AIIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910

301/587-8202

Centimeter

Inches

MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.

Conf-940144--3
SAND94-0292C

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

COMPUTER CAST BLAST MODELLING

by

Stephen Chung
ICI Explosives Canada
North York, Ontario

Mike McGill
ICI Explosives USA
Dallas, Texas

Dale S. Preece
Sandia National Laboratories
Albuquerque, New Mexico, USA

ABSTRACT

Cast blasting can be designed to utilize explosive energy effectively and economically for coal mining operations to remove overburden material. The more overburden removed by explosives, the less blasted material there is left to be transported with mechanical equipment, such as draglines and trucks. In order to optimize the percentage of rock that is cast, a higher powder factor than normal is required plus an initiation technique designed to produce a much greater degree of horizontal muck movement. This is a significant change from normal blasting practice where fine fragmentation and sufficient muck movement were the prime requirements to permit efficient excavation.

This paper compares two blast models known as DMC (Distinct Motion Code) and SABREX (Scientific Approach to Breaking Rock with Explosives). DMC applies discrete spherical elements interacted with the flow of explosive gases and the explicit time integration to track particle motion resulting from a blast. The input to this model includes multi-layer rock properties, and both loading geometry and explosives equation-of-state parameters. It enables the user to have a wide range of control over drill pattern and explosive loading design parameters. SABREX assumes that heave process is controlled by the explosive gases which determines the velocity and time of initial movement of blocks within the burden, and then tracks the motion of the blocks until they come to a rest. In order to reduce computing time, the in-flight collisions of blocks are not considered and the motion of the first row is made to limit the motion of subsequent rows.

Although modelling a blast is a complex task, the advance in computer technology has increased the computing power of small work stations as well as PC computers to permit a much shorter turn-around time for complex computations. The DMC can perform a blast simulation in 0.5 hours on the SUN SPARCstation 10-41 while the new SABREX 3.5 produces results of a cast blast in ten seconds on a 486-PC computer. Predicted percentage of cast and face velocities from both computer codes compare well with the measured results from a full scale cast blast.

Figures and Tables following text.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

This work was supported by the United States Department of Energy under Contract DE-AC04-94AL85000.

MASTER

INTRODUCTION

In most mining operations, successful blasting often provides good fragmentation and a muck pile profile that allows the digging equipment to work at its maximum efficiency. For dragline operations in the open pit coal mining industry, maximum overburden casting can further reduce the amount of re-handling while a good profile minimizes the amount of pad preparation.

As part of a continuing effort to support the use of explosives in achieving maximum mining productivity, we have developed an awareness of the complexity of the multi-block motion and collision effects in the heave process. In collaboration with SANDIA National Laboratory, a computer code designated as DMC has been developed in parallel with the SABREX-Heave model. It has the capability of handling a multi-layer rock structure and an actual bench face profile. In addition, with the provision for input of rock structure properties, explosive parameters and loading geometry, it enables the user to have a wide range of control over blast design parameters. The extra details as a result of the increased computational complexity will be of use in many problem-solving situations in fundamental blasting studies. DMC requires a great deal of computing power, so it is only intended for running on a workstation. A typical cast blast simulation takes half an hour on the SUN SPARCstation 10-41.

The need for an engineering model to enable blast studies to be carried out on site and to determine alternative designs without the expense of full scale trials was introduced in 1987 (Kirby, Harries and Tidman, 1987). The complex heave process in blasting is simplified in SABREX to allow the simulation to be performed on a PC computer. Although the rock type is restricted to one in each case study, and the muck pile profile is treated on a vertical plane intersecting with the bench face at 90 degrees, it can handle a blast loaded with up to three different types of explosives and variable drill patterns between rows. A typical simulation of a cast blast takes about ten seconds on a 486-PC computer.

This paper presents selected features offered by both SABREX and DMC as mentioned above. A comparison of results from a full scale cast blast and predictions from both programs is also included.

THE MODELLING OF CAST BLASTING

Basic inputs for modelling the rock motion in both SABREX and DMC are similar. They are :

* detonation and explosion properties of loaded explosives, including velocity of detonation and borehole pressure; up to three explosives types per blast can be input to SABREX, one to DMC

* dynamic elastic properties of rock such as Young's Modulus and Poisson's Ratio; one set per case in SABREX, no restriction in DMC

* delay timing, bench face angle and drill hole geometry; one face angle per case in SABREX, no restriction in DMC

There are, however, additional inputs required in each computer code to model more specific site situations. More details are given in the following sections.

The Effect of Rock Absorption and Swell Factors on Heave Computation in SABREX

The heaving process happens after a shock wave has passed and cracks are generated in the blasted rock mass. The explosive gases flow into cracks, extending them towards free faces. The face does not move until the gas-generated cracks cause the rock to fail. Then the gas pressure, reduced from its initial value because of expansion and cooling, imparts a momentum to the rock, beginning with blocks at the free face and ending with rock at the back and base of the blast. The face velocities that control the shape of the muck profile are calculated at three locations namely the crest, mid-face and toe on the vertical plane intersecting the bench face at 90 degrees. These velocities are sensitive to the drill pattern, the properties of the burden rock, and the available explosive energy excluding the portion being lost through stemming ejection or venting into open cracks in the rock mass. Since the energy lost is likely a site specific phenomenon, a Rock Absorption Factor (RAF) has been designed to rate the efficiency of gas expansion into the burden rock. Depending on the rock porosity and competency, this value falls between 0 and 20%. A higher value indicates more energy would be absorbed, and therefore less heave or throw would be resulted. These factors can be determined through the study of high speed film and the surveyed muck pile profile of a typical production blast (Chung and Tidman, 1988).

Once the initial velocities have been calculated, the model breaks up the burden into a number of square blocks and treats them as if they were each thrown by the blast. When the blocks land on the ground or on stationary blocks, they do not bounce but may be shifted horizontally to maintain an angle of repose. The final profile of the muck pile is defined by adding the amount of swell which is proportional to the fallen height of blocks. Figure 1 shows a simulated muck pile of a bench blast and the effect of RAF and Swell.

The Effect of Element Packing Angle and Damping on Rock Motion Computation in DMC

Besides the required basic input as described above, DMC applies the spherical Element Packing Angle to treat the sedimentary formations with bedding planes. DMC also applied the Damping Coefficient to define the velocity distribution in a burden. The code uses discrete spherical elements and explicit time integration, to track particle motion, resulting from the load of explosive gases flowing outward from the blastwell. The gas flow calculation is performed assuming the surrounding rock media is porous. The loads on the spherical elements are calculated using the gas flow characteristics. The porosity of the gas flow model is modified as each discrete element moves. Figures 2 and 3 show a bench blast example and the effects of these additional factors on the shape of the final muck pile profile (Preece, 1990).

SIMULATIONS COMPARED TO FIELD DATA

The example given here took place at the Lee Ranch Mine owned by the Santa Fe Pacific Coal Company. The mine is located about 25 miles north of Grants, New Mexico. Figures 4 and 5 show a bench cross-section and descriptions of the strata being studied. The bench is located at the western end of the pit. The values for Young's modulus, Poisson's ratio and density have been used and reported in a previous study (Preece, Burchell and Scovira, 1993).

Field Measurements

The bench face and pit geometry were surveyed by means of a Laser Profiler before the blast. The face movement was tracked with a Locam camera operating at 350 frames / sec. This high speed camera was located in the pit approximately 300 m off the end of the blasted section viewing almost parallel to the bench face. The measured face velocities are given in Figure 5 along with the velocities computed by

DMC. The muck pile was surveyed after the blast at the same cross-sectional location as the pre-blast survey covering the muck pile and part of the spoil pile. The comparison is relatively good, though there are some differences at the back of the blast and where the muck pile meets the spoil pile. The percent cast determined from the survey and DMC were 29% and 28% respectively.

Computer Simulations

The spherical element model used in this simulation and a few selected time frames of the computation are shown in Figure 5. This simulation used a maximum packing angle of 30 degrees which allows a significant amount of dilatation as the spheres move with increased horizontal friction. This setting supports a curved front face during the heaving process. The model has 1960 spheres and the entire calculation executes in 5300CPU seconds on a SUN SPARCstation 2 computer workstation.

SABREX uses the same data base as described in Figure 4 except that the rock property has been averaged. The swell factor used is 1.18, a value determined from the surveyed result. The RAF is set at 0.05, a value used mostly for average blasting conditions. Figure 6 shows the input as well as the predicted face velocities and muck pile pprofile. It is noticed that these predicted values agree well with the results quoted in Figure 5. The simulation of this cast blast is completed in ten seconds on a 486 notebook computer equipped with a math co-processor.

CONCLUSIONS AND DISCUSSIONS

Both DMC and SABREX have demonstrated their abilities to predict the results of a full scale bench blast. The DMC code can simulate blasts involving more complex rock structure. Although it takes more computing power to perform a case study, the ability to provide details of blasting physics allows for its use in many problem-solving situations and furthers the development of blast modelling. SABREX is a good engineering tool which can offer quick answers to alternative blast design problems on site. Although it can only handle blasting of a single type of rock at a time, but its fast turn around performance and accuracy make it a predictive tool especially for field operation.

REFERENCES

Kirby, I.J., G.H. Harries & J.P. Tidman. *ICI's Computer Blasting Model SABREX - Blast Principles and capabilities*. Proceedings of the Thirteen Conference on Explosives and Blasting Technique. Soc.Explo. Eng., Miami, Florida, Feb. 1-6, 1987.

Chung, S.H. & J.P. Tidman. *Effective Modelling for Cast Blasting*. Proceedings of An International Symposium on Mine Planning and Equipment Selection, Calgary, Alberta, Nov. 3-4, 1988.

Preece, D.S.. *Rock Motion Simulation of Confined Volume Blasting*. Proceedings of the 31th U.S. Symposium on Rock Mechanics, Colorado School of Mines, Golden, Colorado, June, 1990.

Preece, D.S., S.L. Burchell and D.S. Scovira. *Coupled Explosive Gas Flow and Rock Motion Modeling with Comparison to Bench Blast Field Data*. Proceedings of the Fourth International Symposium on Rock Fragmentation by Blasting, Technical University, Vienna, Austria, July 5-8, 1993.

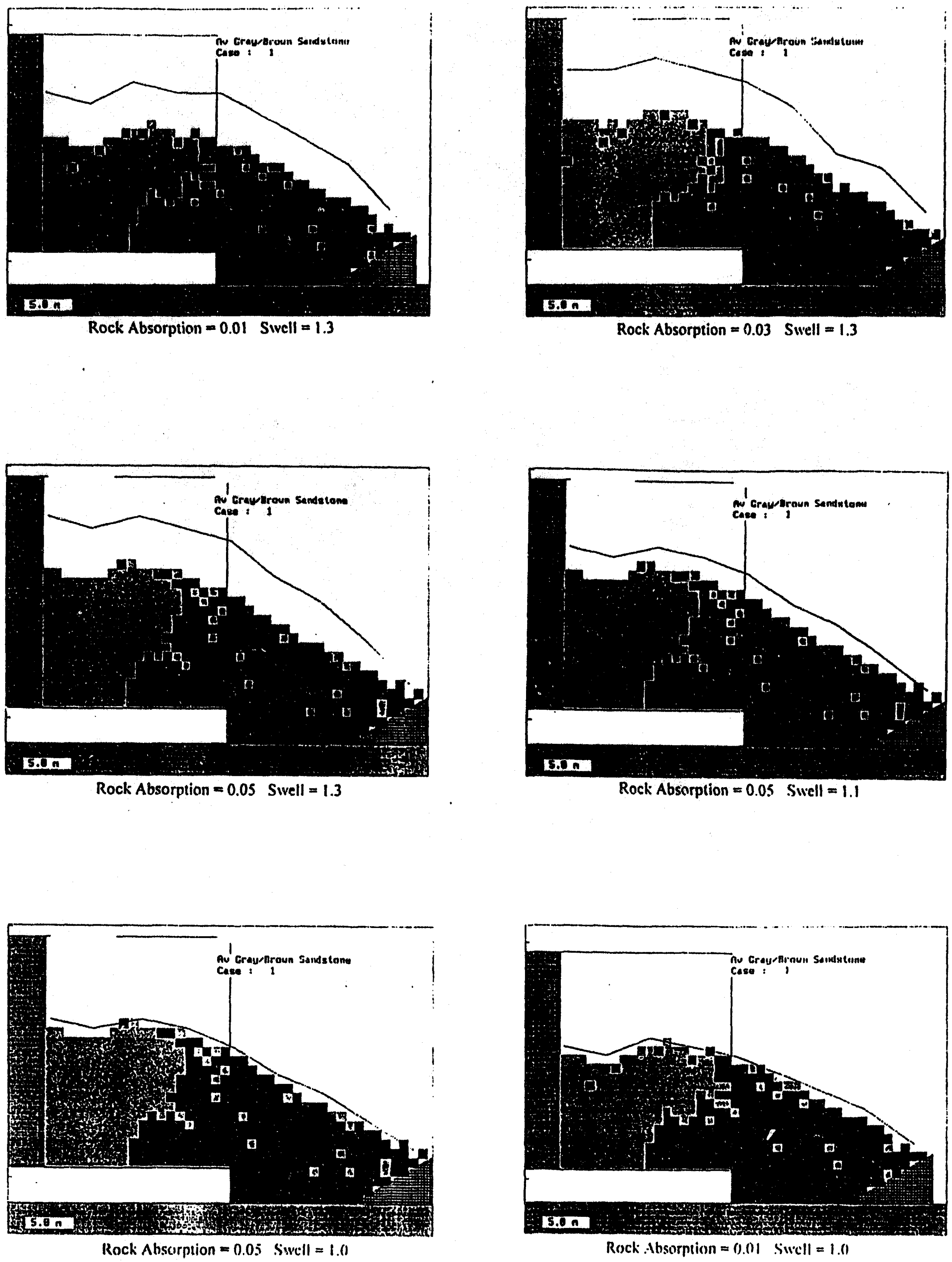


Figure 1. Effect of Rock Aborption and Swell on heave computation in SABREX

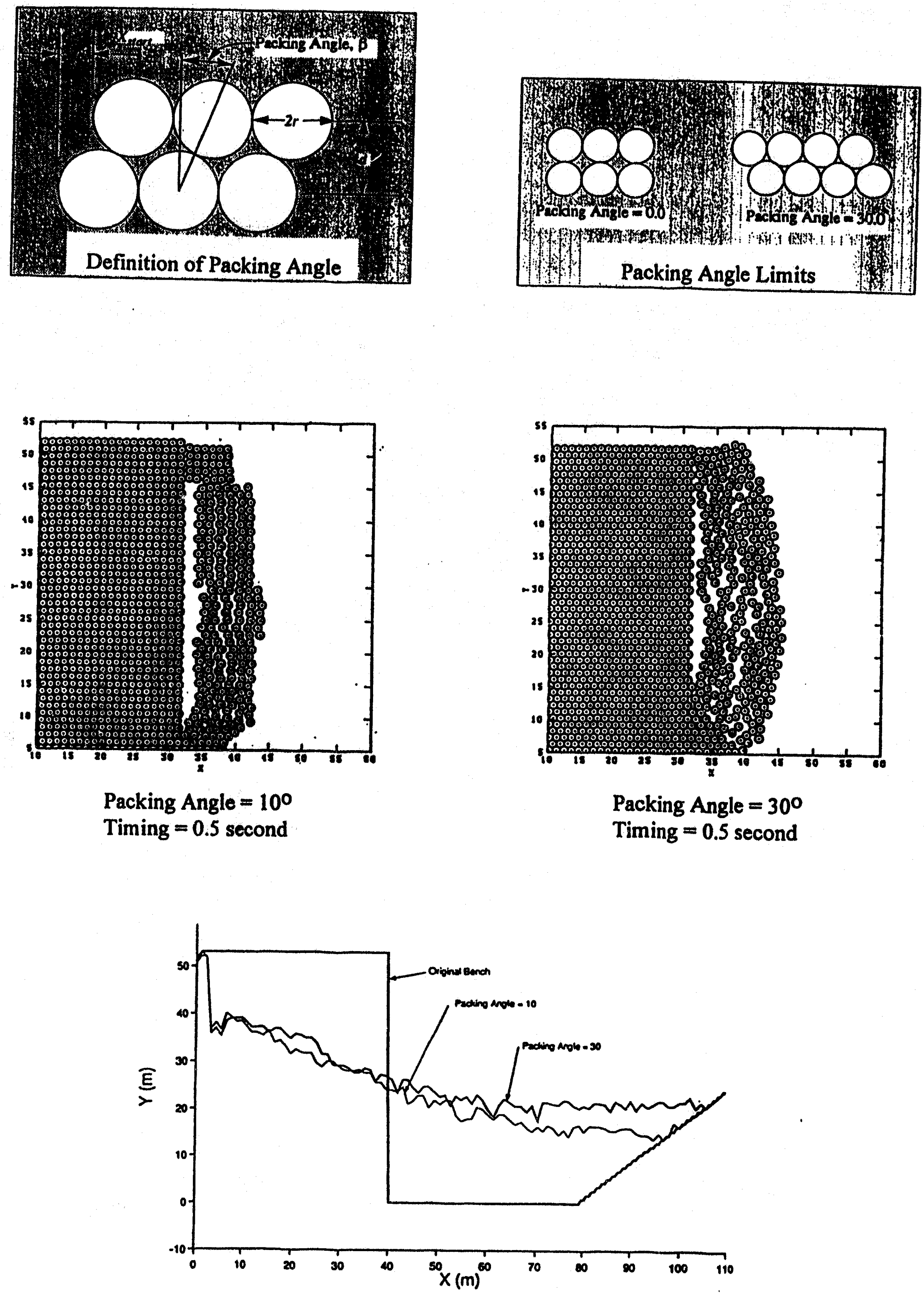


Figure 2. Definition of Packing Angle and its effect on motion computation in DMC

Material Parameters

Material	Thickness (m)	Youngs Modulus (GPA	Poissons Ratio	Specific Gravity
Coal Layers	7.0	25.0	0.20	2.10
Gray Shale	17.0	10.0	0.14	2.51
Sandy Gray Shale	3.0	10.0	0.14	2.51
Gray Sandstone	4.0	9.3	0.12	2.38
Brown Sandstone	22.0	3.0	0.18	2.22

Blastwell Parameters

No. of Rows	Burden (m)	Spacing (m)	Explosive	Hole Dia. (mm)	Row Delay (ms)
5	7.3	4.9	Heavy ANFO 75/25[a]	200.0	150.0

a. Mixture ratio, ANFO to Emulsion

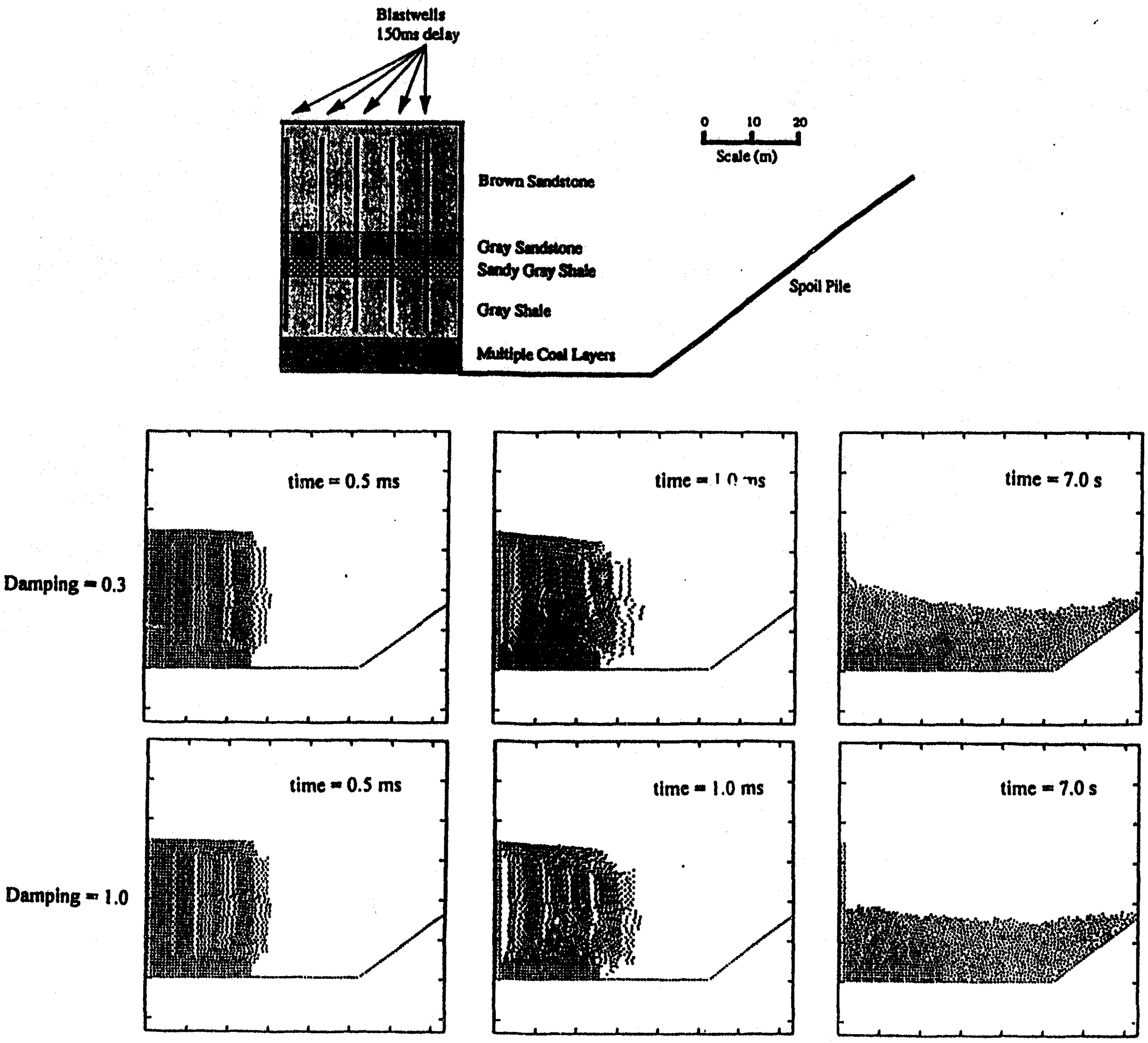
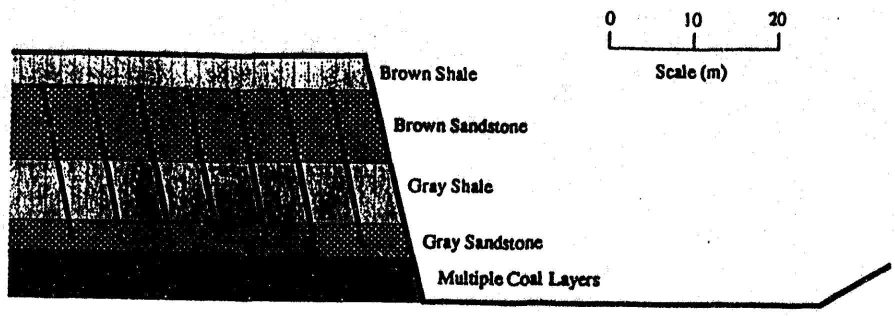


Figure 3. Bench blast example and the effect of Damping



Schematic of Bench Blast Example Problem

Material Properties

Material	Thickness (m)	Youngs Modulus (GPA)	Poissons Ratio	Specific Gravity
Coal Layers (multiple)	4.48	50.0	0.20	2.10
Gray Sandstone	3.27	40.0	0.12	2.38
Gray Shale	6.05	10.0	0.14	2.52
Brown Sandstone	8.14	40.0	0.12	2.38
Brown Shale	5.49	10.0	0.14	2.52

Blast Design Parameters

Row No.	Burden (m)	Spacing (m)	Explosive	Hole Dia. (mm)	Hole Angle (degrees)	Row Delay (ms)
1	4.88	4.57	ANFO	270.0	15	0
2	"	9.14	"	"	"	100
3	"	"	"	"	"	125
4	"	"	"	"	"	142
5	"	"	"	"	"	165
6	"	"	"	"	"	200
7	"	"	"	"	"	242

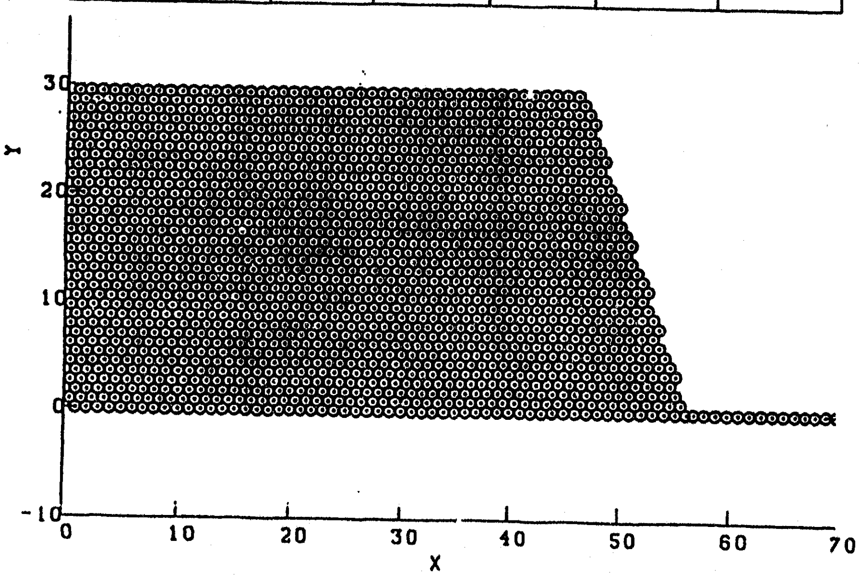


Figure 4. DMC Spherical Element Model for cast blast simulation

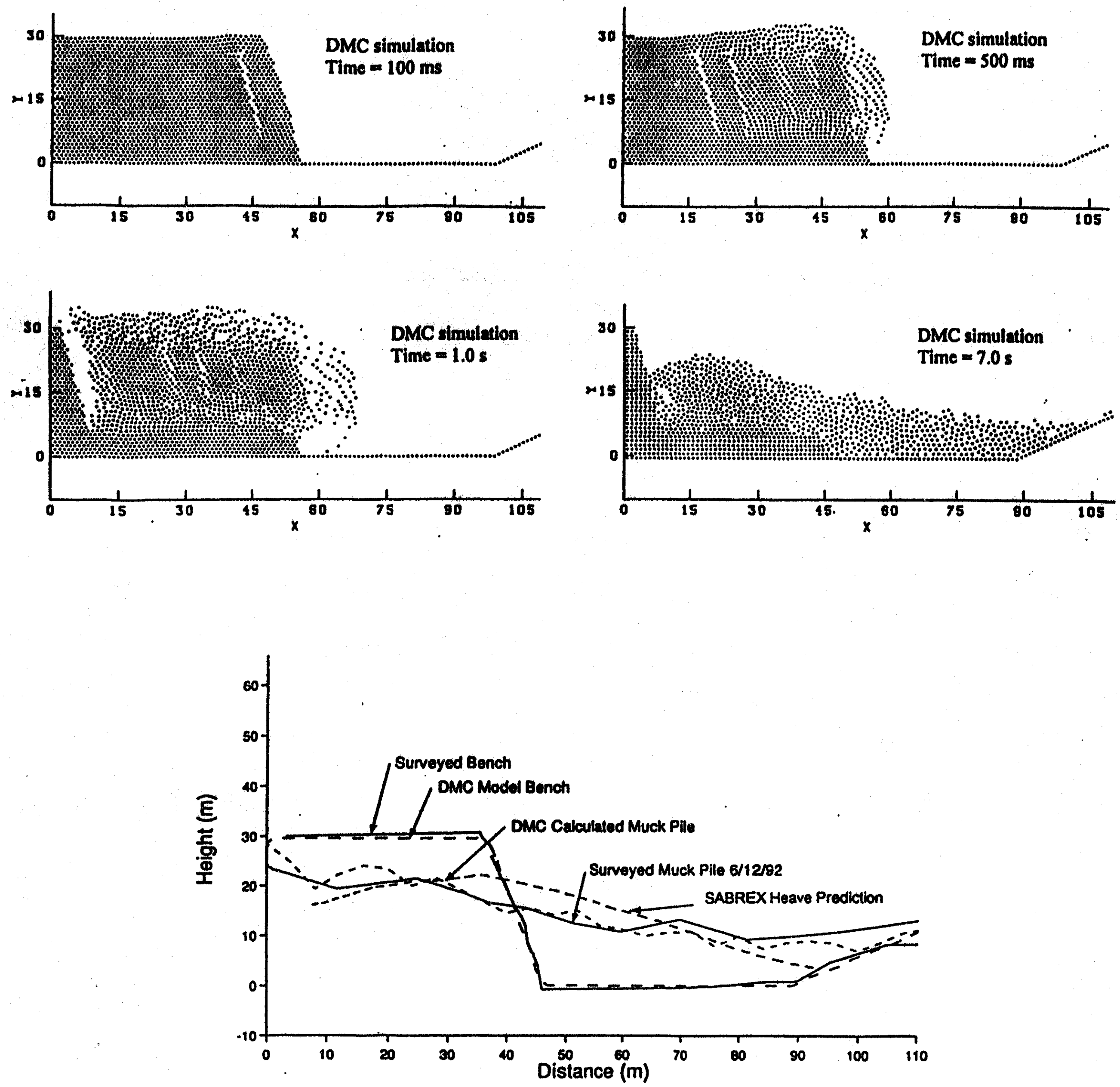
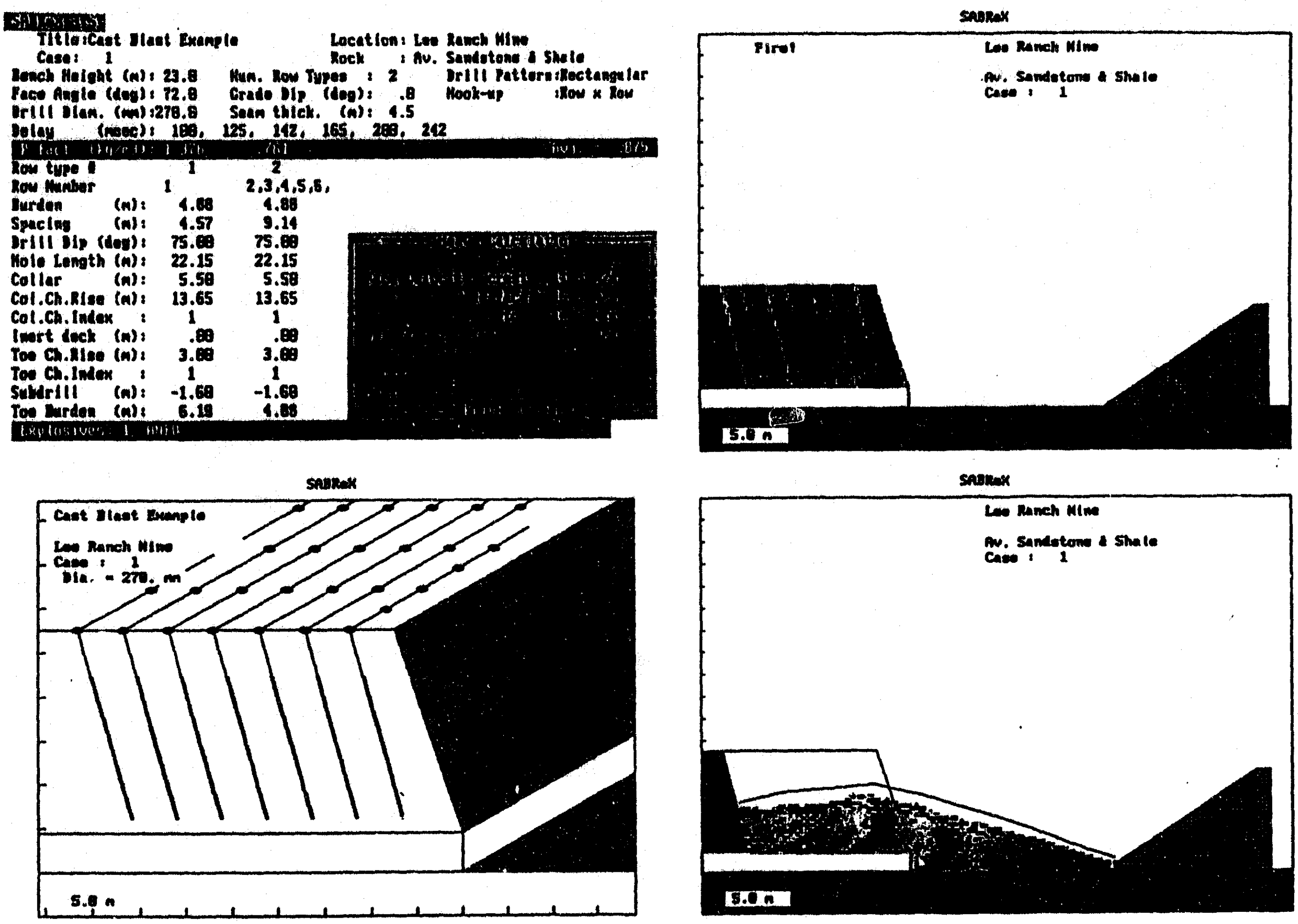


Figure 5. Comparison of measured results versus computer predictions



Summary of Measured and Computed Results

Distance From Bench Top (m)	Measured Face Velocity (m/s)	Computer Predicted Velocities	
		DMC (m/s)	SABREX (m/s)
5.5	12	12	11
7.9	19	18	-
10.4	19	19	17
12.8	16	17	-
15.2	14	16	15
21.1	4	4	-
Amount Cast	29%	28%	30%

Figure 6. SABREX simulation using data given in Figure 4 with Summary of Results

DATE
FILMED
8/3/94

END