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Numerical back-analysis of impacted rockfall barriers steel posts: discussion on the effectiveness of the system

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SUMMARY: Flexible rockfall barriers are effective structures for rockfall risk mitigation, capable to withstand very high impact energies, up to 10000 kJ. The assessment of the barriers is demanded to the appropriate European Assessment Document EAD 340059-00-0106 (EOTA, 2018): it ties the performance to a standard test procedure, in which the net is the only impacted element. Despite this impacting case is representative of the majority of the cases, other impact positions are possible, e.g. on the supporting elements. Hence, the debate on the performance assessment for the rockfall barriers is still open.
The producing company Geobrugg AG has recently conducted experimental tests producing an impact at the midspan of an internal steel post on a 500 kJ rockfall barrier. In this paper, a numerical back-analysis of these tests is performed to analyze the failure mechanisms and to be able to extend the results for different impact positions on the structural element, evaluating the system effectiveness.

Keywords: rockfall barrier, impact, steel post, energy dissipation, numerical back-analysis

Introduction

Flexible rockfall barriers, also called net fences, are effective protection measures for mitigating rockfall risk, capable to withstand very energetic block impacts. For the limited encumbrance and environmental impact and the low weight of these systems, they are often the only option to protect elements at risk. Net fences are composed by an interception element (constituted by a steel net), sustaining elements (usually realised with structural steel commercial profiles), rope cables (which transmit the load to the anchor foundations) and energy dissipating devices. While traditional civil engineering structures are subjected to plastic deformations just in ultimate limit state conditions, an extensive damage of net fences can be produced even in impacts with low kinetic energy. These systems are thus realised so that a relevant portion of energy dissipation occurs in parts that can be easily substituted, like energy dissipating devices.

Even if rockfall protection structures performance assessment is still debated (De Biagi et al., 2020), today its evaluation is made through the procedure defined in EAD 340059-00-0106 (2018): through codified impact tests both a maximum and service energy absorption capacity are derived, named MEL and SEL, respectively. During the tests, block impacts are performed in a given position, i.e. in the centre of a three-modules structure: this might not be comprehensive of the wide variability of the possible impacting positions. Moreover, the impacting block is a quasi-spherical polyhedron realised in concrete which should impact the intercepting net with a velocity equal or higher to 25 m/s. Despite these limitations, the efficiency of systems designed and tested following the EAD 340059-00-0106 (2018) has been demonstrated for many other load cases (Yu et al., 2021). As an example, numerical simulations have demonstrated that a certified barrier can withstand to impacts due to areal loads such as small or large slabs (Koo et al., 2017). On the other hand, the standard test procedure has also

shown some lacks: experimental tests have shown that a decrease of the impactor size (keeping constant impacting energy) produces a decrease in failure energy (Spadari et al., 2011; Mentani et al., 2017).
All the works mentioned above considered the net as the impacted element. Nevertheless, the scientific literature has not adequately addressed the likelihood of block impact affecting the connecting elements or the support components, i.e. the posts. The steel posts main aim is to keep the interception structure, the steel ropes and the energy dissipating devices in their design positions: hence, sustaining components are not designed to bear the impact load. However, the possibility of an impact on these structural elements exists and it is not negligible. For this reason, producers have recently started to perform internal tests to evaluate their products response to this load case. In this context, the Swiss company Geobrugg AG performed an impact test directly on the post with an incoming energy equal to 180 kJ, that represents the product SEL value. The test performed in Walenstadt (CH) test site, has shown the rockfall barrier ability to stop the block for the first impact.
This paper aims to develop a feasible numerical model of the structure and the impact. The model is calibrated through the back-analysis on the impact that occurred in the test site. Failure mechanisms and energy dissipation at the impact are discussed. The simulation also allows to estimate how energy dissipation is allocated among the components of the system.

Methodology

The numerical simulation is tailored on the experimental test by comparing the steel post deformed shape after the impact. Then, the model is used to estimate how different impacting positions and different ropes layouts influence the system performance. In this section the realised experimental impact test is presented, together with the developed numerical model.

As can be seen from Fig. 1(a), in the experimental test the impact has been produced at the midspan of an internal steel post. This structural element is connected at one end with the ground anchor by means of a steel plate, and at the other one with the upslope rope cables and the rockfall barrier longitudinal rope: these ropes represent for the post an external restraint, being activated in the impact occurrence. The steel post is constituted by a HEA 120 profile realised in steel S355. The impacting block is realised in concrete, following the EAD 340059-00-0106 (2018) requirements for standardised tests. During the test, no ruptures have been observed in the impactor, while severe plastic deformations have occurred in the steel post, as can be seen in Fig. 1(b).

Figure 1(a). SEL impact on a 500 kJ flexible rockfall barrier steel

Figure 1(b). Deformed steel post

The realised numerical model is a FEM one (Abaqus CAE, 2024 release), shown in Fig. 2(a). The impactor is modelled as a discrete rigid element while the steel post is modelled using three tied shell elements, for computational time saving purposes. The impactor velocity field is imposed on a vertical axis (Y axis) which passes at the midspan of the impacted post. However, this does not necessarily imply an exact midspan impact occurrence, and possible imperfections in the impactor position on the X axis (Fig. 2(a)) are considered.
The steel post material is steel S355: due to the severe plastic deformation which occurs on the structural element, both hardening phase and damage phase are included in the finite element modelling. In particular, a Cowper-Symonds power low is introduced in the model for the former and a Johnson-Cook damage model for the latter. Appropriate parameters for these laws have been taken from specific studies on the material S355 (Forni et al., 2016; Ribeiro et al., 2016). Since the experimental deformed shape shows a significant portion of energy dissipation occurring in the connecting element between the ground anchor and the steel post, this connection is introduced in the model. It is realized through a shell element which is hinged at one end to reproduce the connection between the steel post and the base plate. At the other end the connecting plate is tied to the post profile web: this is believed to be a good approximation of the real behaviour because the actual connection is realized by means of both bolting and welding. The connection between the sustaining ropes and the steel post is realized by modelling the actual post head shape and inserting the steel ropes in their position inside the assembly. The interaction between materials during the dynamic phenomenon occurrence is considered by means of a general contact approach, considering a friction coefficient for tangential behaviour equal to 0.4.
Both upslope and longitudinal ropes are modelled using an indefinite elastic steel, since plasticity is not expected to occur in these structural elements. To consider that in the real conditions the ropes react with their stiffness after an initial displacement (Escallón et al., 2014), an extra rope loop is modelled on all the steel ropes. The extra rope loop length applied to each steel rope depends on its length. Mesh attributes are chosen after a mesh dependency analysis.

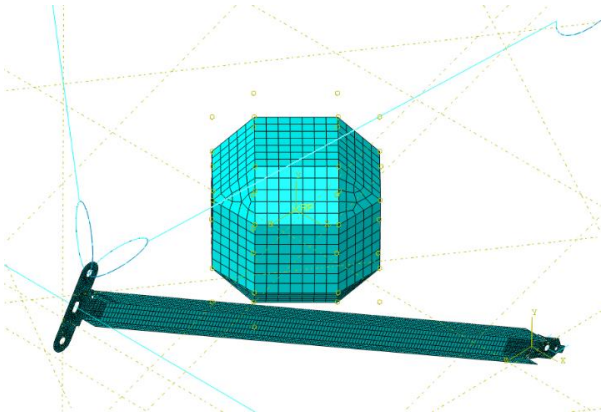

Figure 2(a). Numerical model of the impact

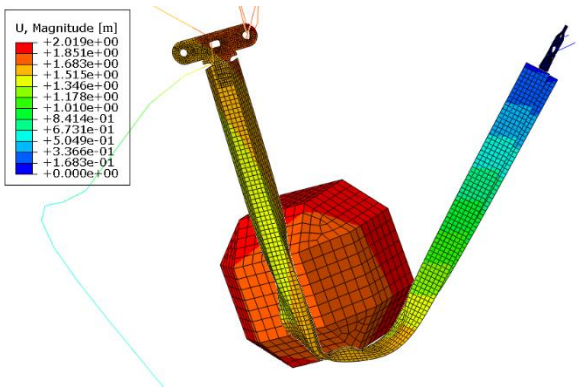

Figure 2(b). Deformed shape (t= 0.1 s)

Results

The impact numerical modelling confirms the suitability of the system to absorb at least one SEL event. The development of the plastic hinge shown in Fig. 1(b) is accurately reproduced in the model, as can be appreciated by the extraction of the deformed shape reported in Fig. 2(b). However, the rotation developed by this plastic hinge is strongly dependent on the introduction of X-axis imperfections in the impacting area (Fig. 3(a)) and on upslope and longitudinal ropes extra rope loop length (which is also dependent on the possible activation of energy dissipators). The experimental evidence of a significant energy dissipation occurrence in the base connecting plate and in the post head is confirmed by the model outcome (Fig. 3(b)).

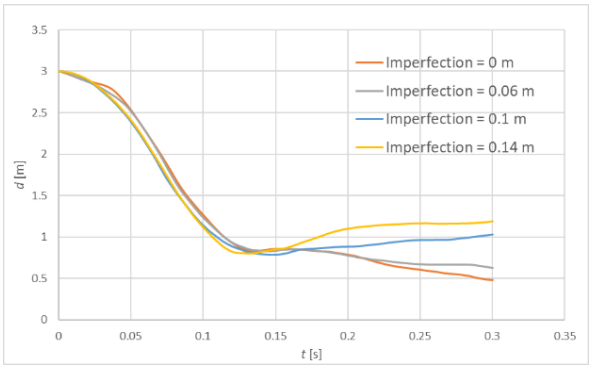

Figure 3(a). Distance between the post ends for various X-axis imperfections of the impact

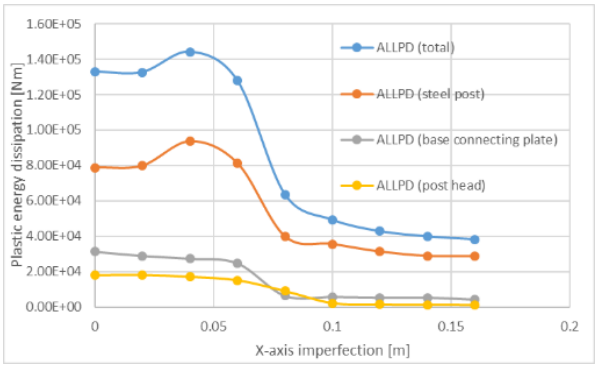

Figure 3(b). Plastic energy dissipation allocation: influence of the impact X-axis imperfection

Conclusion

The developed numerical model proved to be feasible to represent impact situations differing from the usual one, i.e. impacts directly on the posts of the system. The model can thus be used to evaluate the system efficiency in different loading conditions. In the modelled case, i.e. an impact with an energy equal to the SEL one, even if a large deformation of the post occurs, the barrier stops the block. It should be noted that the barrier ability to withstand impacts occurring on the posts is strictly related to the technology examined in this study. Thus, the result cannot be immediately extended to flexible rockfall barriers with different energy classes, and the model should be tailored for considering different technologies. Further refinements are currently under progress and include the detailed study of the effect that different impact positions and rope loose lengths have on the steel post energy absorption performance and the investigation on the contribution provided by the non-impacted steel posts.

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