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Probabilistically based vulnerability index of reinforced concrete buildings due to rockfall impacts

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The assessment of the structural vulnerability of buildings which are threatened by rockfalls represents a very important part of the Quantitative Rockfall Risk assessment. The interest is mainly concentrated on the evaluation of a vulnerability rate for a structural typology, for a range of rockfall magnitudes, in order to be used as an input into the following risk equation:

Risk=Hazard x Exposed elements x Vulnerability of exposed elements

Up to now, the most popular approaches in practice are mainly empirically or judgmentally based, given the limited scientific background in the field of structural vulnerability evaluation due to rockfalls. The aim of the work that is presented here is to introduce a methodology for the quantified assessment of the vulnerability of reinforced concrete structures, which are subjected to potential rockfall impacts. The objective is to provide an output, in terms of a vulnerability rate, given a specific structure, rock boulder diameter and velocity at the moment of the impact. The presented methodology applies for direct rock impacts on the basement columns of reinforced concrete buildings. It is considered that only an impact on structural elements (columns, beams) may cause collapse of the structure, whether an impact on a non-structural element such as an infill wall may only result in local damage of the element itself. Here, the structural vulnerability is determined by the first type of damage, as in the case of structural collapse repairing maybe technically difficult as wells as highly costly up to the point of not applicable, while non-structural damage is maybe easier repaired.
For the evaluation of the structural vulnerability of a building due to a rock impact, we have modified a methodology that we have previously developed, by introducing the probability of collapse. The vulnerability is thus obtained by combining the probability of building collapse with the impact probability. The steps are the following: 1) calculation of the probability of impact on a structural element Pimp according to the geometry of the exposed façade(s) and the rock boulder size, 2) evaluation of the extent of the effect of the initial impact, which is mainly limited to local damage, 3) assessment of the post-impact stability of the intact structure in terms of probability of collapse and 4) iteration of the previous steps for the calculation of the vulnerability rate for different rockfall magnitude scenarios.
For the assessment of the extent of the local damage due to the impact at step 2, the capacity energy of one individual column is analytically calculated. Given the column energy capacity and the rock motion parameters, it is possible to determine the number of structural elements that fail. For the evaluation of the post-impact response of the building at step 3, a collapse factor is used. It is analytically calculated for each structural element, as equal to the ratio:

cf= post-impact static loads / element capacity

In order to calculate the probability of collapse Pc, the introduced uncertainty is the resistance of the reinforced concrete and the expression for the probabilistic analysis is:

Pc= max P[cf>1]

where P[cf>1] is the probability of collapse for each structural element.

The vulnerability of the building is then defined as:

$$V = P_{imp} \times P_c$$

The methodology is applied for a reinforced concrete structure. The obtained results are presented on a three-dimensional diagram that correlates the vulnerability of the building with the size of the rock boulder d and its velocity v. The interpretation of the vulnerability index results is made and the efficiency of the index is discussed.