

FALLING WEIGHT TESTS ON ROCK FALL GALLERIES WITH CUSHION LAYERS

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Impact tests on six reinforced concrete slabs with different cushion layers were performed by dropping concrete boulders from different falling heights. A conventional cushion layer and special cushion systems consisting of high-tensile steel wire meshes filled by cellular glass were tested. The tests reveal the measured reaction forces at the supports, the accelerations in the boulder and in the slab as well as the strains at the upper slab surface and in the bending reinforcement. In addition, a high speed video system recorded the impacts.

Keywords: rock fall impact, large-scale falling weight tests, cushion system, cellular glass, reinforced concrete slabs

INTRODUCTION

The impact load capacity of existing rock fall protection galleries is of great interest when deciding on the necessity of renovation or strengthening. The Swiss design guideline for rock fall galleries was published in 1998 [1]. Older galleries are mostly designed based on oversimplifications by local engineers. The guideline is based on impact tests carried out in 1996 [2] that focused on the influence of the cushion layer. The test results were extrapolated by using finite element simulations [3]. Further research was performed on the dissipation capacity of different cushion materials [4]. The response of the structure and the interaction between the impacting rock, the cushion layer and the reinforced concrete slab are the main focus of the presented study. Therefore, large-scale field tests on reinforced concrete slabs are performed in an old quarry close to Walenstadt in the Swiss Alps.

A survey of the existing galleries in Switzerland has shown that most galleries consist of reinforced concrete slabs covered with a cushion layer [6]. Normally, granular soil from the surroundings or gravel is used as cushion layer. Protection galleries typically span 9 m with a slab thickness of approximately 0.70 m. The back side of the galleries is clamed supported at the retaining wall; the valley side is supported on columns. Typical column spacing is 7 meters.

TEST SETUP

The slab's dimensions of 3.5 x 4.5 m correspond to an average rock fall protection gallery in a scale of 1:2. They were line supported along one side and pile supported on the remaining two corners (see Figure 1). The slabs are covered by a conventional or by a special cushion system consisting of high-tensile steel wire mesh filled with a layer of light-weight cellular glass (Misapor). Two instrumented boulders of 800 and 4000 kg were used as falling weights to

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impact the slabs. The tests have been performed by gradually increasing the falling height from 2 to 15 m until plastic strains in the bending reinforcement reached a certain level or shear failure occurred. The kinematics of the impacting bodies was analyzed and the dynamic response of the reinforced concrete slab was investigated by measuring reaction forces strains and accelerations with sample rates of 3.2. The tests are recorded by a digital video camera with a recording rate of 250 frames per second with a posterior analysis of the trajectory using tracking software. The camera and the instrumentation are triggered manually. A repetition of some identical tests staying in the elastic range of the slabs showed that the statistical spread of the test results stays small. The high-energy impact tests were carried out only once. Altogether 38 impacts were executed. The test setup and test program are described more detailed in [5].



Figure 1: Test setup with gravel cushion and 4000 kg boulder

RESULTS AND OBSERVATIONS

It was observed, that after the tests the cushion layer was less compacted than before. The separation of cushion layer and slab was clearly observable with the high-speed video recording. The stopping process of the boulder was different for the gravel cushion or for the system out of cellular glass.

In difference to real rock fall galleries, the slabs are not restrained from lifting off the supports. This was also observed in the high-speed videos.

During the latest phase of the slab response, slab, cushion system and boulder are in free oscillation. From the oscillation period, the stiffness of the slab can be deduced.

The failure mode that could be observed in all slabs was a combined bending shear failure close to the simple supported corner. According to the design of the slabs, a bending failure along the middle of the slab was expected. Punching resistance of the slab was close to the bending resistance. For the structural analysis and the design of the structure, the supposed

failure mode plays an important role [7]. The structure's response is also important for an adequate assumption of the dynamic material characteristics.

CONCLUSIONS AND OUTLOOK

Large-scale tests have been presented that simulate the impact of a falling rock onto a rock fall protection gallery. With the special system reaction forces at the supports could be reduced substantially.

From comparing the independent measurements on the slab and on the boulder as well as the recorded videos, it could be shown that the test setup produces reliable results. The obtained data using a sampling rate of 3.2 kHz is sufficiently detailed for the range of impact velocities concerning rock fall impacts. The data allows for an extensive analysis that describes the rock impact, the behavior of the cushion system and the interaction between impacting boulder and concrete slab.

The test results are used to develop and evaluate physical and numerical models. The models will lead to a design concept for rock fall galleries. Progress in the prediction of the performance of protective structures is one element, which has to be combined with the progress in the other disciplines in rock fall studies. These are for example the detachment of blocks from cliffs, trajectory analysis and geotechnical studies of the cushion layer. Collaboration between the different researchers will improve the handling of rock fall problems. Thus Teamwork will improve to mitigate the damage of infrastructure or humans lives due to rock fall.

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