Evaluation of Hybrid Stress Blasting Model (HSBM)

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Abstract

The HSBM is a state of the art 3D blasting model capable of modelling detonation, shockwaves, fragmentation and blast movement. The HSBM project is managed by the SMI, University of Queensland. The HSBM is an interconnected package of programs including Blo-Up from the Itasca company, Vixen detonation models (Braithwaite and Sharpe), JKSimBlast and JointStats from the JKMRC. The project is supported by nine companies with mining and explosive interests including Rio Tinto.

The ability to predict blasting outcomes is very valuable as blasts can be designed using the mine-to-mill concept, increasing the efficiency of the entire mining process. The HSBM evaluation was undertaken to provide Rio Tinto with objective testing of the model in order to gain an understanding of the HSBM's current capabilities and limitations. The major limitation of the HSBM is that only small scale blasts can be solved in reasonable timeframes, thus it currently does not have an application in prediction of production blasts. The gas model in HSBM does not appear to produce the expected results, though rock discontinuities are well represented.

Though this document focuses on current model limitations it should be noted that the HSBM project has broadened the understanding of numerical blast modelling and provided many beneficial findings to project sponsors.

1. Introduction

Rio Tinto is a continuing sponsor of the Hybrid Stress Blasting Model (HSBM). The HSBM offers the possibility of accurately simulating blast designs using numerical modelling. Blast designs can be theoretically assessed pre-blast to ensure optimal blast outcomes. The guess work of blast design can be removed, resulting in increased mine efficiency thus a subsequent reduction in mining costs.

Rio Tinto has not had a large influence on the coding of the model, hence an understanding of the limitations of the model is lacking within the group. Rio Tinto is seeking some objective testing of the HSBM software. This CEED project will comprehensively analyse the HSBM software using the January 2009 version (Blo-Up2.04). The CEED project will discover current model limitations and its applicability to Rio Tinto.

1.1 Empirical Fragmentation Models

To date the majority of fragmentation prediction software are based on empirical models. The Kuz-Ram model, developed by Cunningham (1987) is one such model. Cunningham combined the Kuznetsov and Rosin-Rammler equations as well as his own algorithm. It is generally accepted that the Kuz-Ram model is inaccurate in predicting fines. Since its creation the Kuz-Ram model has been surpassed in accuracy by other fragmentation models. However, the simplicity of the Kuz-Ram model along with its tolerable accuracy still sees it widely used in fragmentation prediction of production blasting.

The HSBM gives the possibility of addressing some of the limitations of empirical models, such as inaccurate fines predictions, and lack of the representation of inter-hole blast timing.

1.2 HSBM Theory

The following section will provide some basic information regarding the HSBM. More comprehensive explanations can be found in Ruest *et al* (2006), Onederra *et al* (2007) and Cundall (2008).

The HSBM dynamically links the Vixen ideal and non-ideal detonation codes (Braithwaite and Sharpe) to a geomechanical rock model (Onederra, *et al* 2007). The rock model is comprised of two regions, the near field region modelled using a continuum grid, while the main rock body is modelled using a discrete spring/node lattice system (Cundall, 2008).

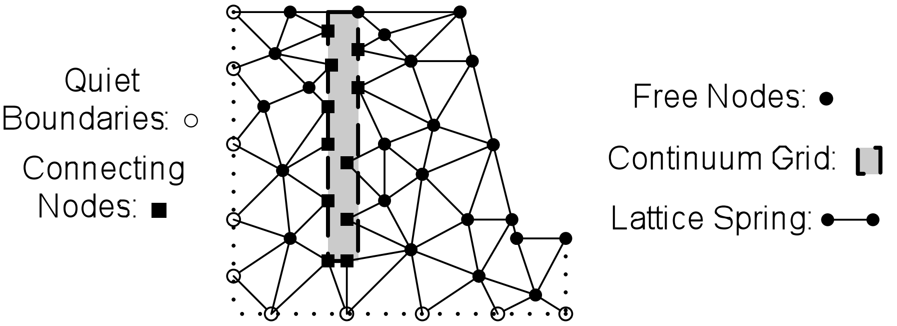

Figure 1: 2D Schematic showing the lattice and the connection to the continuum grid.

The lattice displacement can be solved by applying Newton's Second Law at each node. Unbalanced forces are composed of spring and viscous damping forces. Damping is required to reproduce the attenuation observed in real rock. Using a central difference approximation for acceleration the nodal locations can be found for each time step.

The flow of gas through individual micro cracks is not represented explicitly; however larger scale macro-crack's are used as an approximation improving computational time (Onederra, *et al* 2007). Macro-cracks are used to replace six or more micro-cracks within a given volume. The formation of a macro-crack will lead to additional nodal forces due to the high pressure gasses that would occupy this space. The gas logic will deactivate when nodal separations exceeds an inbuilt tolerance.

Several boundary conditions are available in HSBM; the two most applicable to this project are free surfaces and quiet boundaries. Free surfaces allow the reflection of stress waves, while quiet boundaries model continuous rock and allow transmission of stress waves.

Joints are geological *in situ* fracture planes that are common in many rock types. These geological features have a significant influence on fragmentation and movement. The HSBM has modelled these joint planes to conform to Itasca's Smooth Joint Model (SJM). The SJM alters the direction of forces between nodes along a joint plane. The resultant shearing is more accurate as the "bumpy road" behaviour of particle models is overcome (Cundall *et al*, 2007).

2. Methodology

The HSBM has incorporated several state of the art features that require testing. Such features are gas logic, non-ideal explosive modelling, rock discontinuities and muckpile formation. All simulations have been completed using the January release Blo-Up2.04. Three major studies have been conducted, these being a sensitivity analysis, blast movement testing, and joint testing.

2.1 Sensitivity Analysis

A sensitivity analysis was completed in order to evaluate the behaviour and robustness of the HSBM. Eight simulations were completed varying the parameters: model resolution, rock type, explosive type (ideal vs. non-ideal detonation model), and gas logic. By comparing the outcomes of each simulation the effect of each parameter can be quantified. Simulations were completed on a dual-core 2.2GHz laptop with 2Gb RAM running Windows Vista.

SIM #	Model Resolution (cm)	Rock Type	Explosive Type	Gas Logic Used	Number of Nodes
1	10	Test	Non ideal	yes	342000
2	10	Test	**Ideal**	yes	342000
3	10	Test	Non ideal	**no**	342000
4	10	**Dolomite**	Non ideal	yes	342000
5	**8**	Test	Non ideal	yes	668000
6	10	Test	**Ideal**	**no**	342000
7	10	**Dolomite**	Non ideal	**no**	342000
8	**8**	Test	Non ideal	**no**	668000

Table 1: Plan for Simulation Set 1 (Test Rock is USC200 Quartzite).

Simulations were completed with one explosive column and a basic bench geometry that follows basic bench design theory (Dight, 2009). The blast was designed to under-confine the explosive to result in significant fragmentation and blast movement.

2.2 Blast Movement

In order to confirm results from the sensitivity analysis it was decided to reproduce the unpublished work by others Ruest (2009). In this work blasts in 3m concrete cubes were monitored for use in HSBM calibration. The aim was to benchmark Blo-Up2.04 against other versions, and to take their analysis further in terms of blast movement.

The refined model (spring size = 2.5cm) resulted in a model with 2.14 million nodes. The 32bit version of Blo-Up2.04 was not capable of building a model of this size. Thus the simulations were completed on a quad-core machine running 64bit Windows XP with 4GB of RAM. Simulation to 1ms took approximately 30 minutes.

2.3 Joints

Testing of the HSBM's joint model is required for a complete analysis. Joints are geological discontinuities which are planes of weakness, therefore they will reflect stress waves, provide paths for gas venting, and affect the explosive confinement. As a result there are expected outcomes from each joint orientation in terms of fragmentation and blast movement.

Four basic joint orientations (θ = 0°, 60°, 90°, 120°) have been simulated. The blast geometry is similar to that described in section 2.1. Simulations were run until 300ms after detonation.

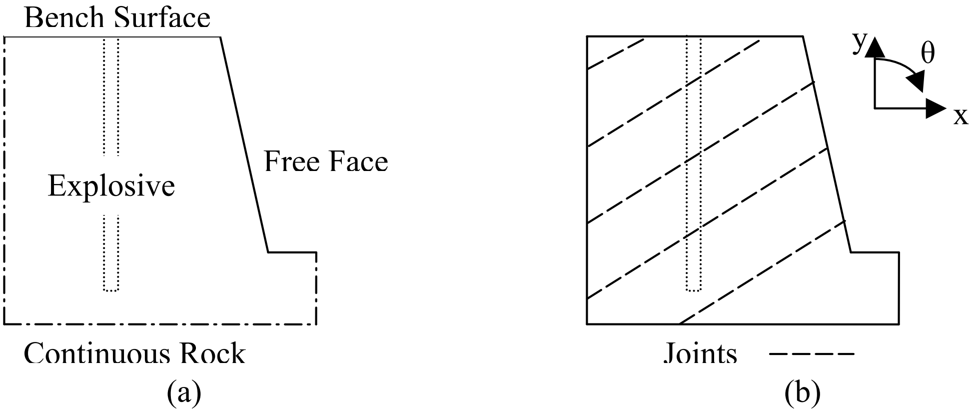

Figure 2: Schematic of model boundaries (a) and joint orientation angle θ (θ=30° shown) (b).

3. Findings and Discussion

3.1 Sensitivity Analysis

Simulations have been compared using the Blo-Up2.04 outputs: nodal velocities, explosive pressures, cumulative fragmentation curves, gas cell plots and fragmentation screenshots.

The findings of the sensitivity analysis have been briefly summarised below;

- The current version does not have non-ideal explosive modelling capabilities.
- Material type is well represented in the model.
- The coding that controls gas logic duration is flawed, and is highly sensitive to model resolution.
- Gas logic acts to increase individual particle velocities, and provide a step increase in velocity (Onederra, *et al* 2007) but its effect on movement as a whole is unclear.
- Initial fragmentation appears to be well modelled, though lacking radial fractures.
- There is possibly a bug or current limitation that hinders muckpile formation, or the model damping is too high and causes the model to come to rest. Blast movement appeared static during times 50 – 500ms. The model is possibly over-confined due to lack of rock discontinuities, making blast rules of thumb (Dight, 2009) invalid.
- An erratic response is produced in the stemming region during the periods 0 – 0.1ms.
- Reducing the resolution (spring size) from 10cm to 8cm nearly doubled the number of nodes, increasing the computational time by more than twice.
- The shockwave is independent of model resolution. The magnitude of nodal velocities are similar at early times. After approximately 1ms nodal displacements begin to vary due to the differing lattice geometry.
- Fragmentation is affected significantly by model resolution, as fracture toughness is dependent on model resolution (Potyondy, 2004).
- The majority of fragmentation in the HSBM occurs in the first 4ms as shown by cumulative fragmentation curves exported at different times.

The above findings outline some possible problems and/or bugs in Blo-Up2.04. These may have been rectified in more recent HSBM releases. The time taken to run a simulation is highly dependent on resolution, and it is not practical to model production scale blasts due to time limitations.

3.2 Blast Movement

Using the unpublished work of Ruest (2009) the blast movement 100ms after detonation showed promising results. The direction of blast movement shown in figure 3(a) closely matches that reported. However, the degree of fragmentation within the burden relief is far smaller, and the significant radial fracturing seen in field tests was absent (Ruest, 2009).

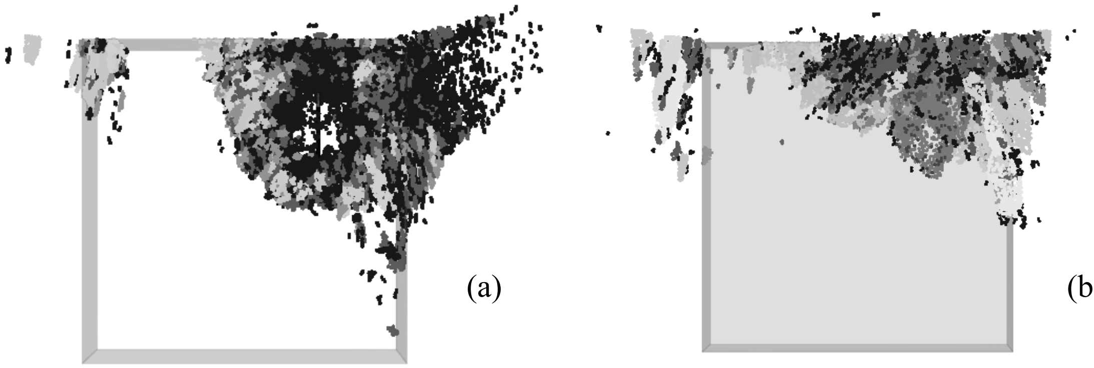

Figure 3: Fragmentation at 100ms after detonation, borehole plane (a) and side plane (b).

In Comparison with Ruest (2009) the fragmentation along adjacent walls shown in figure 3 (b) is reasonable. A major difference is the significant fragmentation at the rear of the cube. Back breakage was not observed in the tests, which is possibly due to the fixed base assumption, or in tact rock approximation.

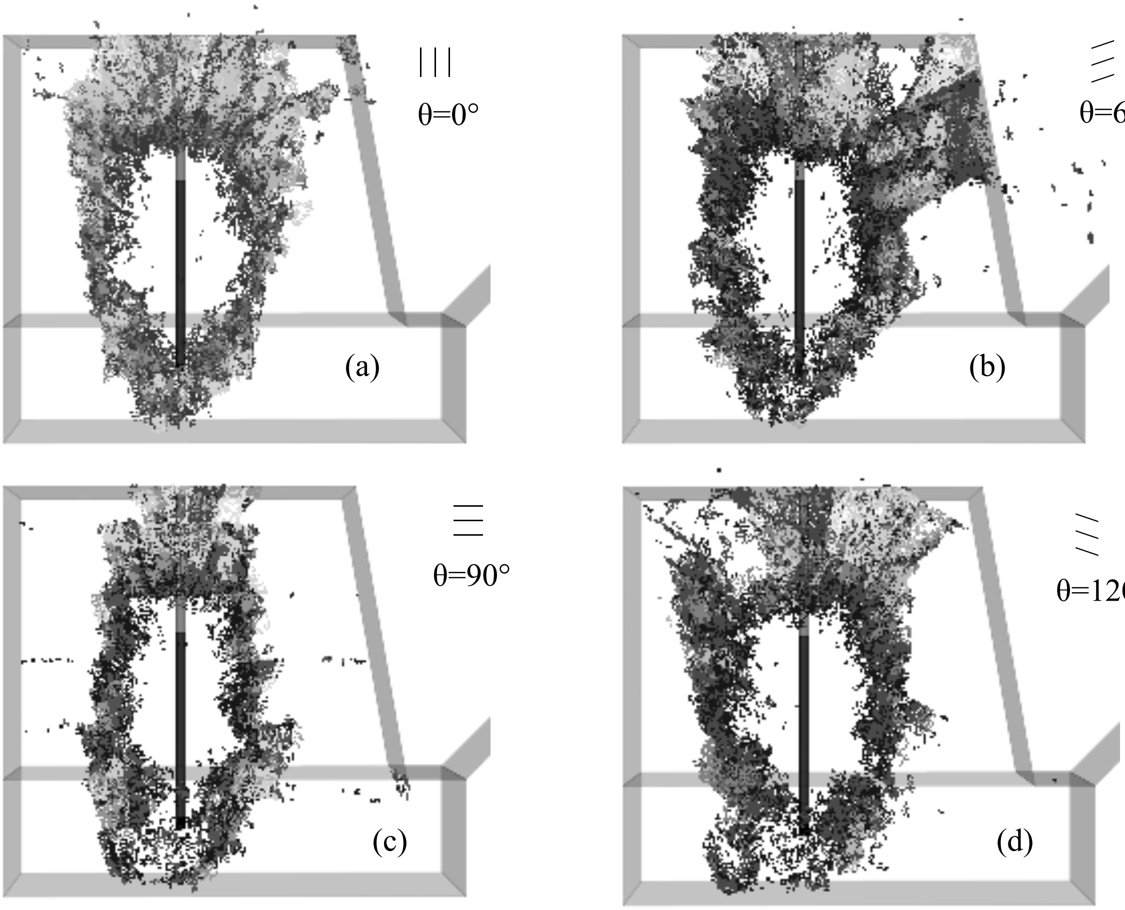

Figure 4: Fragmentation distribution of four joint orientations 100ms after detonation.

3.3 Joints

The influence of jointing on blast outcomes appears to be well replicated by the HSBM. *In situ* jointing appears to have produced the expected blocky fragmentation in all cases and promoted blast damage along and adjacent to these planes. However, the gas logic only acts for very short periods (<1ms). Gas logic is turned off before it is distributed throughout the entire model; the gas does not act on free faces, which is most likely unrealistic.

Jointing 'out of the face' shown in figure 4 (b) has resulted in a path of least resistance for blast damage to the free face, resulting in blocky fragmentation. The orientation has also produced a significant number of spalling particles as expected due to the weakness along the slanted face. The same response is not seen in figure 4 (a,d) due the influence of joint orientation.

Horizontal jointing in figure 4 (c) has prevented damage extending to the bench surface as expected, however no spalling particles are produced as in figure 4 (b), reasons for this are unknown.

4. Conclusions

The HSBM is currently limited to small models and thus it is not applicable to production blasts. However it may be used as a tool to evaluate the effect of differing blast variables (such as joint orientation) on small scale blast outcomes. Findings may be relevant to larger scale operations. The HSBM would benefit from manual control of gas logic duration to fully quantify the effect of it has on fragmentation and blast movement.

5. References

Cunningham, C. (1987) Fragmentation estimations and the Kuz-Ram model – four years on. *Int Symp on Rock Fragmentation by Blasting*, (2) pp. 475-487.

Ruest, M., Cundall, P., Guest , A. & Chitombo, G. (2006) Developments using the particle flow code to simulate rock fragmentation by condensed phase explosives. *Fragblast8*, pp. 140-151.

Onederra, I., Ruest, M. & Chitombo, G. (2007) Burden Movement Experiments Using the Hybrid Stress Blasting Model (HSBM). *Explo 2007*, pp. 177-183.

Cundall, P. (2008) Recent Advances in Numerical Modelling for Large-Scale Mining Projects. *ACG News* (30), 1 – 7 June 2008.

Cundall, P., DeGarné, D. & Furtney, J. (2007) The Hybrid Stress Blast Model – Progress Report Number Three. Submitted to HSBM Sponsors.

Ruest, M. (2009) Private communication.

Dight, P. (2009) Private communication.

Potyondy D.O. & Cundall, P. (2004) A bonded-particle model for rock. *International Journal of Rockmechanics*, (41) pp. 1329-1364.