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IMPACT OF ROCK FALLS AND ROCK SLIDES ON PROTECTIVE BARRIERS: COMPARATIVE CALCULATIONS USING DISTINCT ELEMENT METHOD (DEM)

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Dimensioning of protective barriers for falling rock represents a very important task to minimize risk to human life and infrastructure. Current approaches for the estimation of the dynamic impact of rock falls are providing static equivalent forces and are limited to the analyses of single block impacts (e.g. [1]). Two DEM-programs, PFC and UDEC of Itasca Consulting Group, have been used to analyze the different effects of action (max impact forces) from single rock fall compared to rock mass fall by means of simple numerical models. Moreover, the models have been used in order to get a better understanding of the mechanics of rock falls, rock mass falls and rock slides.

Keywords: rock fall, rock fall embankment, impact forces, rock mass fall, rock slide

INTRODUCTION

The estimation of the effects of action as a result of the dynamic impact of rock falls and rock slides is essential for the dimensioning of protective barriers, such as rock fall embankments. In order to realistically calculate impact forces, knowledge of the velocity, the incident angle and the mass of the rock fragment, as well as the interaction between rock fragment and embankment (penetration depths and damping) are of importance. Current approaches providing static equivalent forces are based on empirical relationships [1]. Those approaches are limited to the analyses of single block impacts; the dynamic impact of small rock mass falls or rock slides is not considered. In reality, dynamic impact is not always caused by single blocks, but often by (sliding or falling) fragmented rock mass.
Until now, there is no satisfying reference if and how the impact of rock mass differs from the impact of a single block. Using simple numerical models based on Distinct Element Method (DEM), the (significant) differences between the impact of a single block and the impact of fragmented rock mass have been analyzed and evaluated. For this purpose, the programs UDEC and PFC of Itasca Consulting Group have been applied.

ANALYSIS 1: SLIDING BLOCK VS. ROCK SLIDE

Objective of Analysis 1 was the estimation of the maximum impact force (both, dynamic and static) of a rock slide onto a protective barrier, depending on the number of blocks and their joint spacing. The DEM-codes UDEC and PFC (Itasca Consulting Group) have been applied using strongly idealized model geometry, as shown in Figure 1a. The sliding plane (bedrock) was chosen at a constant angle of 30° and the impact plane (stiff barrier) was defined perpendicular to the sliding plane, at all times (Fig. 1a). Comparative calculations have been conducted

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using rigid blocks, at which elastic and plastic deformations are represented by means of contact models. Elastic deformations were modeled by means of a linear contact model, whereas plastic deformations were simulated by means of an appropriate damping model, accordingly. With PFC, the viscous damping model was used, whereas with UDEC, the Rayleigh damping proportional to the joint stiffness was used for the simulation of the plastic deformations. The default local damping, proportional to acceleration, was deactivated for all kinds of block movements. The damping factors used for this comparison have been calibrated equal to a restitution coefficient of 0.2 by means of simulated drop tests.

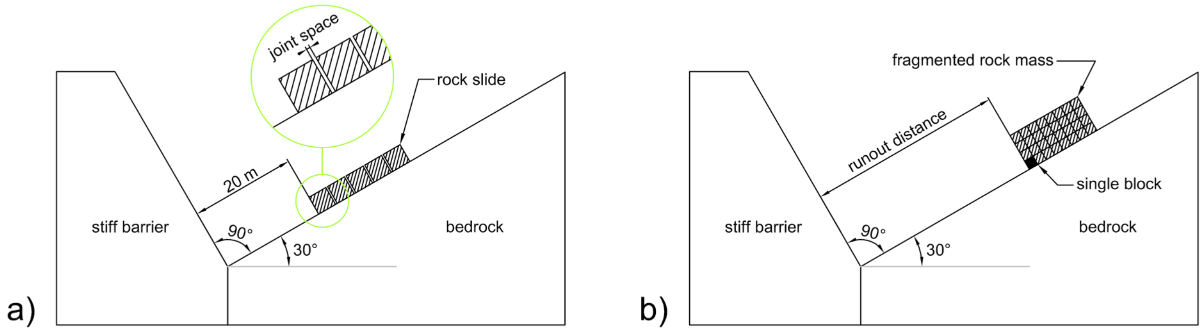

Figure 1: a) Model used for Analysis 1; b) Model used for Analysis 2

The initial state of the model is shown in Figure 1a. A chain of a given number of cubic shaped blocks of 1 m³ volume each was released at a constant distance of 20 m from a stiff barrier, which was placed perpendicular to the sliding plane. The number of modeled blocks was varied between 1 and 30 and the joint spacing between the adjoining blocks was varied between 0 and 20 mm. Figure 2 shows the relation of the maximum total impact force to the number of adjoining blocks of the rock slide.

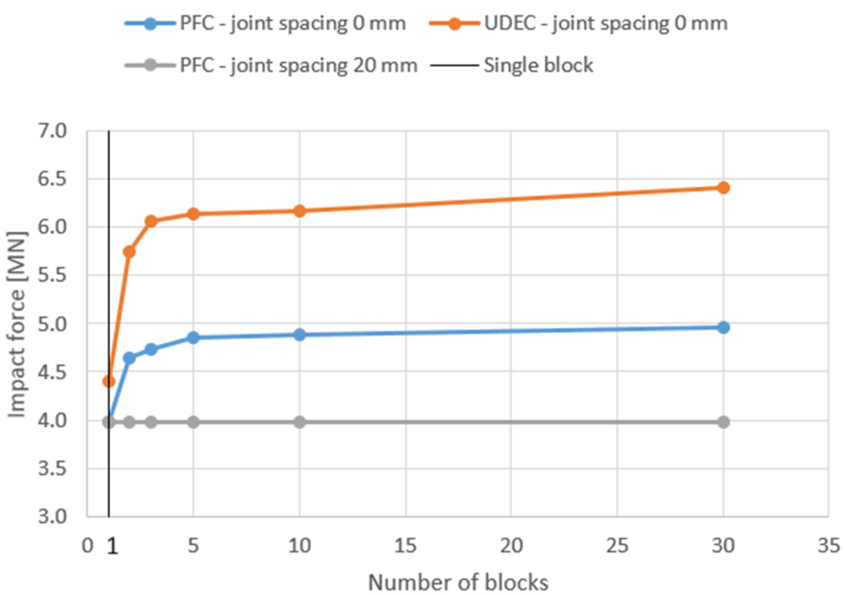

Figure 2: Maximum impact force vs number of blocks

For the case of directly adjoining blocks (joint spacing 0 mm) both, PFC and UDEC show an increase of the maximum impact force with an increasing number of blocks. However, the increase of the impact force is significantly high between the single block and the five-block-chain. With an increasing number of blocks beyond five the increase of the impact force is insignificant. For assemblies with a joint spacing greater than zero, the maximum impact force is identical to that of a single block. However, UDEC and PFC show slightly different results in terms of the amount of the max. impact force. The reason could be the different damping models used with PFC and UDEC. Both damping models have been calibrated by means of simulated drop tests, however, this procedure may not be sufficient for the calibration of the Rayleigh damping used with UDEC.

ANALYSIS 2: ROCK FALL VS. ROCK MASS FALL

Objective of Analysis 2 was the investigation of the ratio of the maximum impact force generated by rock mass fall to the maximum impact force generated by comparative single rock fall. The model setup used for the analysis is shown in Figure 1b. Both, the geometry and the damping and material parameters are as defined in Analysis 1. An assembly of discrete equally sized blocks was released at varying runout distances of 20 m, 50 m and 100 m from a stiff barrier. The number of released blocks was kept constant with 1000 blocks. The volume of the modeled equally sized blocks was varied between 0.1 and 10 m³.The black colored block in Figure 1b represents the block position, which was used for the comparative simulations of single rock fall.
Figure 3 shows the impact force ratio (ratio of the maximum impact force generated by rock mass fall to the maximum impact force generated by single rock fall) as a function of the block volume. Two extreme scenarios have been investigated in terms of rotational velocity, fixed spin and free spin.

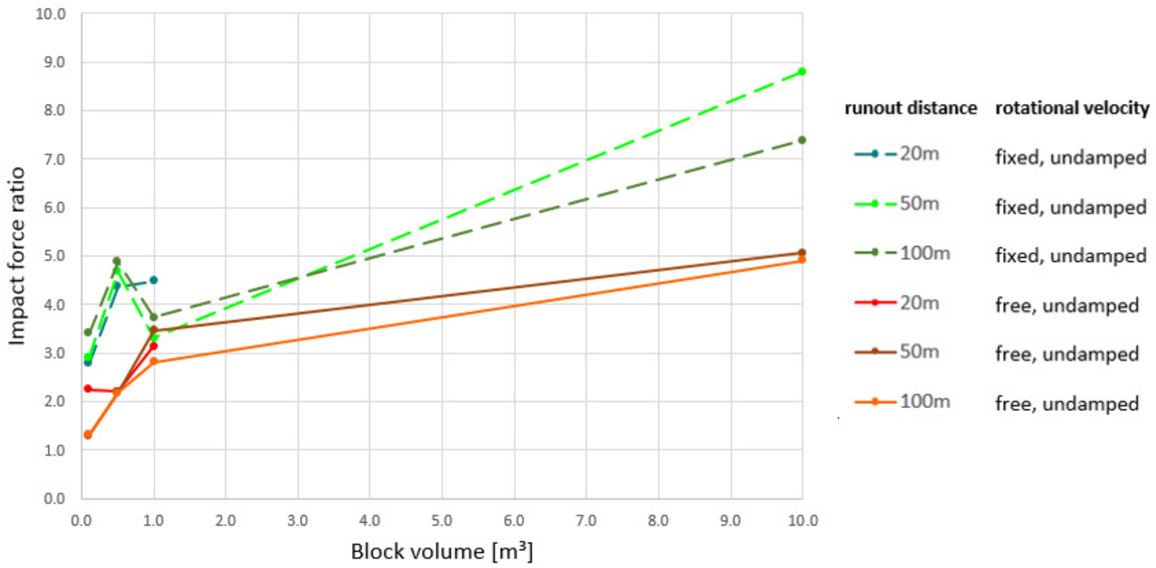

Figure 3: Ratio of the maximum impact force generated by single rock fall and rock mass fall (impact force ratio) for single block volumes of 0.1, 0.5, 1.0 and 10.0 m³.

The analysis shows a dependency of the calculated impact force ratio (rock mass fall / single rock fall) on the block volume and on the rotational damping (fixed spin and free spin). Compared to these parameters, the runout distance has minor influence on the impact force ratio.
Figure 4 shows the course of the impact force and the accumulated material at the barrier for a simulated rock mass fall with a single block volume of 1 m³ and a runout distance of 50 m (Fig. 1b).

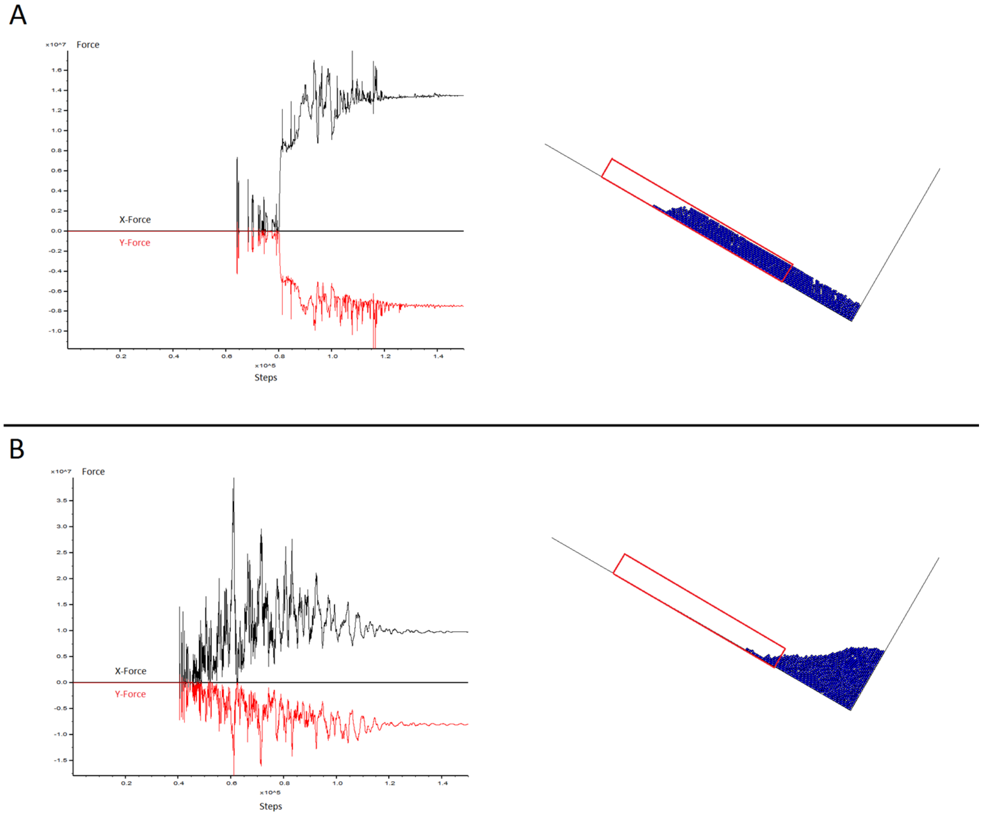

Figure 4: Impact force vs. calculation steps (left) and end position of the released blocks (right) for a runout distance of 50 m and a block volume of 1 m³. The red rectangle indicates the release position of the simulated 1000 rock blocks. A) rotational velocity fixed, B) rotational velocity free

CONCLUSIONS

This study provides first results of an extensive study with regards to the dynamic interaction of rock slide and rock fall onto protective barriers.
The results of Analysis 1 indicate that the front part (i.e. the first five blocks) of a rock slide generates 90-98% of the maximum impact force. The effect of the following sliding blocks (beyond five) is negligible. An explanation could be that the first few blocks, after their impact, are acting as a barrier themselves, taking up most impact force of the following blocks.
The results of Analysis 2 indicate that there is a relationship between single rock fall and rock mass fall, which predominantly depends on block volume and rotational damping.

REFERENCES

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