Accounting for embankments in rockfall simulations

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ACCOUNTING FOR EMBANKMENTS IN ROCKFALL SIMULATIONS

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This study discusses some precautions to be taken when conducting 3D rockfall trajectory analyses while in the presence of a protective embankment. Trajectory simulations and small scale tests were conducted revealing limitations associated with block rebound models, DTM accuracy, and block shapes effects. These limitations are discussed and solutions for improving the simulations are provided.

Keywords: embankment, rebound model, spatial resolution,

CONTEXT

Rockfall propagation codes can be used to estimate the hazard reduction resulting from the building of embankments and to optimize the design of such structures with the aim of meeting a residual hazard target. In general, published studies pay a limited attention to the relevance of using available simulation tools in the presence of embankments [1]. Nevertheless, conducting rockfall simulations in such a situation may result in abnormal trajectories of the blocks after reaching the embankment (Fig. 1). These results were obtained with a 3D code that can be considered representative of available tools using a DTM modeled as a raster map (RockyFor3D in this case) [1]. After reaching the 5.5m high embankment with a mountain-side facing inclination of 70°, the blocks exhibit unrealistic trajectories with very high passing heights (Fig. 1). This was attributed to the rebound model and to the spatial resolution of the DTM. Besides, small scale tests have revealed that the risk of block bouncing or rolling over the embankment may be significantly different depending on the blocks shapes. This study addresses these three facets.

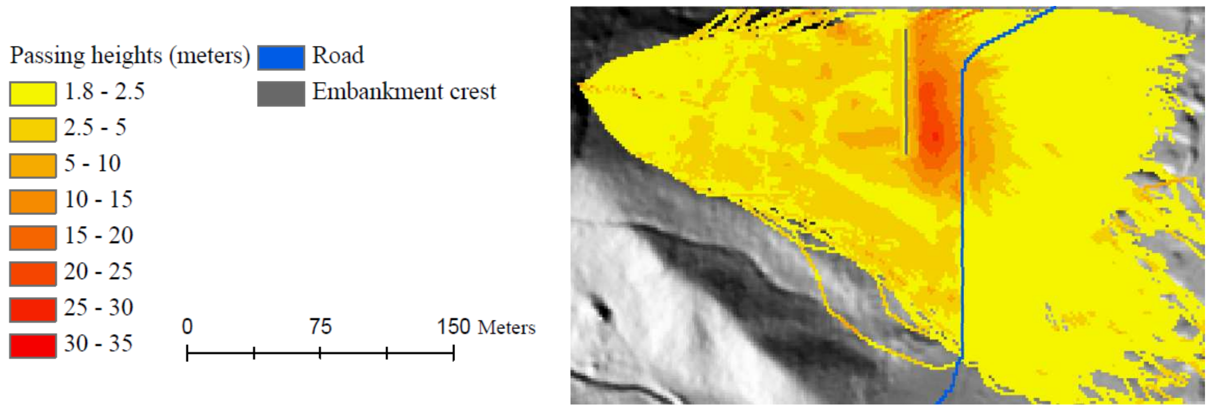

Fig. 1 3D rockfall simulation may result in abnormal block passing heights in the embankment vicinity

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REBOUND MODEL

Rebound models used in simulation codes have mainly been calibrated based on observations after real events or on tests in the lab both on rather steady slopes. The considered impact angles are shallow with typical average inclinations ranging from 0° to 45°. This significantly differs from impacts on the embankment facing or in the ditch (Fig. 2). For this reason, classical rebound models are unable to account for what happens in the ditch and on the embankment facing, rebound model calibrated for any incidence angle from shallow to normal impacts should be used to solve this problem (e.g. [3]).

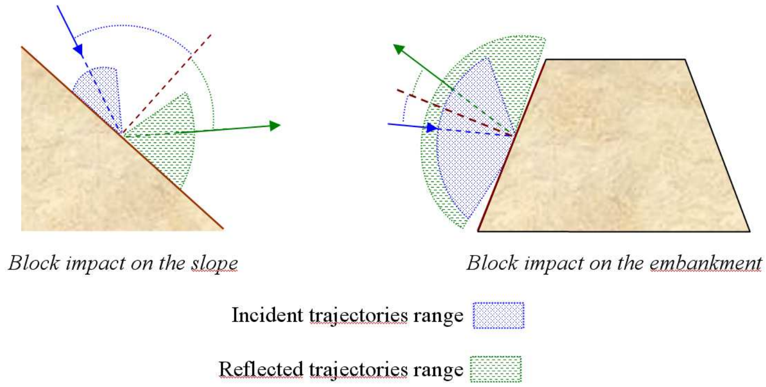

Fig. 2 Ranges of incident and reflected trajectories on the slope and on the embankment facing

DTM SPATIAL RESOLUTION

At the site scale, the resolution that is practically used ranges from 1 to 10 m. This resolution allows saving computation time while keeping the DTM resolution precise enough for obtaining good estimates of the run out distance without embankment, but is insufficient to satisfactorily reproduce the rapid changes observed in the embankment vicinity. The slope changes are smoothed in the DTM resulting in two detrimental effects: a reduced ditch width and a higher mountain-side embankment vertical batter. This would not be a problem using a TIN map, where resolution can be easily increased locally, or with a 2D code. But for 3D codes using a raster map, specific methodologies providing a more precise slope description in the embankment vicinity should be developed. For example it's possible to couple a model with a high resolution for modelling the trajectory in the embankment vicinity with a model with a lower resolution at the site scale (e.g. [2]).

Fig. 3 is an updated version of Fig. 1 after solving the rebound model and spatial resolution issues as suggested.

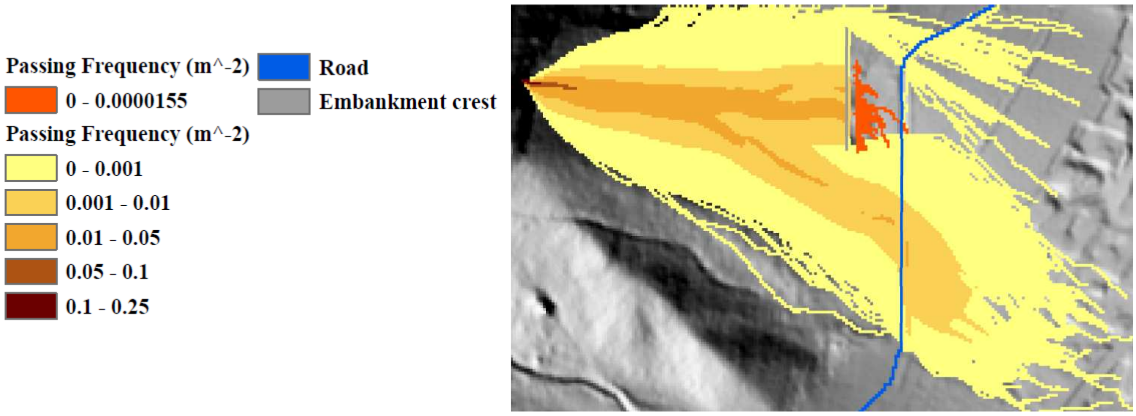

Fig. 3 Adopting a specific rebound model and coupling a high resolution DTM model in the embankment vicinity to a "normal" model at the site scale allows coping with the abnormal trajectories observed Fig. 1

BLOCK SHAPE

It is well known that the block shape strongly influences its trajectory on a slope [4]. Consequently, the velocity, spin and passing height of a block are expected to be different depending on its shape when it approaches the embankment. Fig. 4 shows the difference in trajectories observed from 150 small scale release tests involving blocks of different shapes (cube, sphere and parallelepiped with an aspect ratio of 2.5). The spherical blocks fall in the ditch before rolling towards the embankment and a significant ratio roll over the embankment. On the opposite, parallelepiped blocks either impact the ditch or the embankment but all are stopped. In particular, direct hits on the embankment facing result in high embankment penetration, leading to significant energy dissipation, contrary to spherical blocks. The trajectories of cubic blocks are intermediary between the previous ones. This shows that the block shape influences the block trajectory and its interaction with the ditch and embankment. This parameter should be accounted for, either considering blocks with real shapes or adopting specific rebound models (i.e. local slope modification) (e.g. [5]).

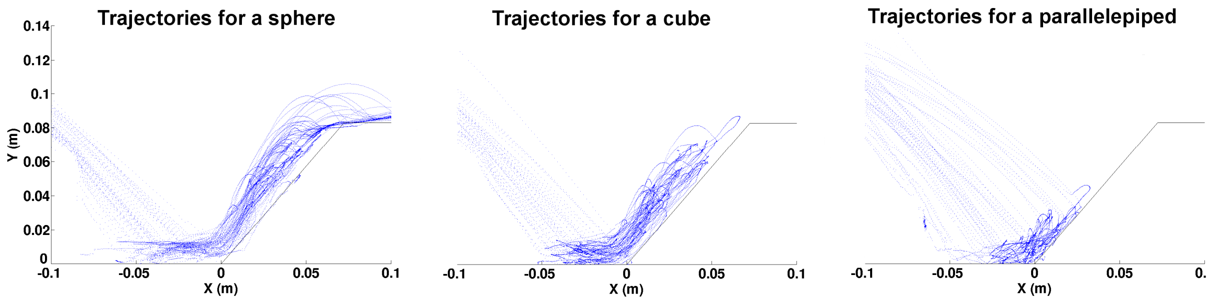

Fig. 4. The block trajectory in the embankment vicinity is strongly influenced by the rock shape

CONCLUSION

While embankments play a major role in reducing rockfall hazard, no study really addressed the relevancy of rockfall propagation codes in assessing the benefit derived from their construction in terms of residual hazard down the structure. This study has evidenced limitations due to the DTM spatial resolution, the rebound model and the block shape. Methods for solving these problems have been proposed and proved efficient.

REFERENCES

[1] LAMBERT, S., F., BOURRIER (2013) Design of rockfall protection embankments: a review. Engineering geology, Vol. 154 (28), p. 77-88.

[2] LAMBERT, S., BOURRIER, F. and D. TOE (2013) Improving three-dimensional rockfall trajectory simulation codes for assessing the efficiency of protective embankments. International Journal of Rock Mechanics and Mining Sciences, Vol. 60, p. 26-36.

[3] BOURRIER, F., ECKERT, N., NICOT, F., and F. DARVE (2009) Bayesian stochastic modeling of a spherical rock bouncing on a coarse soil. NHESS, Vol. 9, p.831–46.

[4] DORREN, L.K.A., DOMAAS, U., KRONHOLM, K., and V. LABIOUSE (2011) Methods for predicting rockfall trajectories and run-out zones. In: S. Lambert & F. Nicot (eds.). Rockfall engineering. ISTE Ltd. / John Wiley & Sons Inc.: pp. 143 - 173.

[5] TOE, D., LAMBERT, S., BOURRIER, F. and F. Berger (2013) Improving rebound models in 3D rockfall simulation codes used for the design of protection embankments. 8-th International Symposium on Impact Engineering (ISIE2013), Osaka, Japan, 2-4 sept.