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SIMULATIONS OF UNDERGROUND STRUCTURES SUBJECTED TO DYNAMIC LOADING USING THE DISTINCT ELEMENT METHOD

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ABSTRACT We present results from an investigation into the stability of underground structures in response to explosive loading. Field tests indicate that structural response can be dominated by the effect of preexisting fractures and faults in the rock mass. Consequently, accurate models of underground structures must take into account plastic deformations across fractures and not simply within the intact portions of the rock mass. The distinct element method (DEM) is naturally suited to simulating such systems because it can explicitly accommodate the blocky nature of natural rock masses. We will discuss details specific to our implementation of the DEM and summarize recent results.

INTRODUCTION: Continuum mesh based methods have been applied successfully to many problems in geophysics. Even if the geology includes fractures and faults, when sufficiently large length scales are considered a continuum approximation can be sufficient. Using this approach, the response of field-scale rock masses can be modeled using standard elastic-plastic continuum equations. However, for problems where the structures of interest have sizes comparable with the block size, individual rock discontinuities must be taken into account. In addition, it is possible that while the structure may experience loads that do no measurable damage to individual blocks, deformation along the discontinuities may lead to structural failure (see Fig. 1). We have developed a distinct element capability for simulating the deformation within both the intact rock and across the rock joints [Morris et al 2004].

Fig.1 The blocky nature of the rock mass is evident in the collapse of this cavern in Tuff.

PROCEDURES, RESTULTS AND DISCUSSION: The Livermore Distinct Element Code (LDEC) has been used to simulate the response of underground tunnels to dynamics loading [Morris et al. 2004]. In practice the extent of the facility considered is limited by the computational effort required to simulate the necessary number of rock blocks. We recently performed a series of simulations on the "Thunder" supercomputer at Lawrence Livermore National Laboratory. This allowed us to consider models of greater size and complexity than had previously been possible. Our solution domain spanned 60m in each direction and encapsulated a generic facility which included several tunnel sections and a lift shaft (see Fig. 2).

Several geologic models were considered as part of this study. In particular, the behavior of regular, persistent joints was compared with the effect of non-persistent randomized joints. In both cases discussed here, the joint patterns resulted in typical block sizes of 30cm. Consequently each model contained approximately 8 million individual rock blocks, making these the largest simulations of its type performed to date. The facilities were subjected to loading corresponding to one kiloton at the surface 50m above.

The results obtained for the regular, persistent joint set and irregular, non-persistent model differed in several key ways:

1. The regular model exhibited strong anisotropy. Since the joints are weak under shear loading, the regular, persistent joint sets tend to channel the waveform, resulting in variations in wavespeed with direction of propagation.
2. The irregular model exhibited higher attenuation. Again, because the joints are weak under shear loading, the irregular joint structure results in more plastic deformation on the joints and, consequently, more attenuation.
3. Persistent joints allow shear motion along the entire length of the computational domain, resulting in large "chimney" effects above collapsed tunnels sections.
4. The irregular model resulted in more diffraction of waves around cavities in the rock mass.

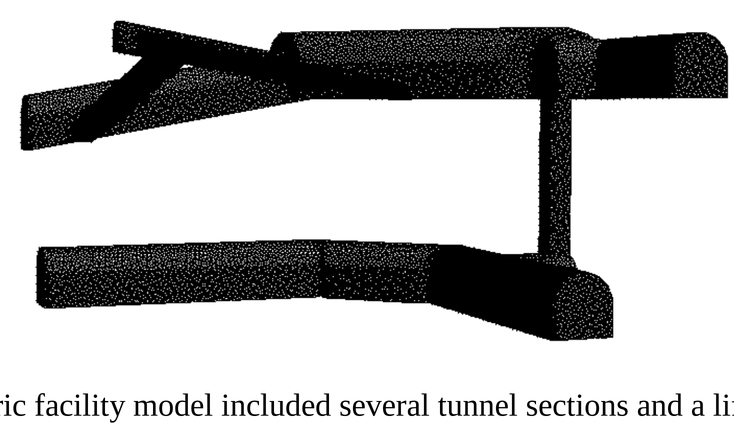

Fig.2 The generic facility model included several tunnel sections and a lift shaft.

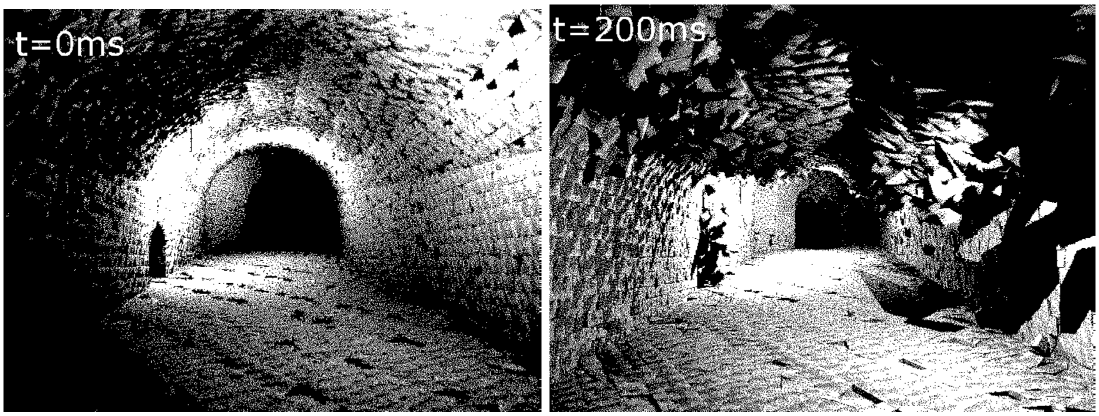

Fig.3 The simulation predicts that this large room within the facility would completely collapse under the applied loading.

Fig. 3 shows two snapshots of the collapse of the largest room within the facility from the irregular, non-persistent joint set simulation. Our presentation and extended paper will show more detail from other locations within the facility. In summary:

1. The largest room within the facility is totally collapsed.
2. The narrowest access tunnels experience minimal damage.
3. The midsize tunnels show a range of damage, with most damage occurring in tunnel sections containing a junction with another tunnel or lift shaft. This is consistent with the tunnel junction compromising the tunnel strength.

CONCLUSIONS: The Livermore Distinct Element Code (LDEC) has simulated the response of large-scale facilities to dynamic loading. Such large scale studies allow us to investigate the interaction between different parts of the facility. Results obtained highlight the importance of including realistic, irregular, non-persistent joint sets.

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