IMPROVED BLASTING RESULTS WITH PRECISE INITIATION

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1 INTRODUCTION

The primary purpose of all blasting is to fragment the rock into pieces of suitable dimensions for further handling. An improved fragmentation can result in reduced costs for both blasting and transportation of the blasted rock, improved environmental aspects, and reductions in energy consumption during crushing and grinding of the blasted rock, as well as improved metal recovery.

Using blasting caps with electronic delay units, it has become possible to employ wave superposition in rock blasting. A hypothesis proposed by Rossmanith (2002) states that fragmentation is improved in areas between blast holes where the tensile waves meet, overlap and interact. There are practical experiences showing that improved fragmentation, throw, swelling, and diggability, can be achieved through this, see e.g., Vanbrabant & Escobar (2006). However, quantitative computational models that describe this phenomenon are lacking.

The current project was initiated to further investigate the hypothesis by Rossmanith (2002) and to develop better computational tools for simulation of blasting with electronic electronic programmable delay (EPD) caps. The objective of this project is to: (i) achieve a better fragmentation, throw and other results from blast in quarries and mines, and (ii) study the extension of Rossmanith's concept to a three-dimensional geometry by identifying the rock volumes within a blast where the wave interaction from neighboring blast holes may create additional damage (and thus enhanced fragmentation) for varying detonation delay times.

The current project is a joint project between the industrial partners LKAB and Boliden Mineral AB, and Luleå University of Technology (through Swebrec). The first objective is industrial-oriented, whereas the second objective is more of scientific nature. Additional project work is conducted by consulting firms — Itasca Consultants AB for project management, and Engineering Research AB for computer simulations of blasting. The project comprises nine (9) different tasks involving computer simulations of blast performance, coupled with full-scale field tests, and model scale tests. The project started in the fall of 2008, but initial tests of a methodology for computer simulation proved fruitless. Hence, a revised project plan was developed with the above objectives and with a re-start of the project in August 2009. Due to shortage of research staff, the project was run on low speed until early 2011, when new resources were made available and a new project leader was appointed. The project is now planned for completion by the end of 2012.

2 COMPUTER SIMULATION OF BLASTING

Computer modeling of blast fragmentation is challenging. Firstly, it requires a representative material model, which is difficult to develop for a heterogeneous and sometimes discontinuous material such as rock. In addition, the material model should be able to replicate the rock response to large pressures (of the order of GPa) and subsequent damage to the rock including crushing and fracturing. Moreover, computer simulation requires a material model for the explosive agent. The numerical models must have a high resolution (discretization) to obtain an acceptable representation of the wave interaction and formation of fragments. These requirements are at front of (or even beyond) the current state-of-the-art in three-dimensional dynamic modeling.

The first two tasks of this research project involved investigating two newly developed computer codes for blast simulation (*Vixen* and *BloUp*). Neither of these fulfilled the criteria necessary for meeting the project objectives, see Hansson (2009) and Johansson & Ouctherlony (2009). Hence, a new numerical methodology involving the code *LS-DYNA* is being developed. *LS-DYNA* is a commercially available multi-purpose finite-element code, which is well suited to various types of dynamic modeling. Preliminary results using a configuration with two blast holes are shown in Figure 1. This model comprised 16 million elements, with a resolution (element size) of 40–50 mm. Two different element formulations are being used — Euler formulation in, and close to, the blast hole, and Lagrange formulation in the rock volume farther from the blast hole — to capture the blast wave propagation correctly.

To further develop the computer modeling, a single blast hole model is used as a test case. Concurrently, a methodology to calculate possible fragmentation based on model interpretation is being developed. This will be based on "tying together" areas with calculated damage (yielding) in the model, thus assuming that such volumes of damaged rock constitute a fragment. This approach will also be tested in the single-hole model. Different constitutive models for the rock will be tested. This will probably also include the so-called RHT model for brittle materials (Riedel et al., 1999), which has proven to be suitable to describe the rock response to blasting. This is currently being implemented in *LS-DYNA*.

Following these initial developments, a full-scale simulation will be attempted. This model will comprise four blast holes with a geometry representing a bench blast at the Aitik open pit mine (operated by Boliden Mineral AB). Wave interaction according to the hypothesis of Rossmanith (2002) for short detonation delay times will not extend outside 3-4 holes; thus it is not necessary to model a full bench blast (which may consist of hundreds of boreholes). A resolution (minimum element size) of 50–60 mm is foreseen for this full-scale simulation. Input data to the model comprise mechanical properties of rocks at Aitik collected in previous projects, as well as data based on experience and from the literature.

3 FULL-SCALE BLASTING FIELD TESTS

Some trials using EPD caps have been attempted by both Boliden Mineral AB (in open pit mining) and LKAB (in underground sublevel caving). However, a more comprehensive and controlled test has not been performed. Plans are now underway for a full-scale field test at the Aitik open pit mine (by Boliden Mineral AB). During the spring, base tests will be carried out to determine blast wave characteristics, VOD, and other basic parameters. A detailed test plan is being developed including a monitoring plan to follow-up fragmentation, swell, diggability, as well as energy consumption and throughput of the mill (as a secondary index of achieved fragmentation).

Fragmentation is difficult to measure in a representative and reliable way, as evidenced by previous work at Aitik (Ouchterlony et al., 2010). New systems (based on improved image processing) emerging on the market will be tested as part of this work. The blast tests will be conducted during the fall of 2011.

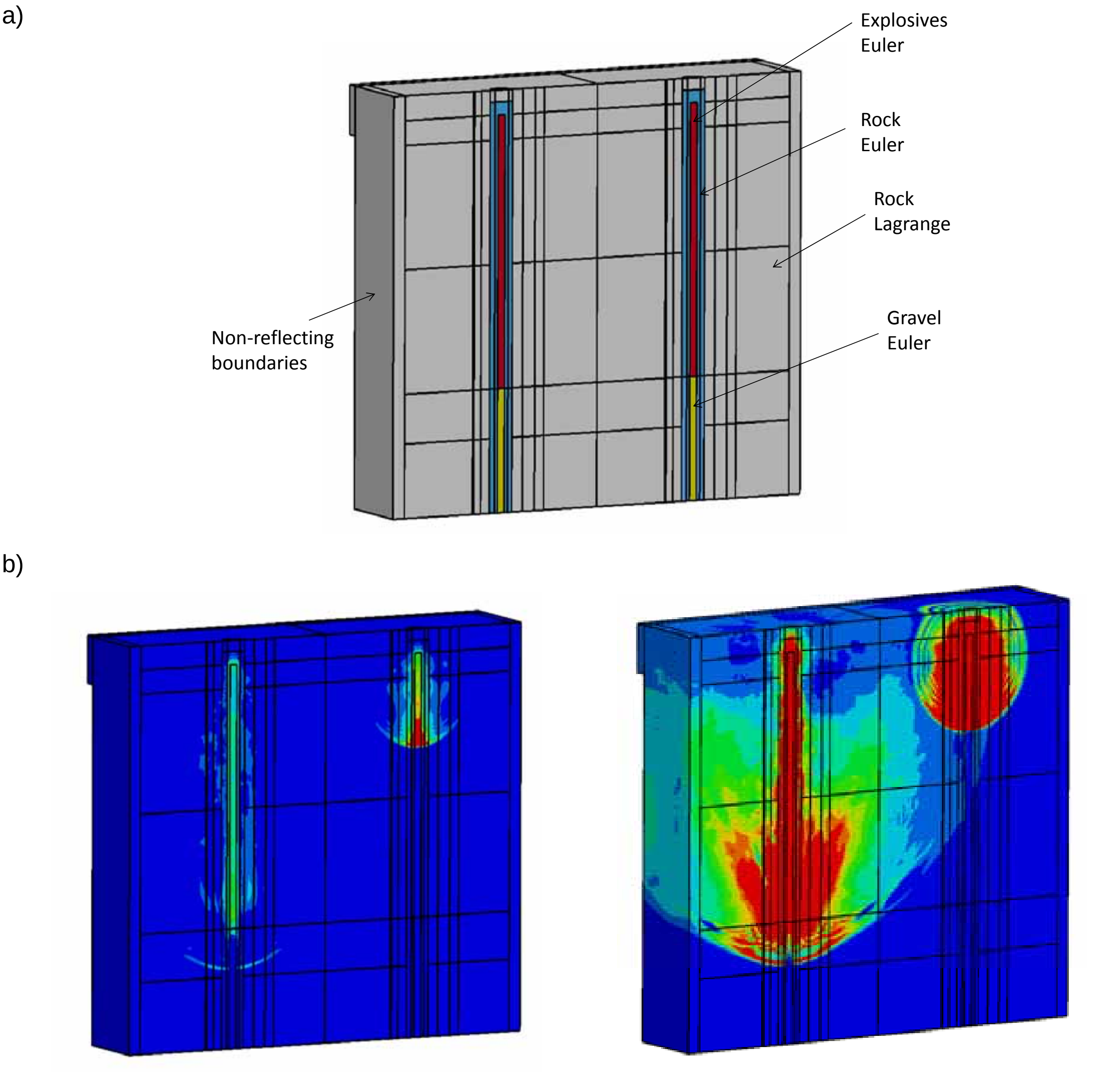

Figure 1 *Preliminary modeling of blast wave interaction using LS-DYNA: a) model set-up of two blast holes, and b) pressures after initiation after the second blast hole (left) and calculated velocities after 2 ms (right).*

4 THE WAY FORWARD

The computer simulations are aimed at producing a methodology for being able to simulate shock wave interaction and damage in the rock for a sub-set of a full bench blast in an open pit mine. With this methodology, and the data from the field tests at Aitik, calibration of computer models will be conducted and additional parametric studies undertaken. This work will focus on optimizing delay times in open pit blasts, with particular application to the Aitik mine.

LKAB have used electronic detonators in previous field trials and these results will be used for validation in the current project. Field tests aimed at identifying the impact of confined blasting conditions (through the caved waste rock) in sublevel caving are currently being performed. Laboratory tests of confined blasting have previously been carried out as input to the present project. Numerical simulations of the model scale tests will thus be performed to further validate the numerical modeling methodology. The final task involve numerical simulation of blasting in underground sublevel caving to better optimize delay times also for this application.

In the coming months, the simulations and the full-scale field tests at Aitik will be conducted in parallel. Simulation of model scale tests will be carried out during the fall of 2011, while modeling aimed at optimizing delay times and blast layout for open pit and underground sublevel cave mining will be performed during 2012. The revised project schedule calls for a completion target date of Dec 31, 2012.

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