A Numerical Investigation for Optimization of the Load Carrying Capacity of a Swiss Rockfall Protection Gallery

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Summary

A variety of natural hazards can endanger the built environment and the lifeline in the Alpine areas of Switzerland. Due to climate changes, rockfall events are among the increasing hazards over the last decades. Rockfall protection galleries are one of the few adequate structural measures, which provide the required safety against falling rocks. They are typically composed of reinforced or post-tensioned concrete slabs covered by a soil cushion layer. Many of the existing galleries in Switzerland were built in the 1970s and 1980s. An accurate evaluation of their load carrying capacity is important for the decision-making on their strengthening and possible further use. Recent developments allow improving the energy absorption and thus the performance of these structures through the use of alternative cushion materials.

The present paper covers a numerical investigation of the impact load carrying capacity of an existing rockfall protection gallery, which is situated below the Lopper cliff at the shore of Lake Lucerne in Switzerland. The numerical results obtained from explicit finite element analyses indicate that the gallery may not be able to perform satisfactorily if it is subjected to the maximum impact energy resulting from an extreme rockfall event with a return period of 100 years. In addition, the possibility of improving the performance of the gallery is examined through a comparison of the slab responses when covered by three different cushion materials, namely gravel, sand, or a so-called Three-Layered Absorbing System (TLAS). The comparison confirms that the performance of the gallery can be optimized by using a cushion material with a better energy absorption capacity than the original gravelly soil, which is currently in place covering the gallery.

Keywords: Rockfall protection galleries, falling-weight impact, post-tensioned concrete slabs, numerical simulations, explicit finite element analysis.

1. Finite element analysis of the gallery

The presently studied Gallery 2 is located at a tunnel entrance on the section of the federal motorway A2 connecting the villages of Stans and Hergiswil and was built in 1980. The gallery is designed with an upward slope in order to catch the falling rocks and is composed of a cantilevering post-tensioned concrete slab anchored into the rock face. Based on a trajectory analysis, [1] a design rockfall event with a return period of 100 years is chosen to correspond to a rock with a volume of 1.5 x 1.0 x 0.8 m^3 and an initial impact velocity of 32 m/s.

A three dimensional explicit finite element analysis is carried out using the program LS-DYNA [2]. The applicability of the finite element analysis method for the evaluation of the response of reinforced concrete slabs covered by soil under impact loading has been verified by comparison to suitable experimental data in [3]. A similar method is applied here to model the galley covered with gravel, sand, or TLAS. The TLAS consists of a 0.5 m thick sand layer on top, a 0.2 m thick reinforced core slab as a middle layer, and a 0.5 m thick Expanded Polystyrene (EPS) block as a

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bottom layer. The finite element model of the gallery covered with a TLAS is shown in Fig. 1. The slab is represented by solid elements for concrete, and beam elements for reinforcement and tendons, respectively. The falling weight and the cushion layers are modeled by solid elements. The gallery is analyzed by incrementally increasing the impact velocity until failure, and is subjected to impacts of a spherical block at a distance of 1.5 m from the free edge.

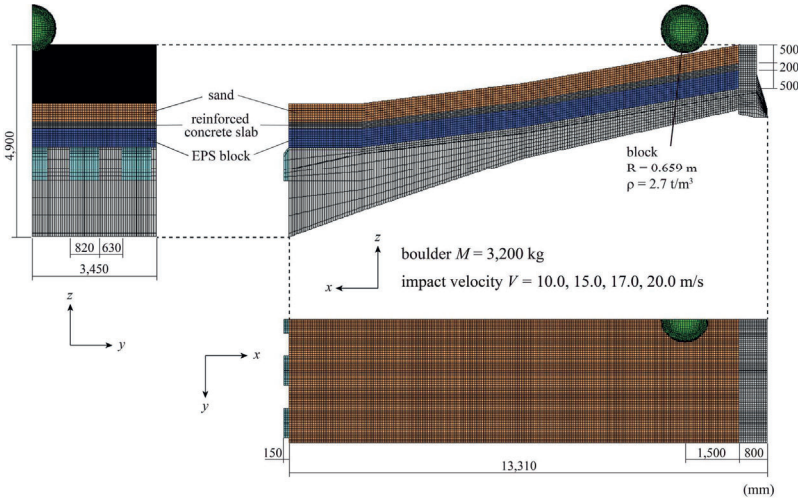

Fig. 1: Finite element model of the gallery covered with a TLAS

2. Results and conclusions

The impact load carrying capacity of an existing rockfall protection gallery in Switzerland is evaluated by means of explicit finite element analyses. The numerical results indicate that if the gallery (originally covered with gravelly soil) is subjected to an impact of a 3.2 tonnes rock, it already fails at an impact velocity of 12.5 m/s (falling height of 8 m). This implies that if the gallery is exposed to an extreme rockfall event with a return period of 100 years (impact velocity of 32 m/s) it may not be able to perform satisfactorily, and it would fail due to concentration of stresses at its kink.

The responses of the slab covered with alternate cushion materials (sand and TLAS) are compared to the response of the slab covered with gravel, in order to explore the possibility of improving the load carrying capacity of the gallery. The comparison confirms that the performance of the gallery can be optimized by using alternative cushion materials, such as the proposed three-layered absorbing system, which can reduce the forces transmitted through the cushion layer to the slab.

3. Acknowledgements

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4. References

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