Modelling rock blast fragmentation with discontinuities and fully coupled gas pressure

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Background: The most efficient process to break hard rock and liberate minerals for mining and quarrying and to create underground space is through blasting with explosives (Fig. 1). The process is extremely complex and blast design is largely informed by empirical equations such as the Kuz-Ram fragmentation model that predicts the broken fragment size distribution from general properties of the rock mass and the explosive characteristics and blast hole layout and timing\(^1\). The Holy Grail is to customise the blast design to achieve the ideal fragmentation size distribution to optimise downstream process costs, reduce unwanted very fine particles. A new generation of discontinuous computational approaches that combine finite and discrete element methods (FEMDEM) can capture dynamic fracture propagation and fragmentation\(^2\). The breakthrough to progress in modelling rock blasting occurred in recent weeks with the development of our two-way coupled Solidity/Fluidity technology and proof-of-concept-results by student Pan Yang\(^3\), (see Fig. 2). The initial impulse, stress wave propagation and gas effect is modelled.

Fig. 1 Typical quarry rock blast

Fig. 2 Coupled FEMDEM/Multiphase CFD blasting model: Initial detonation pressure generates local pulverisation away from the blast hole wall while compressive stress waves propagate outwards generating some key radial cracks. The compressive wave reflects at the free boundaries and tensile stresses form slabbing cracks. The next stage is dominated by the gas pressure heaving the rock fragments outwards with pressure reducing as gas expands and escapes. Note we can distinguish all new fractures formed by tensile (blue) or by shear failure (red). Environmentally interesting phenomena such as air blast, vibrations and fly rock are also captured. The final figure shows colours representing the fragment velocity.
Methods: This project will both further develop these modelling techniques in the context of rock mass properties and blasting models that take into account the effects of the initial discontinuities which can act as reflecting boundaries, see for example Fig. 3. The student will:

i. Familiarise themselves with the use of the coupled codes;
ii. Study the theory behind rock fragmentation by blasting and empirical tools used in industry;
iii. Research the extent to which our Solidity code can capture realistic stress wave propagation and reflection with idealised pre-existing fractures, improve the model and extend to representative systems;
iv. Consider the relationship between 2D and 3D simulation models;
v. Explore the energy partitioning associated with the blasting process;
vi. Develop mechanistic models for fragmentation size distribution prediction;
vii. Keep an open mind to making new discoveries as, to date, very little scientific study has been done with fully coupled generic tools.

Fig 3. Solidity models heterogeneous stresses in rock with DFNs (tunnel collapse left) or outcrop fracture patterns (right)

Outcomes: The research programme will be driven by scientific questioning while it clearly has huge potential to impact mining methods. This is because the models are world-leading in their capability to evaluate blasting using sound mechanistic models that capture the key stages and processes through to state of rest of the blast pile. Fragmentation results can be obtained for a very large parameter space of uncontrollable variables (rock mass properties, intact strength, in-situ block size distribution) and design parameters controllable by the blast engineer: detonation strength, timings, blasthole location, size and spacing etc. To assist validation, we have excellent collaborations with blasting research teams in China, Canada and UK quarry and mining companies.

Training: The successful candidate will join a dynamic research group with world-class expertise in modelling geomechanics of fractured rock masses with FEMDEM and CFD numerical methods. You will be trained in our state-of-the-art software, Solidity and coupled Solidity/Fluidity for simulating blasting and in high-performance computing. You will have an opportunity to develop your career and profile by presenting at international conferences and publishing in high impact journals. You should have a good mathematical background and a good degree/diploma in an appropriate field such as earth science, physics, mathematics, computer science or engineering. Good written and spoken communication skills are essential.

References:

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