

Investigation on the Behavior of Rockfall Flexible Barriers by Numerical Simulation

Massoud Palassi and Sajjad Askar
School of Civil Eng, College of Eng. University of Tehran, Tehran, Iran



Challenges from North to South
Des défis du Nord au Sud

ABSTRACT

One of the commonly protective measures against rockfall in roads and railways is flexible barrier kits. In this paper, the finite element method is used to study the behavior of flexible rockfall barriers. The effect of various parameters such as angle of collision and location of impact on mesh and number of spans is investigated. It is noted that such analyses can be very useful in proper design of rockfall barriers.

RÉSUMÉ

Une des mesures de protection contre les chutes de pierres couramment utilisée dans les routes et les chemins de fer est un système de barrières souples. Dans cet article, la méthode des éléments finis est utilisée pour étudier le comportement des barrières pare-pierres souples. L'effet de divers paramètres, tels que l'angle de collision et l'emplacement de l'impact sur la barrière, ainsi que le nombre de travées est étudié. Il est à noter que ces analyses peuvent être très utiles pour une conception adéquate de barrières pare-pierres.

1 INTRODUCTION

Rockfall is a natural hazard that compared to other hazards usually impacts only small areas. However, the damage to the infrastructure or persons directly affected may be high with serious consequences. It is often experienced as a harmful event. Therefore, it is important to provide the best possible protection based on rigorous hazard and risk management methods. There is a large variety of structural protection measures against rockfall. These include natural protection by means of forests, semi-natural structures such as embankments and ditches and fully artificial structures such as fences, galleries or walls (Volkwein et al., 2011).

Rock slope instability and rockfall can occur due to various mechanisms. At one location shale may be eroding from the slope toe leaving a large overhang, whereas at another, closely jointed limestone may be loosening and ravelling as a result of freeze-thaw action. A rockfall hazard investigation in northern Ontario indicated a relatively high incidence of ravelling and toppling compared with sliding modes of instability. Ravelling appears to be at least twice as prevalent as a source of rockfall hazards. Of 211 hazard sites investigated, relative frequencies were: ravelling 25%; toppling 23%; overhang collapse 15%; ice jacking 14%; block rolling 11%; 2D sliding 8%; and 3D sliding 2% (Palassi and Franklin, 2000).

Flexible barriers are widely used for protection against rockfalls. They consist of a metallic cable net, kept upright by structural steel posts, with the function of intercepting and stopping falling blocks. Loads are transferred through special connecting elements to the relevant foundations. A key feature is that these structures are relatively light yet they can absorb rather high energy levels through the development of large elasto-plastic deformations of the system. This is achieved by the displacement of the cable net and the activation of energy dissipating devices, mounted on the connecting cables. The principal

advantage of using flexible barriers, in addition to their low environmental impact, is that they can be rapidly installed and easily maintained (Gottardi & Govoni, 2009).

A falling rock protection kit is usually made up of a minimum of three functional modules (i.e. at least three fields of principal nets and 4 posts), as illustrated in Figure 1. The main parts of a kit are: the interception structure which bears the direct block impact, the support structures which holds the interception structure in position and all the connecting components through which the loads are transferred to the foundations. Some field photos of flexible barriers are shown in Figure 2.

In this paper, the finite element method is used to study the behavior of this kind of barriers.

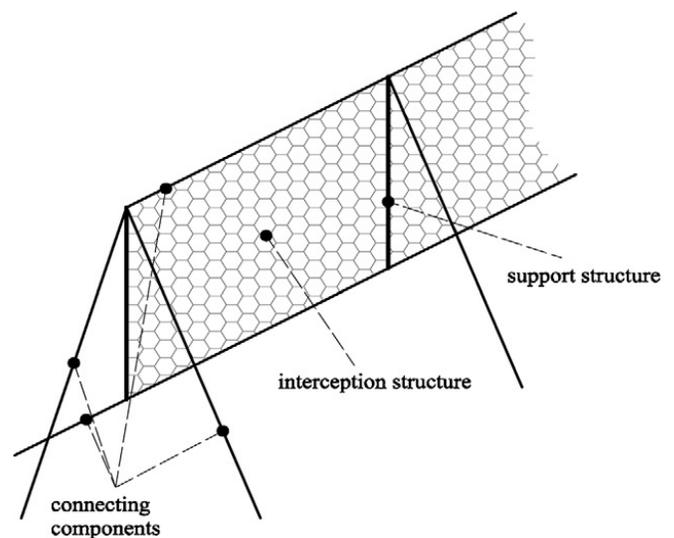


Figure 1. Components of a rockfall barrier kit



Figure 2. Photos of Rockfall barriers in the field

2 FINITE ELEMENT MODELLING

In this paper, modeling is carried out using ABAQUS. The flexible barrier contains a layer of mesh with square cells.

The elastic modulus of the mesh is taken as 200 GPa and their unit weight is assumed to be 7800 kg/m^3 .

The falling rock is assumed to have a unit weight of 3000 kg/m^3 , elastic modulus of 30 GPa and tensile yield strength of 1750 MPa. For the modeling of the posts, beam elements involving structural steel with unit weight

of 7800 kg/m^3 , elastic modulus of 200 GPa, Poisson's ratio of 0.3 and yield strength of 275 MPa is assumed. For modeling of the cables, 18 mm 6X36 wire ropes have been used. The behavior of the 18mm cables as reported by Escallón et al. (2014) is presented in Figure 3.

For loading of the protecting system, a translation velocity with horizontal and vertical components of 10m/sec is applied. The rotational velocity of the rock around its axis is taken as 25 rad/sec. Taking into the account the 300 kg mass of the falling rock, the total kinetic energy is 33.35 kJ.

The kinetic energy vs. time is presented in Figure 4. This figure shows that the reduction of kinetic energy is initially slow and then it speeds up. This means that the protection net has lower rigidity at the start and with the progress of rock the rigidity increases.

Figure 5 shows the magnitude of velocity and its components. From this figure, the stopping time of the falling rock can be determined which is estimated as 0.14 s. The elongation of the model is presented in Figure 6.

The maximum elongation is about 1.23 m and the rate of the increase of the elongation with time is almost linear. The maximum tensile stress in the elements of the mesh is about 1680 MPa at the time of 0.01 s (Figure 7).

In the model with three set of nets (Figure 8) the stopping time of the rock increases by 32% and reaches 0.184 s. the maximum elongation increases 9% and reaches 21.34 m. Also, the maximum stress in the elements of the mesh decreases to 1200 MPa (reduction of 30%). Figure 8 shows the deformation of the rockfall barrier at the time of stopping of the rock. In Figure 9 the forces in the in the lateral cables in the three span model is illustrated.

3 EFFECT OF COLLISION ANGLE AND COLLISION POINT

In the mail model, the angle of collision of the rock to the mesh is taken as 45 degrees with the horizontal. To investigate the effect of the angle of collision, the model is run with other angles; i.e., 0, 37 and 53 degrees measured with respect to the horizontal and the results are compared with the mail model (collision angle of 45 degrees). The ratio of maximum elongation of the mesh for different collision angles to the elongation with impact angle of 45, $S_m/S_m[45]$, is shown in Figure 10. According to this figure, by the increase of collision angle, the elongation of the mesh decreases as expected.

To evaluate the effect of collision point along the net, the model is run while the falling rock collides the mesh in one sixth of the mesh span. This process was carried out both for a rockfall barrier with single span (Figure 11) and a barrier with 3 spans (Figure 12). As shown in Figure 11, the post that is close to the collision point has failed while the other post has not reached failure point. In the barrier with three spans (4 posts) neither of the posts undergoes failure.

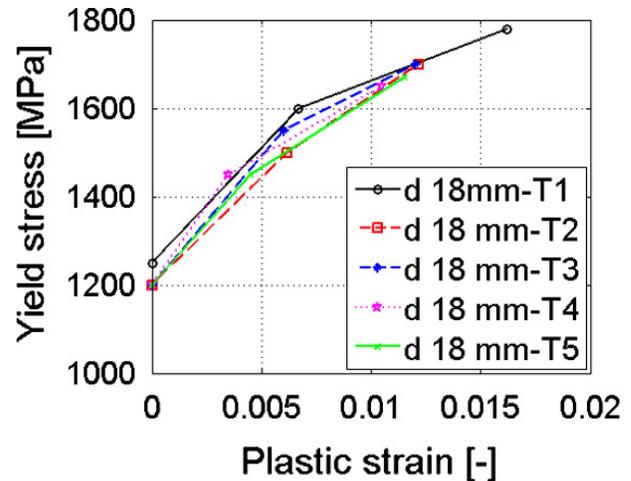


Figure 3. Yield stress vs. plastic strain for 18mm cables as reported by Escallón et al., 2014.

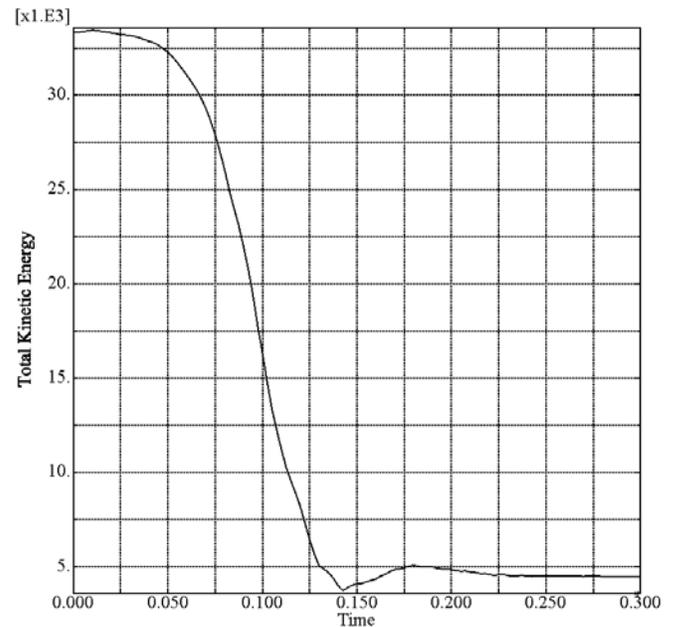


Figure 4. Kinetic energy of the rock vs. time

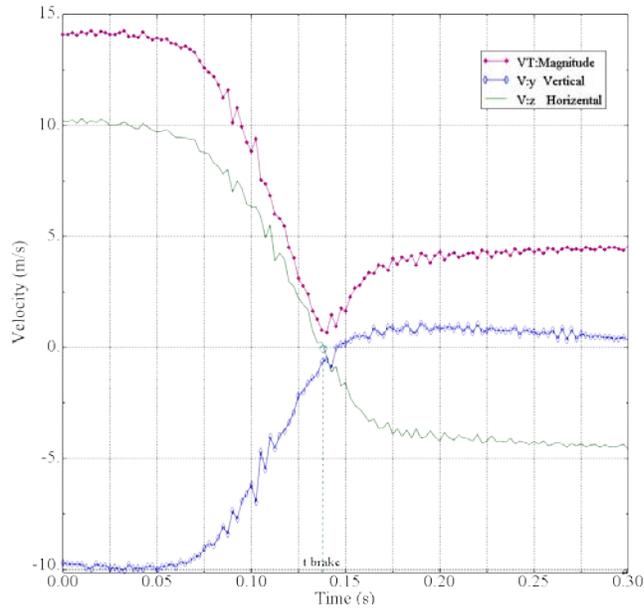


Figure 5. Velocity of rock vs. time

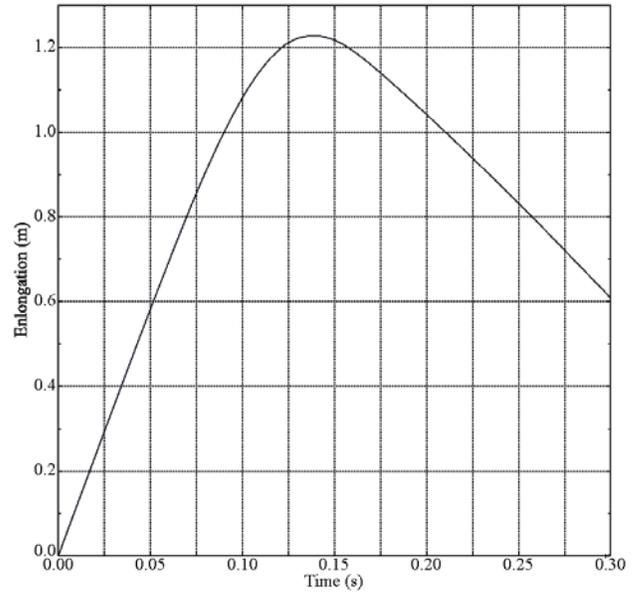


Figure 6. Elongation of the barrier with time

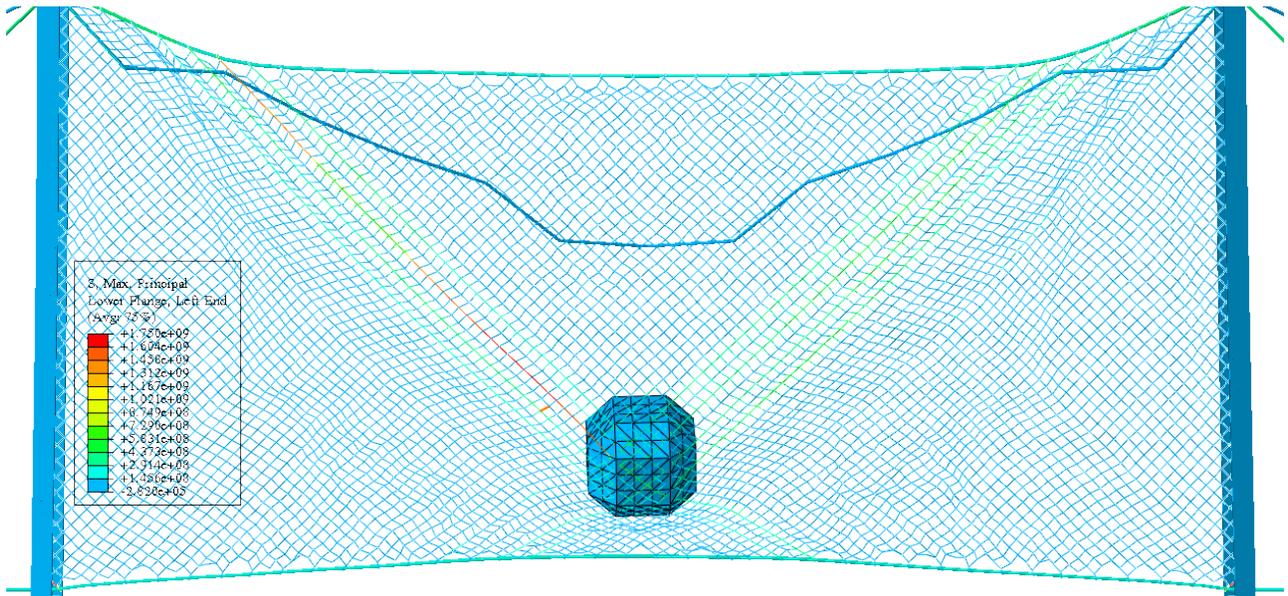


Figure 7. Distribution of the stress in the net at the time of 0.01sec

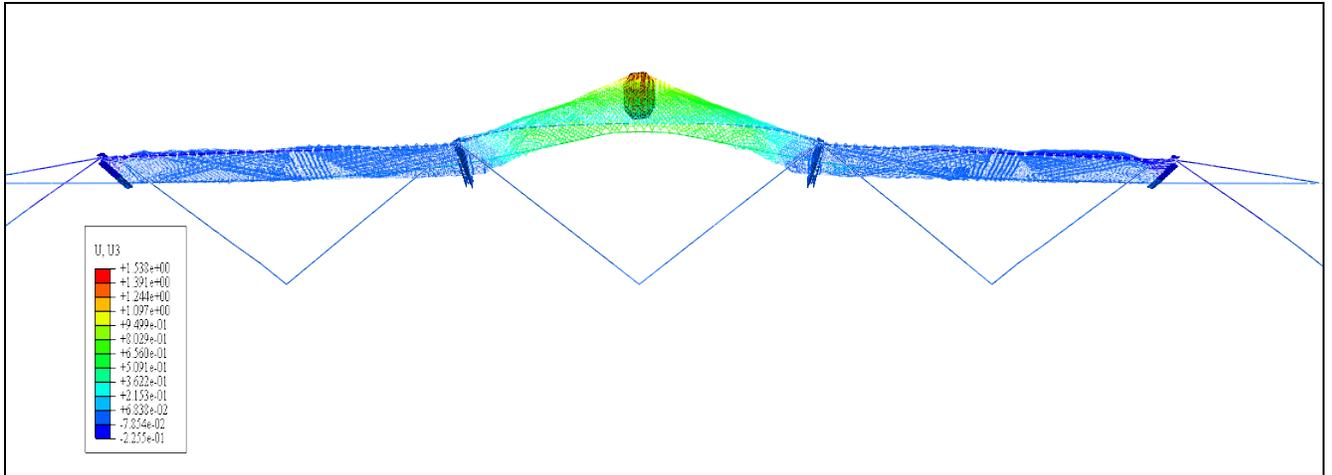


Figure 8. Deformation of the rockfall barrier at the time of stopping of the rock (view from the top)

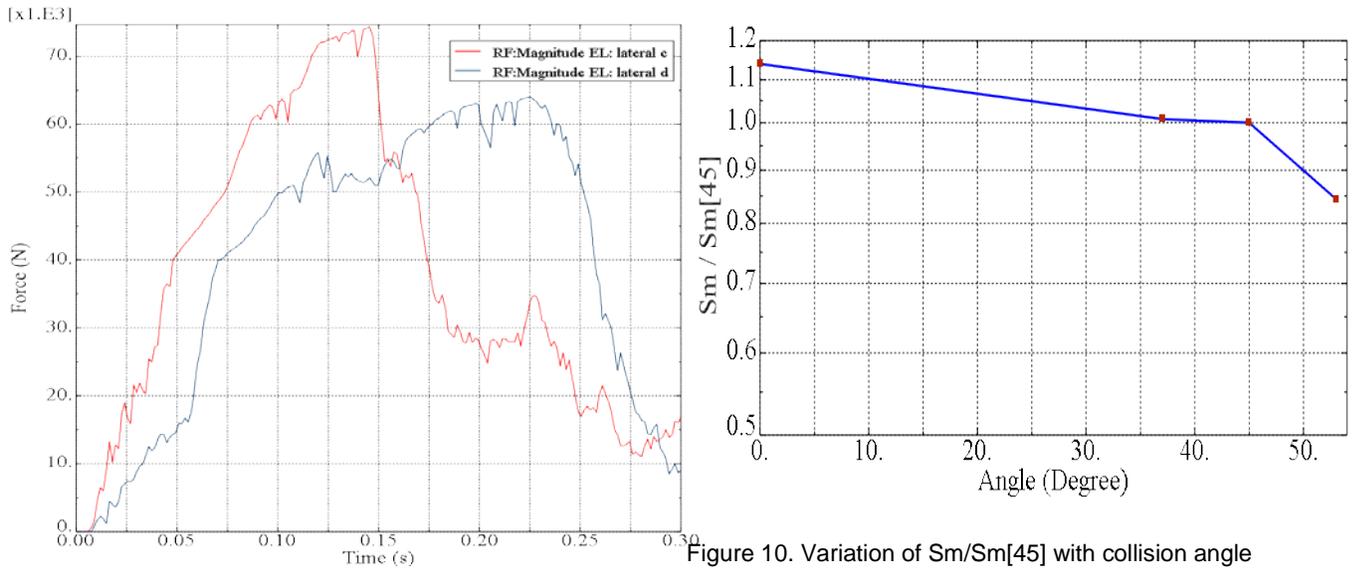


Figure 9. Forces in lateral cables in the three span model

Figure 10. Variation of $S_m/S_m[45]$ with collision angle

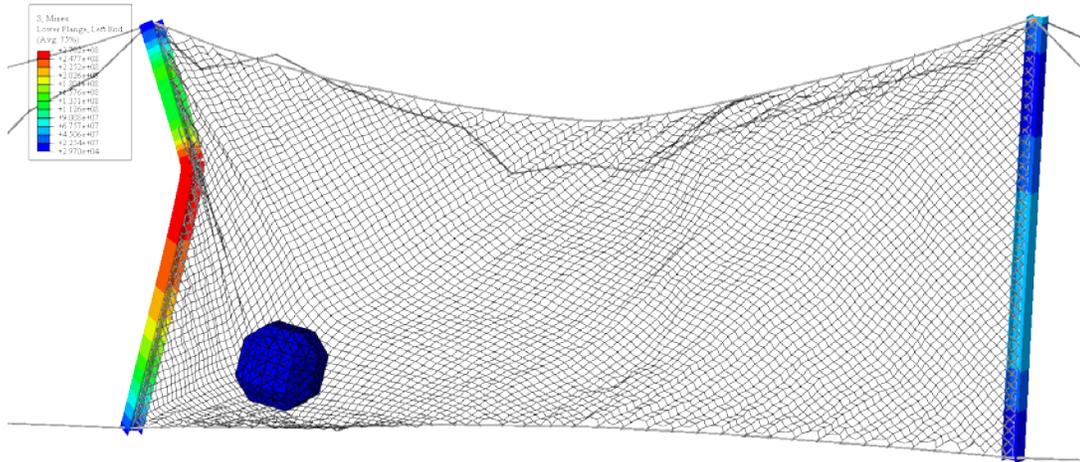


Figure 11. Deformation of the single span barrier system and stress distribution in the posts as a result of collision in one sixth of the span

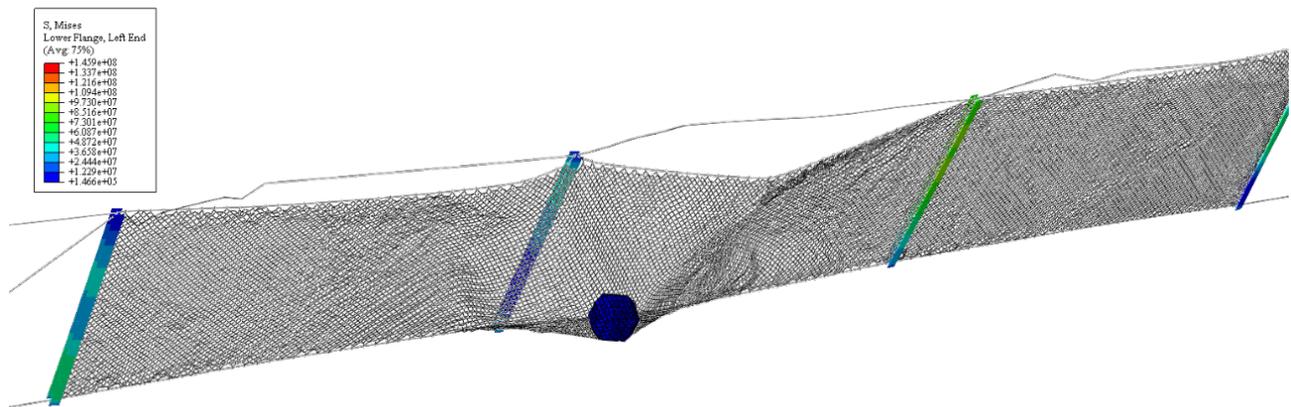


Figure 12. Deformation of the 3 span barrier system and stress distribution in the posts as a result of collision in one sixth of the span

4 CONCLUSIONS

In this paper, the finite element method was used to study the behavior of flexible rockfall barriers. The effect of various parameters such as angle of collision and location of impact on mesh and number of spans was investigated. Such analyses can shed some light on the proper and cost effective design of rockfall barriers.

ACKNOWLEDGEMENTS

The writers would like to thank the University of Tehran for its support in this research.

REFERENCES

Escallón, J.P., Wendeler, C., Chatzi, E. and Bartelt, P., 2014. Parameter identification of rockfall protection

barrier components through an inverse formulation. *Engineering Structures*, 77, pp.1–16.

Gentilini, C., Gottardi, G., Govani, L., Mentani, A. and Ubertini, F., 2013. Design of falling rock protection barriers using numerical models. *Engineering Structures*, 50, pp.96–106.

Gottardi, G. & Govani, L., 2009. Full-scale Modelling of Falling Rock Protection Barriers. *Rock Mech Rock Eng*, 43(3), pp.261–274.

Palassi, M. and Franklin, J.A., 2000. An expert system for evaluation and remediation of rockfall hazards in highway cuts. *CSCE 2000 Annual Conference*, 7-10 June 2000, pp. 426-432.

Volkwein, A., Schellenberg, K., Labiouse, V., Agliardi, F., Berger, F., Bourrier, F., Dorren, L.K.A., Gerber, W., and Jaboyedoff, M., 2011. Rockfall characterisation and structural protection – a review. *Natural Hazards and Earth System Science*, 11(9), pp.2617–2651.