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Risk-Less

Quantitative Vulnerability Assessment for the Evaluation of the Landslide Risk in Inhabited Areas

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SEVENTH FRAMEWORK PROGRAMME

Risk-LeSS

SUMMARY

Landslides constitute a major threat in mountainous areas. In recent years the risk assessment for landslides has shifted from qualitative to quantitative. The components of the risk are the hazard and the vulnerability of the exposed elements. Although for the quantification of the hazard there is a variety of procedures, the work for the structural and societal vulnerability is limited and the evaluations are mostly judgmental or empirical, resulting in high subjectivity. The objective of this work has been the development of analytical methodologies to be applied for the quantification of the vulnerability of buildings and people that are threatened by rockfalls and other types of landslides.The main objectives of the projects included the development of methodologies for the quantification of structural and societal vulnerability and their application to selected case-studies. For the evaluation of the structural response of the buildings, structural analysis methods were used and vulnerability curves were developed.

CONTENTS

1 RESULTS AND IMPACT

The main objectives of this project were: (i) the development of methodologies for the quantification of structural vulnerability, (ii) the development of methodologies for the quantification of societal vulnerability and (iii) the application of both to selected case-studies and their validation. The work that was performed within the framework of the project towards these objectives is explained in the following.

With reference to the first objective (WP1), firstly the characteristic building typologies had to be identified. The analysed typology is low-rise reinforced-concrete frame buildings with 1-3 storeys and 1-4 bays.

To select the scenarios to be analysed a series of issues had to be faced that were not initially scheduled. The first one involved the evaluation of the expected range of the hazard magnitude and intensity, and was necessary in order to be used as an input for the vulnerability evaluation, for a given area. As most methods used so far to this purpose are empirical, to overcome the problem of incomplete time-series a procedure was developed for the calculation of the frequency-magnitude relation of rock blocks that may reach the exposed buildings. The method is based on the remote determination of the frequency-magnitude relation for rockfall scars, which is associated with the magnitude of the expected events in an area; Terrestrial Laser Scanner data and their statistical- probabilistic elaboration were used to this end, indicating a power-law distribution for the frequency-magnitude relation. The parameters of the latter were evaluated. Full details are given in the following publications:

- Santana D, Corominas J, Mavrouli O and Garcia-Selles D (2012), Magnitude-Frequency relation for rockfall scars using a Terrestrial Laser Scanner. Engineering Geology. 145–146, 50–64.

- Santana D, Corominas J, Mavrouli O and Garcia-Selles, D (2011) Magnitude-Frequency relation for rock falls using a terrestrial laser scanner, R O C E X S 2 0 1 1, Interdisciplinary Rockfall Workshop 2011, Austria, Tirol, Innsbruck, Igls, Congresspark, 17 - 19 May 2011.

A second issue that was raised for the establishment of hazard scenarios was the fragmentation after the rockfall mass impacts with the ground. Falling rock masses are expected to break apart after first impacts on the ground, leading to individual blocks that will follow independent paths. Ignoring this phenomenon leads to the assumption of very big rock block masses threatening the buildings, resulting in very high impact intensities and impact probabilities with building key elements, which are over-conservative. So, for the evaluation of realistic scenarios, the fragmentation effect on the size of the rock blocks during an event had to be investigated. Data from real events were compiled and their fitting by statistical distributions as well the parameters of the latter were evaluated. The fragmentation process on the size distribution of the rock blocks was found to be well described by a power-law distribution with exponent equal to the exponent of the power-law relation of rockfall scars. The proposed procedure is shown at:

- Corominas J, Mavrouli O and Moya J (2012) Simplified approach for obtaining the block volume distribution of fragmental rockfalls. ISL-NASL 2012, 11th International & 2nd North American Symposium on Landslides, 3-8 June, Banff, Alberta, Canada.

For the evaluation of the structural performance and the probabilistic quantification of the structural vulnerability evaluation the performed work included the following.

Firstly, an analytical procedure for the evaluation of the response of buildings threatened by rockfalls was developed. The evaluation employed theoretical relations and analytical/numerical models for the response and overcome of resistance of reinforced concrete members (using piece-wise linear models). The potential for a cascade of failures after damage of basement columns by rock block impacts was also assessed using the finite element method. Common reinforced-concrete frames were indicated to be very vulnerable to rock block impacts and to progressive collapse, however the low probability of the initial member damage, makes this a low-probability phenomenon. Additionally, a method for deriving vulnerability curves based on analytical data was proposed. The latter summarize information on the probability of exceeding a certain damage state due to a landslide event, in function of its magnitude and intensity, and are an input for the risk assessment. The incorporated uncertainty was the location of the impact on the building. This work is presented in detail at:

- Mavrouli O and Corominas J (2010) Rockfall vulnerability assessment for reinforced concrete buildings, Natural Hazards and Earth System Sciences, 10(10), 2055-2066.

The structural vulnerability was quantified for other landslide types as well, which were slow-moving landslides and debris flow, in collaboration with other research institutes: the Aristotle University of Thessaloniki, Greece, and the Bureau de Recherches Géologiques et Minières, France, for slow moving landslides, and the company A.M.R.A. s.c.a.r.l, Italy, for debris flow. There is a commitment with Prof. L. Cascini and Prof. G. Sorbino (University of Salerno, Italy), for submitting a manuscript at a special issue of the journal Landslides. within the end of November 2012. In the same issue further publications mentioned in the following are intender to be published. The relevant article is:

- Mavrouli O, Fotopoulou S, Pitilakis K, Zuccaro G, Foerster E and Corominas J (in preparation) Analytical methodologies for the quantification of the vulnerability of buildings to landslides using fragility curves. (To be submitted to Landslides).

Concerning the quantification of societal vulnerability (WP2), the researcher worked in collaboration with the Norwegian Geotechnical Institute for the development of an indicator-based socio-economic vulnerability model, especially for landslides. The model has been presented at:

- Eidsvig U, McLean A, Vangelsten B V, Kalsnes B, Ciurean R L, Argyroudis S, Winter M, Corominas J , Mavrouli O C, Fotopoulou S, Pitilakis K, Bailis A, and Malet J P (2012) Socio-economic vulnerability to natural hazards – proposal for

an indicator-based model European Geosciences Union (EGU), General Assembly, 22-27 April 2012, Vienna, Austria.

and is also expected to be submitted by the end of November 2012 at:

- Eidsvig U, McLean A, Vangelsten BV, Kalsnes B, Ciurean L, Argyroudis S, Winter M, Mavrouli O, Fotopoulou S, Pitilakis K, Bails A, Malet JP and Kaiser G (in preparation). Assessment of socio-economic vulnerability to landslides using an indicator-based approach. (To be submitted to Landslides).

Additionally to what was initially scheduled, the investigation of the physical vulnerability of roadways with respect to the damage caused by debris flows was made, in collaboration with the Transport Research Laboratory, Edinburgh, United Kingdom. Based on a questionnaire, empirically-based fragility curves were derived, relating flow volume to damage probabilities, for three different damage states. The results are presented at:

- Winter M G, Smith J T, Fotopoulou S, Pitlakis K, Mavrouli O-C, Corominas J, and Argyroudis S (2012) Determining the physical vulnerability of roads to debris flow by means of an expert judgement approach. European Geosciences Union (EGU),

- Smith J T, Winter M G, Fotopoulou S, Pitlakis K, Mavrouli O-C, Corominas J, and Argyroudis S (2012) The physical vulnerability of roads to debris flow: an expert judgement approach. ISL-NASL 2012, 11th International & 2nd North American Symposium on Landslides, 3-8 June, Banff, Alberta, Canada.

- Winter M G, Smith J T, Fotopoulou S, Pitlakis K, Mavrouli O-C, Corominas J, and Argyroudis S (in prepatation) An expert judgement approach to determining the physical vulnerability of roads to debris flow. (to be submitted to Landslides).

The last main objective of the project was the application of the developed methodologies to selected case-studies and their validation (WP3). To this purpose the risk for buildings which are situated at the bottom of a rockfall prone slope and may be impacted by rock blocks, was performed. The details of the proposed methodology were presented through an application example at the area of Santa Coloma, in Andorra. The application scale was site-specific/local. The key issues of this work are the consideration of fragmental rockfalls for the selection of the rockfall scenarios and the incorporation of the probabilistc vulnerability of the buildings, according to the developed methods. For every building, the risk is expressed in terms of the annual probability of loss and it is the sum, for all rockfall magnitudes, of the products of the rockfall frequency with the conditional probability of a rock block reaching the building with a certain kinetic energy sufficient to cause a specific state of damage and its associated vulnerability. This work is presented at:

- Corominas J and Mavrouli O (2011) Quantitative risk assessment for buildings due to rock-falls: some achievements and challenges, Proceedings of "2ème journée de rencontre sur les dangers naturels", Université de Lausanne, Lausanne, Switzerland.

The proposed model for the socio-economic vulnerability was also applied at the case-study of the Santa Coloma and further case-studies from different areas in Europe.

Different landslide types were also considered. The results, indicating that Santa Coloma is an area of moderate socio-economic vulnerability to rockfalls, are presented as previously at:

- Eidsvig U, McLean A, Vangelsten B V, Kalsnes B, Ciurean R L, Argyroudis S, Winter M, Corominas J , Mavrouli O C, Fotopoulou S, Pitilakis K, Baills A, and Malet J P (2012) Socio-economic vulnerability to natural hazards – proposal for an indicator-based model European Geosciences Union (EGU), General Assembly, 22-27 April 2012, Vienna, Austria.

- Eidsvig U, McLean A, Vangelsten BV, Kalsnes B, Ciurean L, Argyroudis S, Winter M, Mavrouli O, Fotopoulou S, Pitilakis K, Bails A, Malet JP and Kaiser G (un Assessment of socio-economic vulnerability to landslides using an indicator-based approach. (To be submitted to Landslides).

The investigation that was performed and the results that were obtained from the aforementioned objectives contributed at a global view on the quantitative risk assessment, that incorporates detailed vulnerability aspects, as reflected in the following recommendations, to be submitted to the journal Landslides until next November:

- Corominas J, van Westen C, Frattini P, Cascini L, Malet JP, Fotopoulou S, Catani F, van den Eeckhaut M, Mavrouli O, Agliardi F, Pitilakis K, Winter M G, Pastor M, Ferlisi S, Tofani V, Hervás J and Smith J (under preparation) Recommendations for quantitative assessment of landslide susceptibility, hazard and risk for zoning purposes (to be submitted to Landslides).

Especially for the quantitative risk assessment for rockfalls, the incorporation of the vulnerability is discussed between others in:

- Corominas, J. and Mavrouli, O., (2011) Chapter in book: Rockfall Quantitative Risk Assessment in: Rockfall engineering: from prediction to mitigation (Ed. Stéphane Lambert and François Nicot), pp. 255-296.

Another book chapter discussing rockfall vulnerability and related issues of the quantitative risk assessment is at its final editing stage and expected to be published within the following months. It is titled:

- Mavrouli O, Abbruzzese J, Corominas J and Labiouse V (in print). Chapter in book: Review and Advances in Methodologies for Rockfall Hazard and Risk in: Mountain risks: from prediction to management and governance (Ed. Springer).

The outcomes from this project permit the step-by-step and objective vulnerability assessment of buildings threatened by landslides, in probabilistic terms. The provided methodologies are a tool than can be used by scientists and practitioners working on landslides for the quantified risk assessmnent. The vulnerability in quantitative terms increases the population's perception of risk, and the public awareness. The results of the quantified vulnerability can also be used as a common communication platform by technical and social scientists as well as by stakeholders for decision-taking related to protection measures and urban planning. Public or

private insurance companies can be further end-users of the project results.
This project was realized in link with the thesis project of Mavrouli (2011) and the Safeland project (FP7, No.: 226479).

2 DISSEMINATION

The project results were disseminated through the publication of articles in journals, books and the participation in conferences. The minimum number of articles in journals which were anticipated was 4 (2 or 3 of them before the completion of the project). In the following a complete list is included (in inverse chronological order).

Publications

At journals:

Santana D, Corominas J, Mavrouli O, and Garcia-Selles D (2012), Magnitude-Frequency relation for rockfall scars using a Terrestrial Laser Scanner. Engineering Geology. 145–146, 50–64.

Mavrouli, O. and Corominas, J., (2010). Rockfall vulnerability assessment for reinforced concrete buildings, Natural Hazards and Earth System Sciences, 10(10), pp. 2055-2066

Chapters in books:

Corominas, J. and Mavrouli, O., (2011) Chapter in book: Rockfall Quantitative Risk Assessment in: Rockfall engineering: from prediction to mitigation (Ed. Stéphane Lambert and François Nicot), pp. 255-296.

At conferences:

Corominas, J., Mavrouli, O. and Moya, J. (2012) Simplified approach for obtaining the block volume distribution of fragmental rockfalls. ISL-NASL 2012, 11th International & 2nd North American Symposium on Landslides, 3-8 June, Banff, Alberta, Canada (Full paper)

Smith J T, Winter M G, Fotopoulou S, Pitlakis K, Mavrouli O-C, Corominas J, and Argyroudis S (2012) The physical vulnerability of roads to debris flow: an expert judgement approach. ISL-NASL 2012, 11th International & 2nd North American Symposium on Landslides, 3-8 June, Banff, Alberta, Canada.

Eidsvig U., McLean A., Vangelsten B. V., Kalsnes B., Ciurean R. L., Argyroudis S., Winter M., Corominas J., Mavrouli O. C., Fotopoulou S., Pitilakis K., Baills A., and Malet J. P. (2012) Socio-economic vulnerability to natural hazards – proposal for an indicator-based model European Geosciences Union (EGU), General Assembly, 22-27 April 2012, Vienna, Austria (Abstract)

Mavrouli, O., Corominas, J. Santo A.,Di Crescenzo, G., Ulrich, T., Sedan Miegemolle, O., Malet, J.-P., Remaître, A. Narasimhan, H., Faber, M. H., Maftei, R. Filipciuc, C.T., Van Den Eeckhaut, M., Hervás, J., Smith, J., Winter, M., Tofani, V., Casagli, N., Crosta, B., Agliardi, F., Frattini, P., Cascini, L., Ferlisi, S. (2012) Comparison of landslide hazard and risk assessment practices in Europe. European Geosciences Union (EGU), General Assembly, 22-27 April 2012, Vienna, Austria (Abstract)

Winter M G, Smith J T, Fotopoulou S, Pitlakis K, Mavrouli O-C, Corominas J, and Argyroudis S (2012) Determining the physical vulnerability of roads to debris flow by means of an expert judgement approach. European Geosciences Union (EGU), General Assembly, 22-27 April 2012, Vienna, Austria (Abstract)

Santana, D., Corominas, J., Mavrouli, O. Garcia-Selles, D. (2011) Magnitude-Frequency relation for rock falls using a terrestrial laser scanner, ROCEXS 2011, Interdisciplinary Rockfall Workshop 2011, Austria, Tirol, Innsbruck, Igls, Congresspark, 17 - 19 May 2011 (Extended abstract)

Corominas J and Mavrouli O (2011) Quantitative risk assessment for buildings due to rock-falls: some achievements and challenges, Proceedings of "2ème journée de rencontre sur les dangers naturels", Université de Lausanne, Lausanne, Switzerland.

Expected articles to be submitted at Landslides within 2012:

Corominas J, van Westen C, Frattini P, Cascini L, Malet JP, Fotopoulou S, Catani F, van den Eeckhaut M, Mavrouli O, Agliardi F, Pitilakis K, Winter M G, Pastor M, Ferlisi S, Tofani V, Hervás J and Smith J (under preparation) Recommendations for quantitative assessment of landslide susceptibility, hazard and risk for zoning purposes (to be submitted to Landslides).

Eidsvig U, McLean A, Vangelsten BV, Kalsnes B, Ciurean L, Argyroudis S, Winter M, Mavrouli O, Fotopoulou S, Pitilakis K, Bails A, Malet JP and Kaiser G (in preparation). Assessment of socio-economic vulnerability to landslides using an indicator-based approach. (To be submitted to Landslides).

Mavrouli O, Fotopoulou S, Pitilakis K, Zuccaro G, Foerster E and Corominas J (in preparation) Analytical methodologies for the quantification of the vulnerability of buildings to landslides using fragility curves. (To be submitted to Landslides).

Winter M G, Smith J T, Fotopoulou S, Pitlakis K, Mavrouli O-C, Corominas J, and Argyroudis S (in preparation) An expert judgement approach to determining the physical vulnerability of roads to debris flow. (to be submitted to Landslides).

Expected chapter book to be published within 2012:

Mavrouli O, Abbruzzese J, Corominas J and Labiouse V (in print). Chapter in book: Review and Advances in Methodologies for Rockfall Hazard and Risk in: Mountain risks: from prediction to management and governance (Ed. Springer).

Conferences

Attendance at conferences:

XI International Symposium on Landslides, Banff, Canada. June 2012

ROCEXS 2011, Interdisciplinary Rockfall Workshop 2011, Austria, Tirol, Innsbruck, Igls, Congresspark, 17. - 19. May 2011.

La 2ème journée de rencontre sur les dangers naturels, Université de Lausanne, February 2011.

Mountain Risks Topic Workshop on Risk and Emergency Management, November 2009, Padova, Italy.