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Towards the quantification of rockfall risk assessment for urban areas

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In many mountainous inhabited areas rockfalls are a major threat for structures and population. The quantification of the risk gives an estimate of the potential consequences that allows the analysis of different scenarios, minimizing the subjectivity and the uncertainties that derive from judgmental and qualitative approaches. The four main phases of the rockfall phenomenon have to be determined including: a. the calculation of the frequency of the rock block volumes falling down the slope, b. the calculation of the probability of the rock blocks reaching a reference section with a certain level of kinetic energy; c. the calculation of the spatio-temporal probability of the exposed elements; and d. the calculation of the probability that an exposed element will suffer a certain degree of damage. Here, a step-by-step methodology for the quantification of risk is presented. The methodology focuses on steps (b) to (d).

An example of an urban area that is situated at the toe of a talus cone below of a rocky slope is considered. Three different rock diameters are considered with their respective frequencies (step a). For the calculation of the spatial probability of a given rock size reaching a location, a probabilistic 3D trajectory analysis is performed using the software ROTOMAP. The inputs are the topographic relief, the rockfall source and velocity and the soil parameters (restitution coefficient and friction coefficients). The latter are evaluated by back analysis using historical events. The probability of a given rock magnitude reaching a critical section of the talus cone with a certain level of kinetic energy is evaluated. For the step (c), the spatio-temporal probability of the element at risk is calculated taking into account both the trajectographic analysis of the rock blocks and the location of the elements at risk on the talus cone. For the step (d), the probability of a certain degree of structural damage in the buildings is calculated. To this purpose, the set-up of the exposed buildings at the toe of the talus slope is considered. All the exposed buildings are of reinforced concrete and they have the same structural typology. Using as an input the results of step (c), the probability of a certain damage degree is calculated, according to the location of the building. An analytical methodology developed by Mavrouli and Corominas (2009) is used for the quantification of the damage. The degree of damage is linked to the impact location of the block onto the building and whether it is on a structural or non-structural member. In the first case the potential of a cascade of failures resulting in generalized structural damage is investigated. Four degrees of damage (risk scenarios) are considered: a. local non-structural, b. local structural, c. partial at the bay of the impacted element, d. generalized.

For each building, each risk scenario has the following probabilities:

Scenario 1: Probability of non-structural damage

$$P_1 = \sum_i f_i \times P_r \times P_s \times P_{ns}$$

Scenario 2: Probability of local structural damage

$$P_2 = \sum_i f_i \times P_r \times P_s \times P_{ls}$$

Scenario 3: Probability of partial damage

$$P_3 = \sum_i f_i \times P_r \times P_s \times P_p$$

Scenario 4: Probability of generalized damage

$$P_4 = \sum_i f_i \times P_r \times P_s \times P_g$$

where:

f_i: frequency of fragmented rocks of magnitude I,

P_r: probability of reaching the location of the exposed element with sufficient energy to cause the respective scenario damage,

P_s: spatio-temporal probability of the building,

$P_{ns,}P_{ls,}P_pP_g$: respectively, probability of impact on a structural or on a non-structural element leading to scenarios 1 to 4.

The rockfall risk for each building can be calculated by multiplying the probability of each risk scenario by its associated vulnerability, and summing all of them.

References

Mavrouli, O., Corominas, J. 2009. Vulnerability of simple reinforced concrete buildings in front of the rockfall impact. Landslides. (in press).