Numerical Simulation of Consecutive Rockfall Impacts on Reinforced Concrete Slabs

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Summary

The risk due to falling rocks in Alpine regions is managed by means of various protective structures. Rockfall protection galleries are one of the common types of these structures built to protect the transportation network. In order to establish a rational method to improve the design of rockfall protection galleries, large-scale tests have been carried out in Switzerland. Reinforced concrete slabs were subjected to repeated falling-weight impacts with increasing falling height.

The current work presents finite element modeling of some of these tests and the results are compared to the experimental data. Based on the numerical investigation, a comparison was made between the response of a slab subjected to consecutive impact loading and virgin slabs subjected to similar impacts. For the range of the modeled experiment, it was observed that the maximum reaction force of the slab was reduced up to 25% due to the softening of the slab and its cracking. With virtue of the comparison made based on residual deflections, numerical extension of this study may help investigating the extent of damage to the existing structures which have already sustained one or more impacts during their service life to provide a sustainable decision making for their maintenance and strengthening.

Keywords: Rockfall protection galleries, consecutive impact loading, finite element analysis.

1. Experiment

A series of falling-weight impact tests in a scale of 1:2 was carried out in Switzerland. Reinforced concrete slabs with lateral dimensions of 3.5 x 4.5m were subjected to impacts of 800 kg and 4000 kg boulders with increasing falling height until the slabs failed. The test setup and program is explained in details in [1]. This paper represents finite element simulation of seven impacts carried out on a slab (slab B) with a thickness of 0.35 m. Rebars of 22 mm in diameter were placed at a spacing of 0.155 m in both directions. The slab was covered by a 0.4 m thick gravel layer.

2. Numerical Model

The large-scale experiment is modeled using the finite element method and analysed using the explicit dynamic solver of LS-DYNA [2]. The slab is represented using finite elements where the concrete is modeled by 3D solid elements with eight nodes and the rebars are represented by beam elements. Considering the symmetrical test arrangement only half of the structure is modeled. To save computation time, the initial position of the impacting body is defined at the surface of the gravel layer and is subjected to an initial velocity. For concrete a bilinear model is assumed in compression. Concrete in tension is assumed to behave linearly until a tension cutoff value is reached. Stress-strain curve of the rebars is a bilinear curve with strain hardening. The gravel layer is modeled using a cap-hardening model, where the parameters are determined by curve fitting through experimental data on gravel. As the slab softening and plastic deformation affect the reaction forces of the slab during consecutive impacts, a method is established to model a slab

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subjected to repeated loading. The modeling aimed at following the load history and related deterioration in the slab due to the consecutive loading. Fig. 1 shows the finite element model of an impact test (B1) and the experimental setup.

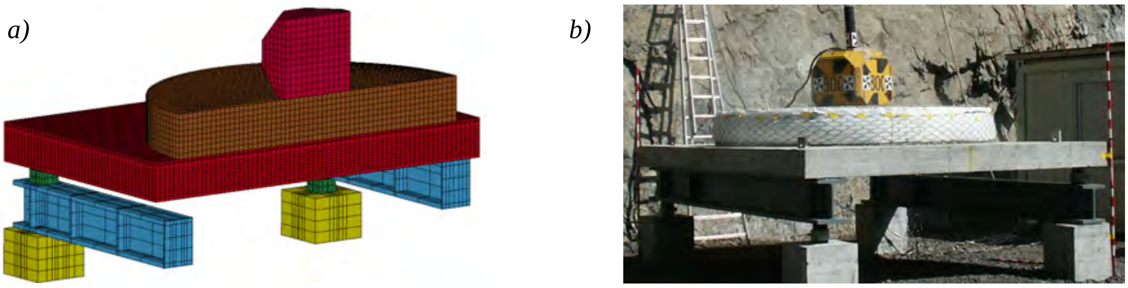

Fig. 1: Finite element model a) and experimental setup b) of a large scale test

3. Results

The applicability of the proposed model was explored by comparison between the numerical results and the experimental ones. The numerical results vary within the range of 40% from the test results. In addition to modeling of consecutive impacts on a single slab, finite element models of the same impacts on virgin slabs were developed. For the range of these experiments the relative reduction in maximum reaction forces (slab response) as well as maximum slab deflections for consecutive loading compared to those of virgin slab was determined. Fig. 2 shows this comparison. Residual deflections obtained from analysis show a rapid increase (20 mm) for the last impact. As during the experiment the slab failed under this impact, this high increase can correspond to the slab failure.

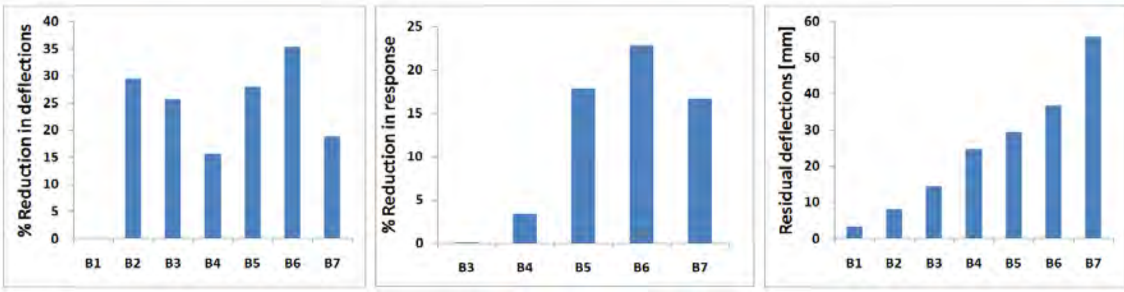

Fig. 2: Reduction in deflection and response of slab due to consecutive loading

4. Conclusions and Outlook

A numerical approach is represented here for modeling reinforced concrete slabs subjected to consecutive impacts. The applicability of the proposed method is investigated by simulating one of the large-scale falling-weight impact tests carried out on reinforced concrete slabs in Switzerland. Seven consecutive impacts on a single slab have been modeled, and the same impacts were simulated on a virgin slab as well. Comparisons of the obtained results show a reasonable agreement with the experimental data. It is observed that for the range of this experiment the maximum reaction forces of the slab were reduced up to 25% compared to the same impact on a virgin slab. As the failure of the slab correspond to a rapid increase of residual deflections, it might be possible to establish a methodology to explore the extent of damage by measuring residual deflections of the existing galleries. This method will further be applied to parametric study of the consecutive impacts on slabs, and to study the consecutive impacts on reinforced concrete beams.

5. References

[1] SCHELLENBERG K., VOLKWEIN A., ROTH A., and VOGEL T., “Large-scale impact tests on rock fall galleries”, *7th International Conference on Shock & Impact Loads on Structures*, 17 – 19 October 2007, Beijing, pp. 497-504.

[2] LS-DYNA Keyword User’s Manual, Version 971, Livermore Software Technology Corporation, 2007.