IMPACT OF ROCKFALLS ON REINFORCED FOAM GLASS CUSHION SYSTEMS

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The trajectory of a falling rock is mainly determined by bounces on the ground or with trees reducing continuously the rock's kinetic energy thus braking it. Free fall experiments on a horizontally positioned concrete slab covered by a special cushion system allow an analysis of the braking process. The process has been recorded using high-speed video and acceleration sensors attached to the rock. These interdependent measurements allow deduction of the kinetic process, i.e. velocity and displacement, obtained from integration of the rock's acceleration and independently from differentiating the video displacements. This contribution shows the validity of both methods and additionally suggests how to evaluate and to classify e.g. novel cushion systems.

Keywords: rockfall, experiment, impact, deceleration, protection structure

INTRODUCTION

The stopping process of falling rocks by protection systems causes deceleration effects that can not predicted easily [1]. The mass and velocity of a falling rock constitute its kinetic energy. The absorption/transformation of this energy into deformation work or heat energy happens during a certain impact time along the braking distance. The latter can reach several meters in a flexible protection system. On the contrary, an impact on almost rigid surface results in a very short braking distance and impact time with very large impact forces. Therefore, concrete galleries usually are protected by an additional cushion layer, which mostly consists of granular soil. In this paper we report on the performance of a new type of cushion material made from foam glass (density = 130-160 kg/m^3, grain size = 10 / 25 mm, friction angle = 55°) has been tested under different load conditions [2]. The cushion material is used normally as aggregate for light-weight and heat-insulating concrete. The test results are compared to the guidelines for loads on rockfall protection galleries [3, 4].

Figure 1 Instrumented 800 kg model rock with cushion system (diameter = 3m, height = 1.2m) prior to tests [2]

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TEST METHODS AND ANALYSIS

Three layers of the cushion material (foam glass) with a thickness of 0.4 m each were placed on the concrete slab (Figure 1). Between the layers and as lateral bound a high-strength steel net was used. The test specimens were equipped with 6 acceleration sensors connected by wire with the central data logging unit. A total of 12 tests were carried out with two different impact masses and falling heights ranging between 2 and15 m (Table 1).

Table 1 Performed tests on special cushion system

Test No.		C1	C2	C3	C4	C5	C6	C7	C8	F1	F2	F3	F4
Mass *m*	(kg)	800	800	800	800	800	800	4000	4000	4000	4000	4000	4000
Falling height	(m)	15	5	5	5	10	15	2	5	7.5	7.5	7.5	7.5
Energy	(kJ)	120	40	40	40	80	120	80	200	300	300	300	300

For a subsequent comparison with the existing FEDRO[3] guidelines [3, 4] the peak force has to be converted into a corresponding acceleration. The guidelines formulate the relation between the characteristic brake force F_k, the impact velocity v and the brake distance d as

$$d = mv^2 / F_k \qquad (1)$$

Assuming F_k to be the maximum acting brake force F the acceleration a is calculable by the use of the 1st law of Newton ($F = m \cdot a$) and equation (1) as

$$a = v^2 / d \qquad (2)$$

stating that the deceleration of a falling rock only depends on the impact velocity and the (measured) impact depth.

RESULTS

It is now possible to analyse the preciseness of both kinetic measurements. The video records (V) have a temporal and aerial resolution of *4 ms* and *~1 cm*, respectively, resulting in a grade of accuracy on the order of a few *cm* for the braking distance and a noise of *2 m/s* for the velocity calculated from the videos. The acceleration sensors (A) with a range of ±*500 g* and a resolution of ±*2 g* restrict the exact definition of the impact time to a few *ms* despite the sample rate of *10 kHz*. The resulting precision of the integrated brake distance is again defined on the order of a few *cm* which also corresponds to the precision of the measured falling height. The comparison between video and accelerations shows very similar values (Table 2).

Table 2 Comparison of measured braking from video records (V) and acceleration sensors (A)

Test No.		C1	C2	C3	C4	C5	C6	C7	C8	F1	F2	F3	F4
Impact time V	(ms)	48	40	36	40	-	36	48	52	68	56	64	48
Impact time A	(ms)	50	44	38	39	37	39	46	49	70	56	64	51
Brake distance V	(cm)	51	26	22	24	-	36	20	29	56	46	49	37
Brake distance A	(cm)	52	28	24	25	33	40	21	30	57	47	50	39
Acceleration A	(m/s^2)	530	370	390	420	615	680	170	260	330	475	320	440

The calculated values of the braking distance (i.e. the impact depth) at the given impact velocity are now compared to the impact characteristics given in the FEDRO guidelines for protection galleries [3, 4]. The deceleration curves show clearly that the existing guidelines for traditional cushion soil can also be used for the dimensioning of a gallery underneath such new cushion systems (Figure 2).

[3] FEDRO = Swiss Federal Roads Office

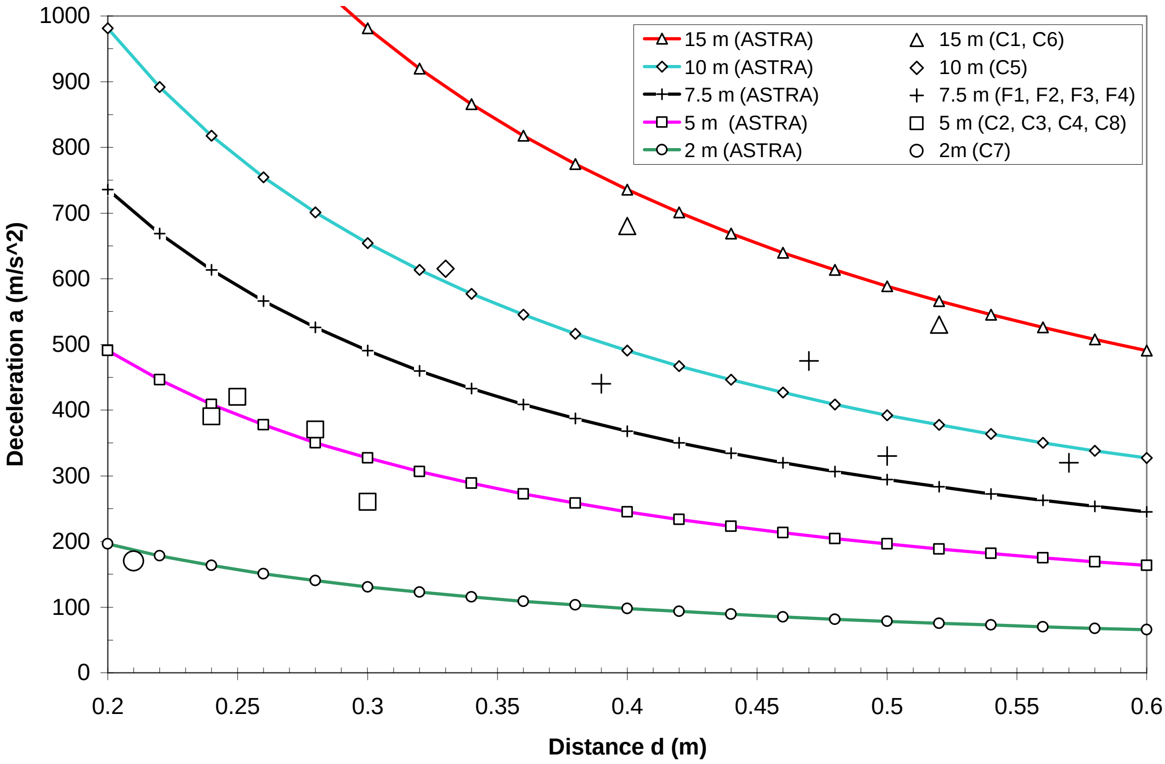

Figure 2 Measured accelerations compared with accelerations for different falling heights calculated according the FEDRO guidelines [3, 4].

CONCLUSION

The results shown above represent the first results of an extensive analysis of the tests described in [2]. After the usability of all measurements has been checked and proven, new models regarding the impact loads on galleries, the performance of different cushion layers and the non-linear dynamics of the impact will be analysed in detail.

Using different cushion material, analysis of the experiments works as shown above. A summary of all tests and some additional results are given in [2]. It can be summarized that the times for braking of the falling boulder are smaller by a factor 10 for the tested foam glass protection system compared to a traditional gravel layer. Thus, decreasing the deceleration of the falling rock by also a factor of 10. Finally, it was demonstrated that the existing guidelines for the dimensioning of protection galleries are also valid using different cushion systems.

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