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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "A new-type flexible rock-shed under the impact of rock block: experimental investigation" *by* S. Shi et al.

S. Shi et al.

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We would like to thank the referee #2 for the careful comments and constructive suggestions, which make our manuscript greatly improved. All the comments are considered seriously and corresponding modifications have been made in the new version of the manuscript. The following are the detailed responses and revision according to reviewer's comments.

1. The authors seem to have performed only one experimental test. This is a very initial step to investigate the behaviour of this new type of structural rockfall protection, but much is yet to come. For example, I guess that multiple structural failure modes or interactions would be possible depending on the type of impact (e.g. vertical vs.

oblique, central vs. eccentric) and the impacted structural element (e.g. nets, vaults, cable). I suggest that the title is changed into "A new-type flexible . . .. . . block: INITIAL EXPERIMENTAL INSIGHTS" or so, and that the authors summarize in the Conclusions the limits of present investigation and a "to do" outlook.

Response:

The authors agree with the reviewer's point that this paper is a very initial step to investigate the behavior of the flexible rock-shed, so the title has been changed into "A new-type flexible rock-shed under the impact of rock block: initial experimental insights".

The authors have summarized the limits of present investigation and a "to do" outlook in the conclusion of the new version of the manuscript and the detailed responses are followed:

Based on the ETAG 027 European guideline and testing procedures for concrete rock-shed, the test procedure is designed and carried out to evaluate the functional performance of the flexible rock-shed. But the flexible rock-shed is differed with the flexible barriers and concrete rock-sheds, so there are some limits of the present experimental investigation and deserved to be discussed in the future:

(1) The failure or deformation models of this structure would be possible depending much on the type of impact (vertical impact or oblique impact), the location of impact (on the central location, on the eccentric location or on the edge), the impacted structural element (flexible nets, support cables or vaulted structure) and the mass, the volume and the shape of the block. In the present test, only one condition of structure impacted by the block on the middle-span location was tested. How the conditions above influence the performance of the structure needs to be further investigated.

(2) In the experiment, the block rebounded after the collision and impacted the net-hanging bracket when the block flew off one side of the rock-shed (Fig. 6). For safety,

the flexible rock-shed should be absorbed much more energy via plastic deformation and friction and the rebounding energy of the block should be reduced.

(3) The single-span flexible rock-shed is designed and tested in this paper, but multi-span flexible rock-shed is much differed from the single span structure because the other span structures can share the lateral binding force and this would improve the deformation of the vaulted structure.

(4) Although the full-scale test provides useful information for design purposes of the structure, the loading mechanisms and energy dissipation by the flexible nets, the support cables and the vaulted structure are not clear, and these would be conducted by the numerical methods for design or optimization purposes or for parametric analyses for the flexible rock-shed.

2. Although fitting into the Aims and Scope of NHESS, the contribution is exclusively focused on structural engineering testing aspects of the proposed rockfall protection approach, and is completely disconnected from real rockfall process and hazard "settings". Rockfalls occur in very different conditions including high and steep rockwalls, cliff-talus vegetated slopes, partially engineered slopes etc. Different rockfall settings involve different typical block sizes, parameter uncertainty, velocity ranges and so on. The proposed protection solution may be suitable in some settings, but completely use less in others (e.g. a 250 kJ capacity seems very low in rockfall settings with medium sized boulders or under high cliffs where significant free-fall occurs). In this form, the paper seems more suitable for a structural engineering journal than for NHESS. Although I agree with the primary focus, I would suggest the authors to better explain the "rockfall environments" in which the proposed mitigation approach would be useful and cost-effective. The advantages and limitations (technical, economic, etc.) of the approach should be better outlined in the conclusions;

Response:

The authors have explained the "rockfall environments" for the flexible rock-shed in the

new version of the manuscript, and the detailed responses are followed:

The flexible rock-shed relies much on the deformation of the flexible nets for energy absorption. In general case, the flexible nets can absorb more energy through larger deformation, but in design, adequate safety distance between the system and the ground to be protected must be taken into account. In addition, rockfall occurs in very different conditions and involves different block sizes, energy ranges and velocity ranges and so on. However, in many regions of the world, such as in Australia and Japan, much lower values of impact energy have been involved ranged from 25 kJ to 250 kJ due to the nature of the geological environments (Muraishi et al., 2005; Buzzi et al., 2013). Therefore, compared to flexible barriers and concrete rock-sheds, the flexible rock-shed has been focused on low levels of impact energy ranged from 25 kJ to 250 kJ considering economic factors, safety distance, technical limitations and kinetic energy level of rockfall happened in normal conditions. The speed of rockfall ranges from a few meters per second to up to 25$\sim$30 m/s (Peila and Ronvo, 2009) and owing to the fact that damages were frequently caused by impacts of small blocks with high velocities, producing the nets perforation, thus the maximum speed of rockfall impacted to the system is constrained to 25 m/s (Cazzani et al., 2002; Volkwein et al., 2011; Spadari et al., 2012).

The authors have designed flexible rock-shed with three levels of impact energy of 25 kJ, 100 kJ and 250 kJ. In the case of 25 kJ, the flexible nets are composed of TECCO wire mesh G65; In the case of 100 kJ, the flexible nets are composed of TECCO wire mesh G65 and cable nets. In the cases 25 kJ and 100 kJ tests, the flexible rock-shed successful stood for the impact energies, and the steel vaulted structure underwent nearly elastic deformation and could be put into service again with minor maintenances, but in the case of 250 kJ test, the vaulted structure was seriously distorted. The basic idea is to minimize the possibility of steel vaulted structure damage and to decrease the maintenance costs on the structure from the engineering point of view, so the performance of the flexible rock-shed under the impact of rock block with energy 250 kJ is presented and discussed in this paper and initial experimental insights have been proposed.

The advantages and limitations of the flexible rock-shed have been outlined in the conclusions of the new version of the manuscript, and the detailed responses are followed:

The flexible rock-shed mixes the flexible barriers and structural rock-sheds, and the protection mode for this structure is differed with the flexible barriers but the same as the rock-sheds. Therefore, this solution possesses the advantages of both the flexible barriers and the concrete rock-sheds and overcomes some limits on them. It is cheaper than the concrete rock-shed with the same energy retention capacity. It is easier to be constructed and quickly installed requiring little equipment. It is unnecessary to evaluate the possible paths of detachable rockfall, such as the bounding height and the runout distance, etc. It is suitable for constructing on bridges because of the lightweight of the structure. It can be manufactured at factory, field-assembled and especially suitable for emergency construction and maintenance.

However, there are some limiting factors in the case of flexible rock-shed according to the rockfall settings and the experimental investigation. The present flexible rock-shed can only be used for low or about 250 kJ energy rockfall settings considering economic factors, safety distance, and technical limitations. If the structure has experienced rockfall event with full energy retention capacity of the structure, the vaulted structure would be deformed much and requires immediate maintenance. The flexible rock-shed cannot be used if the frequency and intensity of rockfall is higher or if the perpetual protection structures are needed from the engineering points and economic factors of view.

3. Again with reference to the low capacity of the structure (250 kJ): authors state (Page 4067, lines 1-2) that higher energy absorption capacity could be achieved where needed by setting up multiple layers of nets. Nevertheless, in the results they show that a 250 kJ impact is enough to damage the steel hanging structure. Could the authors

address better this point? How much do they believe that the structure capacity could be increased?

Response:

The purpose of the authors is to design a flexible rock-shed standing for an impact energy up to 250 kJ considering economic factors, safety distance, technical limited condition and kinetic energy level of rockfall happened in normal conditions.

The authors' point regarding the sentence in Page 4067, line 1-2 is that: if a higher demand for energy level is needed, two or more flexible rock-shed is needed. On the up of the flexible rock-shed, there is still a flexible rock-shed, and so on. But this is only a theoretical opinion, and in the new version of the manuscript, this sentence has been removed.

In the authors' opinions, the capacity of the multi-span flexible rock-shed could be increased because the other span structures can share the lateral binding force and this would improve the load-carry capacity of the vaulted structure. But this point needs to be proved by experimental investigation in the future.

4. As a consequence of Point 1, cited reference linking rockfall processes/hazard/risk to countermeasure needs and design are almost lacking. Cited rockfall literature is either “engineering-oriented” or quite old. I encourage the authors to tell some more about the links between rockfall processes and the related protection needs starting from recent literature (a huge one has grown during the last decade). This could be done in the introduction and recalled in the Conclusions (quite short paper, there is space), and would contribute to better communicate the applicability of the proposed protection approach.

Response:

Recent references linking rockfall processes/hazard/risk to countermeasure have been added in the introduction of the new version of the manuscript.

5. Figures are generally good and informative, but their size and lettering is too small is fitted in the journal editing format. In some cases, it is nearly impossible to see important details. I suggest to pack them more figure insets, enlarge and increase lettering. Tables would be useless if figure details were clearly visible.

Response:

The authors have packed more figure insets, enlarged and increased lettering in Fig. 6, Fig. 7, Fig. 8 and Fig. 10 in the new version of the manuscript.

6. English terms and spelling could be generally improved.

Response:

The authors thoroughly checked English terms and spelling in the new version of the manuscript.

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