{-6} )</td>
</tr>
<tr>
<td>F NOT CREDIBLE</td>
<td>The event is inconceivable or fanciful</td>
<td>( &lt;10^{-8} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Qualitative Measures of Consequences to Property</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 CATASTROPHIC</td>
<td>Structure completely destroyed or large scale damage requiring major engineering works for stabilisation.</td>
</tr>
<tr>
<td>2 MAJOR</td>
<td>Extensive damage to most of structure, or extending beyond site boundaries requiring significant stabilisation works.</td>
</tr>
<tr>
<td>3 MEDIUM</td>
<td>Moderate damage to some of structure, or significant part of site requiring large stabilisation works.</td>
</tr>
<tr>
<td>4 MINOR</td>
<td>Limited damage to part of structure, or part of site requiring some re-stabilisation stabilisation works.</td>
</tr>
<tr>
<td>5 INSIGNIFICANT</td>
<td>Little damage.</td>
</tr>
</tbody>
</table>

(Note: The "Description" may be added to use a particular case)

(Australien Geomechanics, 2000)
Example of qualitative terminology for use in assessing risk to property (2/2)

<table>
<thead>
<tr>
<th>Consequences to Property</th>
<th>Likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very High</td>
<td>VH</td>
</tr>
<tr>
<td>High</td>
<td>H</td>
</tr>
<tr>
<td>Moderate</td>
<td>M</td>
</tr>
<tr>
<td>Low</td>
<td>L</td>
</tr>
<tr>
<td>Very Low Risk</td>
<td>VL</td>
</tr>
</tbody>
</table>

Qualitative Risk Analysis Matrix – Level of Risk to Property

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Consequences to Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>VH</td>
<td>VH</td>
</tr>
<tr>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>VL</td>
<td>VL</td>
</tr>
</tbody>
</table>

Risk Level Implications

- **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.
- **High Risk**: Detailed investigation, planning and implementation of treatment options required to reduce risk to acceptable levels.
- **Moderate Risk**: Tolerable provided treatment plan is implemented to maintain or reduce risks. May be accepted. May require investigation and planning of treatment options.
- **Low Risk**: Usually accepted. Treatment requirements and responsibility to be defined to maintain or reduce risk.
- **Very Low Risk**: Acceptable. Manage by normal slope maintenance procedure.

(Australien Geomechanics, 2000)

Qualitative risk matrix

```
<table>
<thead>
<tr>
<th>Damage</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very high</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>High</td>
<td>Moderate</td>
<td>High</td>
<td>Very high</td>
<td>Very high</td>
</tr>
</tbody>
</table>
```

Glade 2002
Quantitative risk analysis

Total Risk

- Expected loss of human lives, injured, damage to the property and economic activities caused by a landslide event. It can be expressed as annual cost or number or amount of lost units per year.
- It is a function of the elements at risk $E$ and a given intensity $I$ of the landslide:

$$R(I; E) = H(I) V(I;E) W(E)$$

(ARMONIA Project Report, 2005)

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Quantitative risk analysis

According to the considered element at risk, the following risk typologies can be identified – **Induced risk on ….**

- **human life:** expected number of deaths, injured or homeless per year, or their economic worth caused by a landslide;
- **properties:** expected number of damaged houses per year or lost land surface per year, or expected cost of damage caused by a landslide
- **economic activities:** expected cost of direct and indirect damage on economy caused by a landslide
- **goods of public interest:** expected cost of damage on facilities and environment caused by a landslide.

(ARMONIA Project Report, 2005)
Quantitative risk analysis

Risk Formula by Morgan et al., 1992:

\[ R = H \times P_s \times P_t \times P_l \]

- **R**: risk (annual probability of loss of life to an individual)
- **H**: annual probability of the hazardous event
- **P_s**: probability of spatial impact given the event
- **P_t**: probability of temporal impact given the spatial impact
- **P_l**: probability of loss of life of an individual occupant

Adapted for a case involving property damage by Fell & Hartford, 1997:

\[ R = H \times P_s \times V_p \times E_p \]

- **V_p**: Vulnerability of the property
- **E_p**: Element at risk

Uncertainties in risk analysis

- Uncertainties in input factors leads to uncertainties in resulting risk value
  - All stages in risk assessment should be transparent
  - Assumptions made should be stated
  - Uncertainties should be pointed out
- Sources of uncertainties can be inherent in all stages of risk analysis
Sources for uncertainties (1/2)

- Data processing

- Hazard identification & hazard mapping
  - Carrara (1992): results in landslide mapping can differ up to 50% depending on the surveyor
  - Incomplete historical data

- Hazard analysis
  - “Past is the key to the present”
  - Studied time interval

Diagram: Risk analysis over time.
Sources for uncertainties (2/2)

- Consequence analysis
  - Certainty depending on available data
  - Subjective determination of values
- Risk analysis
  - Definition of risk classes

Example for qualitative estimation of uncertainties

<table>
<thead>
<tr>
<th>factor</th>
<th>uncertainty</th>
<th>reason</th>
<th>significance</th>
<th>improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>hazard identification, hazard mapping</td>
<td>low - medium</td>
<td>subjectivity</td>
<td>high</td>
<td>education, training, standard mapping methods</td>
</tr>
<tr>
<td>hazard analysis</td>
<td>medium - high</td>
<td>limitations of models, insufficient data, basic assumptions.</td>
<td>very high</td>
<td>improvement of models, increase of data collection, new concepts</td>
</tr>
<tr>
<td>vulnerability</td>
<td>high - very high</td>
<td>insufficient data, only very little research</td>
<td>very high</td>
<td>back analysis of past events, development of physical vulnerability concepts</td>
</tr>
<tr>
<td>probability of temporal impact ($P_t$)</td>
<td>low - medium</td>
<td>average values</td>
<td>low - medium</td>
<td></td>
</tr>
<tr>
<td>probability of spatial impact ($d_l$)</td>
<td>medium</td>
<td>subjectivity</td>
<td>medium</td>
<td>back analysis of past events</td>
</tr>
<tr>
<td>economic value ($E_{eq}$)</td>
<td>very low</td>
<td>detailed information</td>
<td>low</td>
<td>detailed field investigations</td>
</tr>
<tr>
<td>number of persons ($N_{eq}$)</td>
<td>very low</td>
<td>detailed information on number of residents</td>
<td>low</td>
<td>detailed field investigations</td>
</tr>
<tr>
<td>medium</td>
<td>medium</td>
<td>no official data on employees</td>
<td>low</td>
<td>detailed field investigations</td>
</tr>
<tr>
<td>probability of seasonal occurrence ($P_{se}$)</td>
<td>low - medium</td>
<td>rough estimation</td>
<td>low</td>
<td>detailed field investigations</td>
</tr>
<tr>
<td>risk classes - economic loss</td>
<td>medium - high</td>
<td>subjectivity</td>
<td>high</td>
<td>risk perception studies</td>
</tr>
<tr>
<td>risk classes - risk to life</td>
<td>low - medium</td>
<td>risk factors used in regulation</td>
<td>high</td>
<td>risk perception studies</td>
</tr>
<tr>
<td>resulting risk</td>
<td>high</td>
<td>uncertainties in input factors</td>
<td>very high</td>
<td>reduction of uncertainties in input factors, improvement of risk analysis methodology</td>
</tr>
</tbody>
</table>
**Summary 1/3**

- **Qualitative assessments**
  
  *Limitations*
  - Strongly dependent on expert
  - Approximation only
  - High uncertainty
  
  *Advantages*
  - Fast assessment
  - Cheap analysis

**Summary 2/3**

- **Quantitative assessments**
  
  Limitations
  - High data demand
  - Intradisciplinary collaboration is essential
  - Danger of “trust”
  
  Advantages
  - Objective method and repeatable results
  - Expert judgement is reduced
Summary 3/3

- ANY analysis has high uncertainties
- Risk analysis is strongly dependent on both
  - HAZARD analysis
  - CONSEQUENCE analysis
- DO NOT TRUST numbers
- A qualitative risk analysis can be BETTER than a quantitative risk assessment

References

References

