A numerical study of bench blast row delay timing and its influence on percent-cast* SAND93-2566C

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Abstract: The computer program, DMC (Distinct Motion Code), which was developed for simulating the rock motion associated with blasting, has been used to study the influence of row delay timing on rock motion. The numerical simulations correspond with field observations in that very short delays (< 50ms) and very long delays (> 300ms) produce a lower percent-cast than a medium delay (100 to 200 ms). The DMC predicted relationship between row delay timing and percent-cast is more complex than expected with a dip in the curve where the optimum timing might be expected. More study is required to gain a full understanding of this phenomenon.

1 INTRODUCTION

The largest mining operations in the world are surface coal mines which involve processing and movement of significant amounts of rock and soil to extract the coal and reclaim the land. The surface coal mining industry has adopted a blasting technique called *Cast Blasting* which allows mining engineers to move a maximum amount of overburden material with explosives. This leaves less material to be moved with mechanical equipment such as draglines and trucks and makes the operation more efficient. Sandia National Laboratories and ICI Explosives USA have collaborated since 1987 to develop methods for computer modeling of coal mine bench blasting which includes cast blasting. The Sandia computer program, DMC (Distinct Motion Code), is a discrete element code that uses spherical elements and explicit time integration to track particle motion resulting from a blast. A unique feature of DMC is the coupling of the rock motion capability with a gas flow capability. The code models the flow of the explosive gases outward from the blastwell. A porous medium is assumed for modeling the rock during the gas flow calculation. Spherical element loads are calculated using the gas flow characteristics and the porosity of the gas flow model is modified as the discrete elements move. Input to this model includes rock properties, geometrical configuration and explosive equation-of-state parameters. This enables the user to have a wide range of control over blast design parameters including explosive type. DMC is currently being used on a SUN SPARCstation 10-41 computer workstation.manufactured by Sun Microsystems Incorporated.

DMC with the coupled gas flow capability has been exercised on a bench blast configuration with different delay times between rows. This exercise was performed to test the ability of the code to predict differences in blast-induced rock motion over a wide range of row delay times. Practical blasting experience indicates that very short delay times (< 50 ms) as well as very long delay times (>300ms) between rows do not produce as much rock motion as an intermediate row delay time. The relationship between row delay timing and rock motion for intermediate delay timings is not very well understood, having had only superficial examination, either in the field or numerically. A numerical study of this phenomenon is presented in this paper.

2 ROW DELAY TIMING AND PERCENT-CAST

Optimal row delay timing depends on many variables including geometry, explosive properties and rock properties. For the following discussion keep in mind that the burden is the material between the explosive row and either the free face or the next row of explosives (see Figure 1). Present theory indicates that the optimum timing should allow time for some space to open up in front of the next burden to be shot. This allows each burden to move freely since it has space into which it can expand. However, as each burden is blasted it can also assist in pushing the burdens that were blasted in front of it, adding to the momentum of the entire rock mass. Thus, long delay times prevent the burdens from assisting each other to enhance the motion. An optimum delay time is long

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enough to keep the burdens from bunching up while also allowing interaction to enhance the motion (Olofsson, 1988). This can be likened to a system with a natural frequency which exhibits a stronger response when the loading frequency and natural frequency are close to each other. In this paper the same spherical element model was used in a parameter study where only the delay timing between rows was varied.

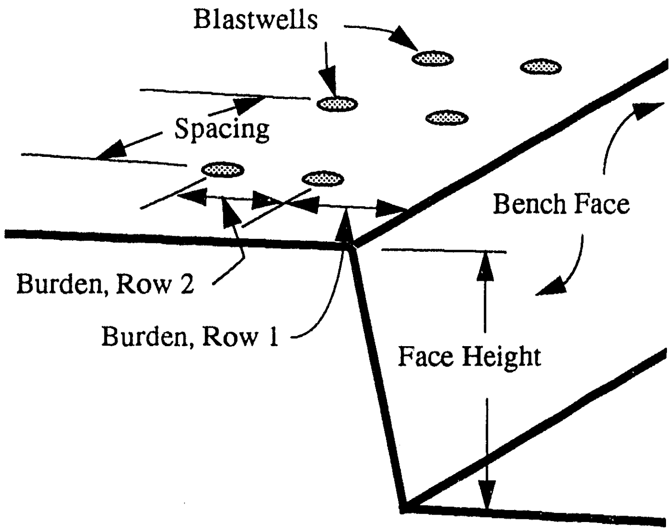

Figure 1: Definition of Bench Blasting Terms

Comparison between DMC calculations and field data for this site is the subject of another paper (Preece, 1993c). Figure 2 illustrates the definition of percent-cast, a concept commonly used to measure blast-induced rock motion. The cast-line is parallel to the angle of repose of the spoil pile and intersects the bottom of the face. Percent-cast refers to that portion of the overburden that is beyond the cast-line and thus resides in its final position, not requiring any rehandling. Consistent percent-cast differences of as little as 4% can have a significant impact on the economics of many surface mining operations.

3 SITE DESCRIPTION

The example bench blast modeled here occurred at the Lee Ranch Mine owned by the Santa Fe Pacific Coal Company. The mine is located approximately 25 miles north of Grants, New Mexico. The coal is mined using an open pit bench blasting technique where the pit is slightly over a mile long and lies in an east/west direction. A cross-section of the pit is shown in Figure 3. The sedimentary geology of the site consists of gently dipping strata where the major coal seams are approximately 27 m deep at the western end of the pit and 11 m deep at the eastern end. The pit is advanced from west to east with the blasting being done in sections that are approximately 360 m long. The bench blast studied occurred at the western end of the pit where the face is approximately 30 m high. A description of the strata at the western end of the pit is presented in Figure 3 and Table 1. The values for Youngs' modulus, Poissons' ratio and density were not actually measured at the site but come from measurements on similar materials at other coal mines. The face and the blastwells are angled at approximately 15°, and the spoil pile opposite the face has a 35° angle of repose.

The blasting design results from an optimized trade-off between blast casting and preventing the coal from being severely damaged or unrecoverable. Higher explosive loads will result in a better cast of the overburden material which is more economical because less material needs to be moved with mechanical equipment. However, very high explosive loading can result in significant

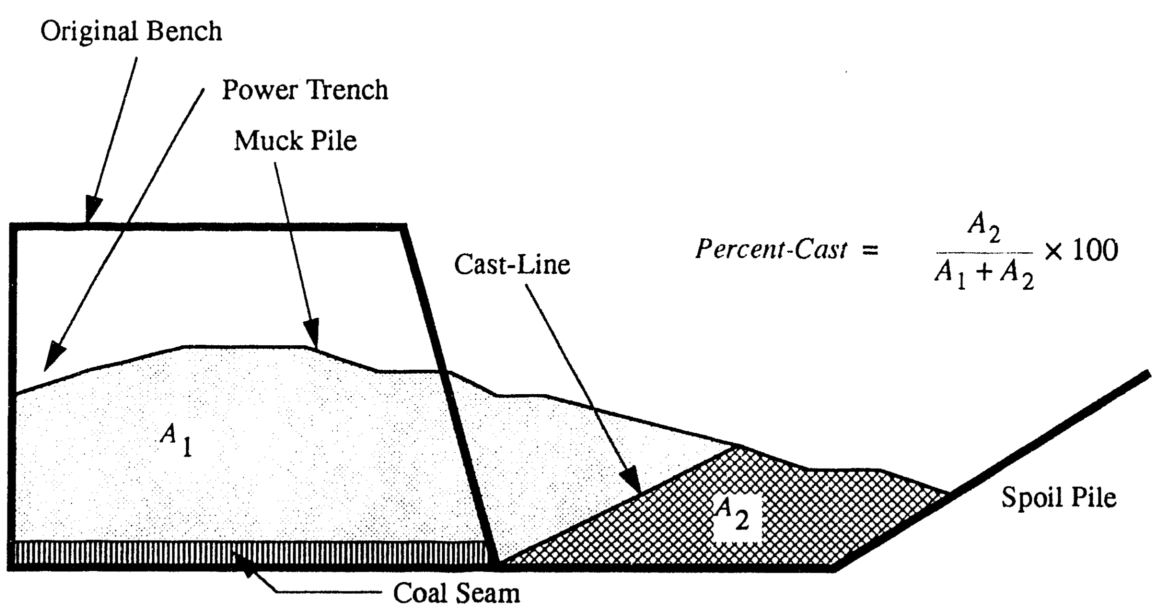

Figure 2: Illustration of Definition of Percent-Cast Based on Areas A_1 and A_2.

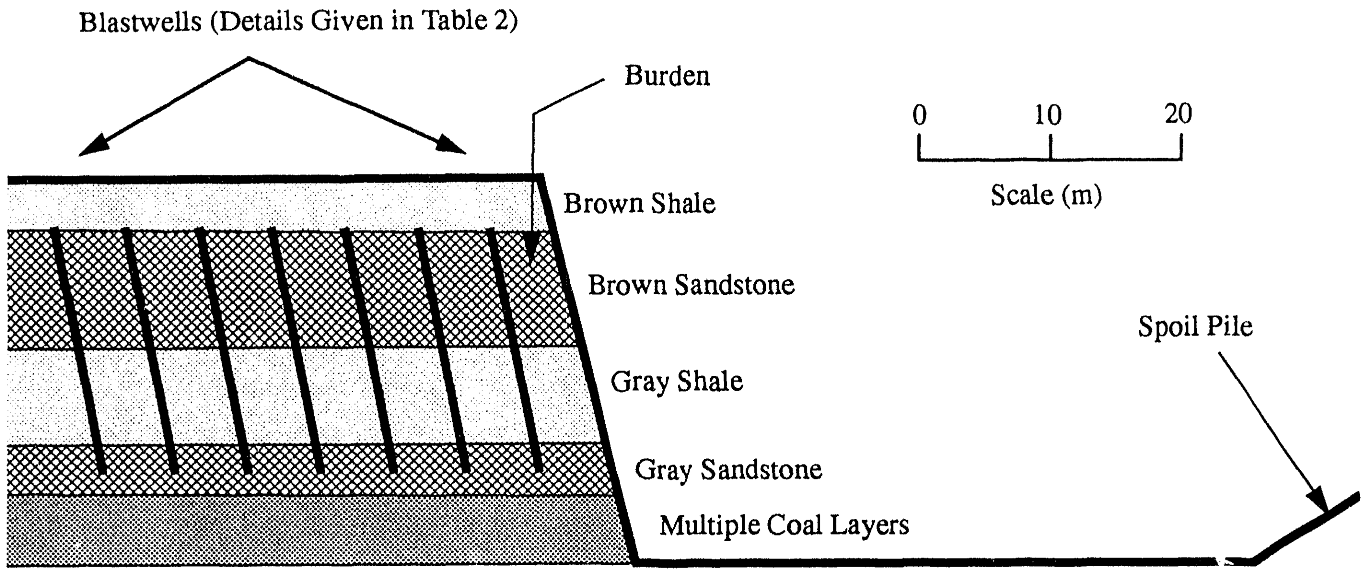

Figure 3: Schematic of Bench Blast Example Problem

Table 1: Material Properties

Material	Thickness (m)	Young's Modulus (GPA)	Poisson's 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

movement and damage to the coal seam offsetting the economic advantages of higher percent-cast.

The blast design parameters include burden, spacing, blastwell diameter, explosive type, blastwell angle and row delay. The blast design parameters are given in Table 2. The powder factor given in Table 2 is the mass of explosive per unit volume of rock. It is determined from the blastwell geometry and explosive density along with the burden, spacing and face height. These values are typical of this type of mine. The powder factor is higher in the front row because the spacing is half of that on subsequent rows.

4 COMPUTER SIMULATION

A DMC model was created to simulate the bench blast just described. All of the geometry, material and explosive parameters described in Section 2 have been included in the DMC simulation. The techniques used by DMC are well documented in other publications and will not be repeated here. The capabilities and the references describing them are given below.

4.1 DMC Capabilities

DMC is a two-dimensional spherical element discrete motion code that was originally developed by Taylor and Preece (1989 a&b and 1992) for modeling the motion associated with rock blasting. Spherical element bulking mechanisms have been added to allow spherical elements to behave more like rocks (Preece and Taylor, 1990). The program has been used for modeling confined volume blasting associated with oil shale retort blasting (Preece, 1990 a&b). DMC has been coupled with a gas flow com-

Table 2: Blast Design Parameters

Row No.	Burden (m)	Spacing (m)	Explosive	Powder Factor (Kg/m^3)	Hole Dia. (mm)	Hole Angle (degrees)	Row Delay (ms)
1	4.88	4.57	ANFO	1.3	270.0	15	40 to 500
2 thru 7	"	9.14	"	0.63	"	"	40 to 500

putation capability so that the explosive loading is automatically treated when an explosive is specified along with its physical parameters and equation-of-state (Preece and Knudsen, 1992a),(Preece, 1993a). This past year DMC has been customized to run in a bench blasting environment (Preece and Knudsen, 1992b), and the importance of spherical element packing angle (Preece, 1993b) and row delay timing (Preece,1993c) have been examined.

4.2 Discrete Element Model

The spherical element model used in this simulation is shown in Figure 4. The geologic layers are shown in different shades of gray. The blastwells are defined geometrically but are not displayed. This spherical element model has a packing angle of 10^{o} which allows significant sphere motion along horizontal bedding planes without much dilatation (Preece, 1993b). The model has 1521 spheres and the entire calculation executes in 1191 CPU seconds on a SUN SPARCstation 10-41 computer workstation.

4.3 Computational Results

Figures 5,6 and 7 show the model, with row delay times of 100 ms, at 100 ms, 500 ms and 7 s respectively. The 7 s configuration represents the final muck pile shape. The graph in Figure 8 illustrates the relationship between row delay timing and percent-cast derived from 16 different simulations using this model. Each simulation was performed with a different value of row delay timing and then the final muck pile shape was processed for the corresponding percent-cast. The expectation at the onset of these calculations was a smooth concave downward curve representing the relationship between row delay and percent-cast. The shape of the derived curve is a bit surprising compared to the expectation. Figure 9 illustrates five muck pile shapes corresponding to row delay timings of 40 ms, 60 ms, 120 ms, 150 ms and 500 ms. These timings represent the peaks and valleys of the curve in Figure 8. The 60 ms blast is obviously the best with the deepest trench (commonly referred to as the power trench) to next to the backwall and with the hump beyond the power trench being the furthest out of the three. It also has a significant pile of material next to the spoil pile. The dip in the curve in Figure 8, with the bottom at 120 ms, can be attributed to the fact that a hump of material (120 ms delay profile, Figure 9) does not make it past the cast-line (see Figure 2). Longer delays seem to overcome this problem.

The difference in calculated percent-cast between the high and low values for this model is only approximately 7.5% but is large enough to have a significant economic impact on a mine operation. Careful consideration of the muck-pile profiles in Figure 9, especially in the area of the power trench and the associated hump, leads one to the conclusion that differences in row delay timing produce stronger or weaker responses from the system. The oscillatory relationship between percent-cast and row delay timing is probably due to the fact that this is a complex dynamic system with many parameters having an effect. The mine operators have varied row delay timing somewhat from blast to blast in search of the optimum, which has been difficult to find. The search may be complicated by the fact that the bench height varies along the pit and optimum timing is probably effected by bench height. Finding an optimum timing by searching along the curve in Figure 8 one blast at a time also represents a significant challenge. This type of computer modeling can complete the 16 simulations required to produce this curve in less than a day and can thus provide considerable assistance in blast design.

5 CONCLUSIONS

The ability of DMC to predict differences in muck-pile shape and percent-cast as a function of row delay timing has been demonstrated. It was also discovered, during this study, that the relationship between timing and rock motion can be quite complex. It was demonstrated that in accordance with current blasting theory, very short or very long delay times produce the lowest material movement. Optimum timing resides somewhere between short and long delay times where enough time is allowed to prevent material bunching but the detonations are close enough to reinforce each other. However, this study also indicates that the timing versus percent-cast curve may have a local minimum where one might expect to see a local maximum (optimum timing). Thus, an intermediate row delay timing should not be assumed to produce a per-

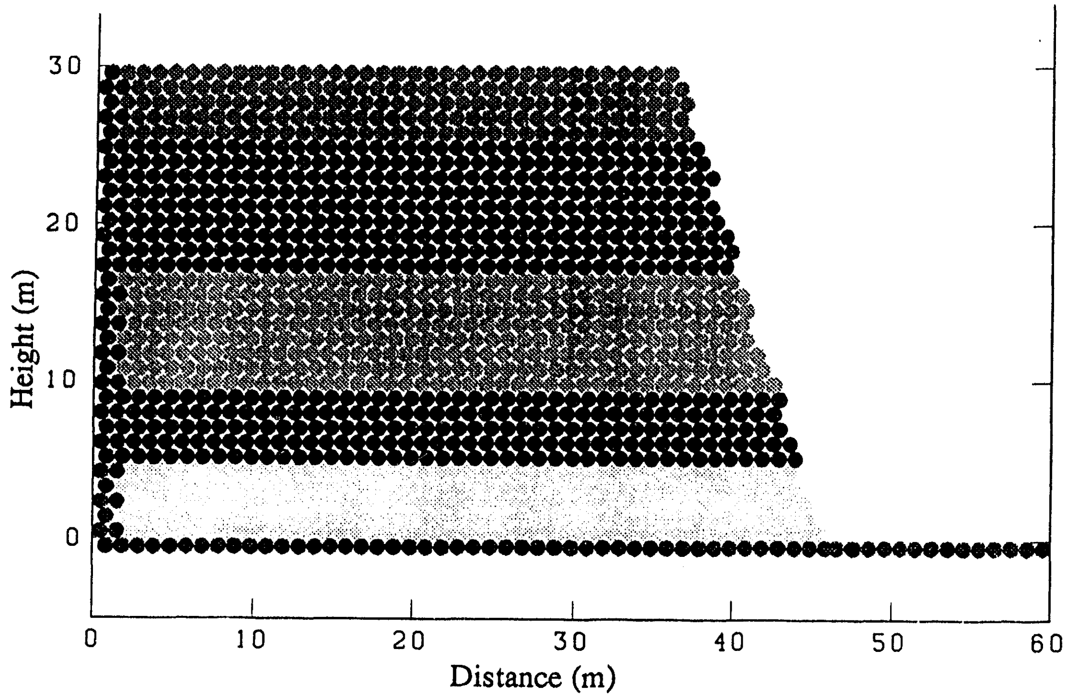

Figure 4: Close-In View of Spherical Element Model.

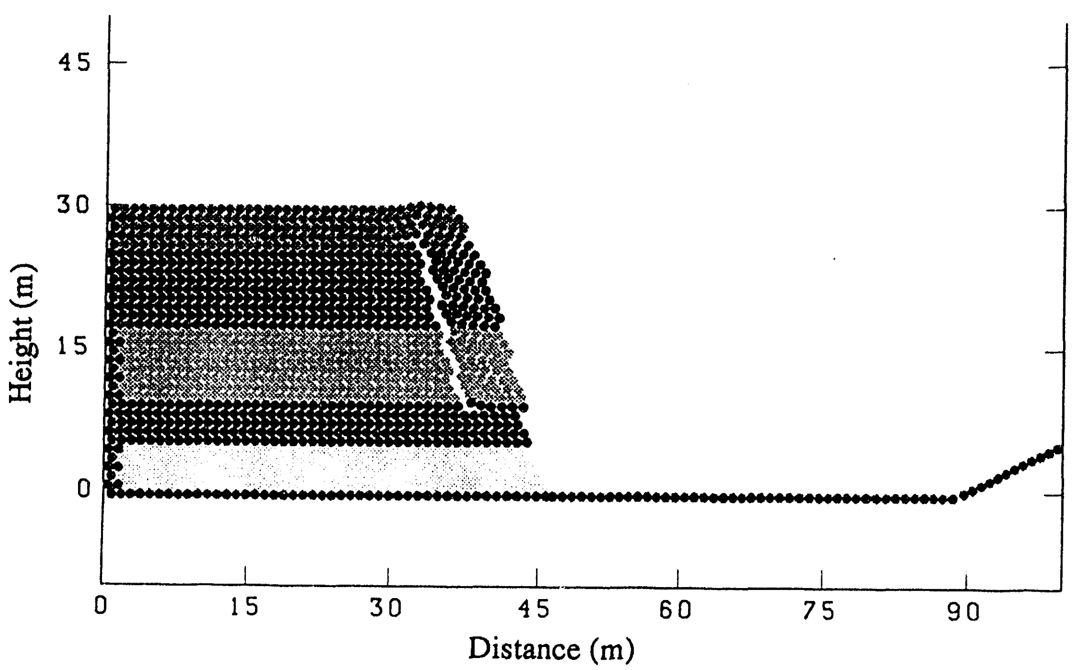

Figure 5: Spherical Element Model at 100 ms. Calculation With 100 ms Delay.

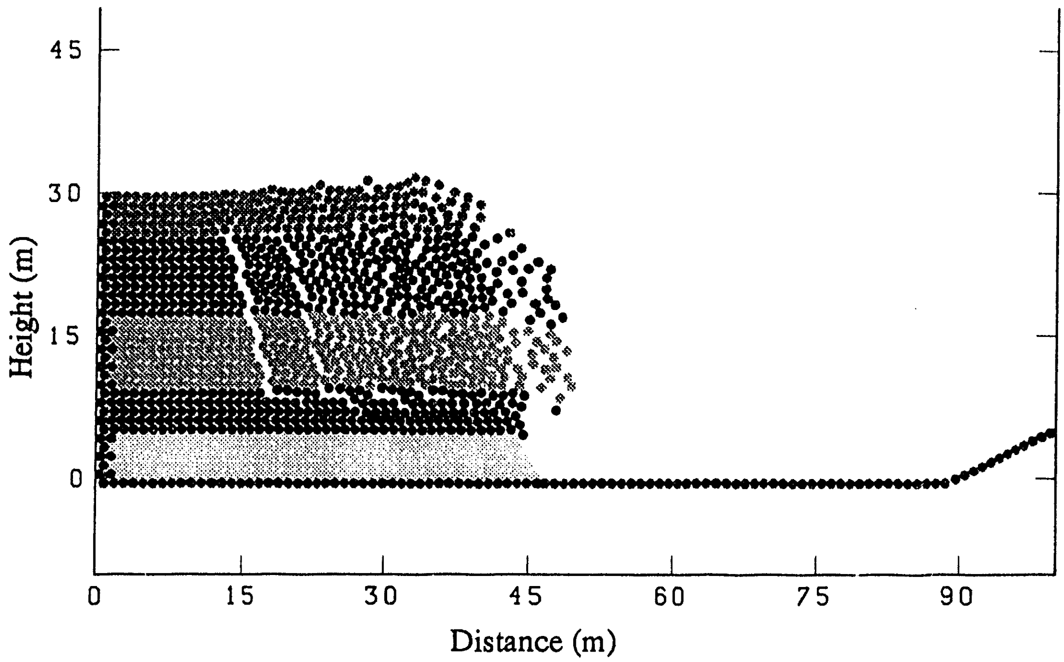

Figure 6: Spherical Element Model at 500 ms. Calculation With 100 ms Delay.

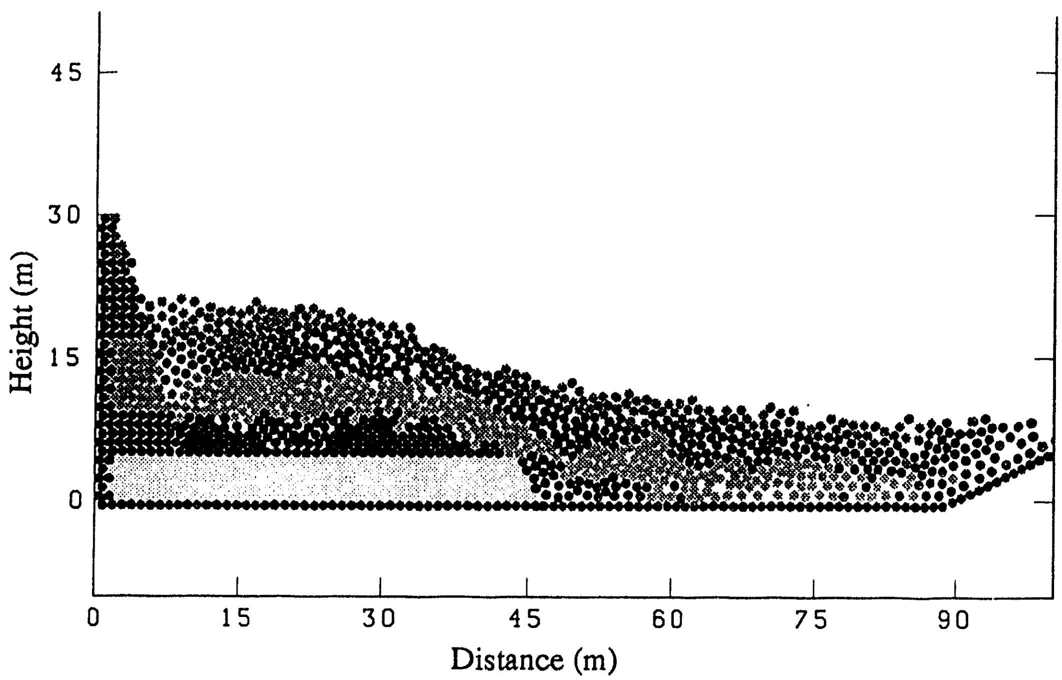

Figure 7: Spherical Element Model at 7.0 s. Calculation With 100 ms Delay.

cent-cast close to optimum.

A real need exists for further study of the effects of row delay timing, especially in the field using data from full scale bench blasts. This study will continue in the future.

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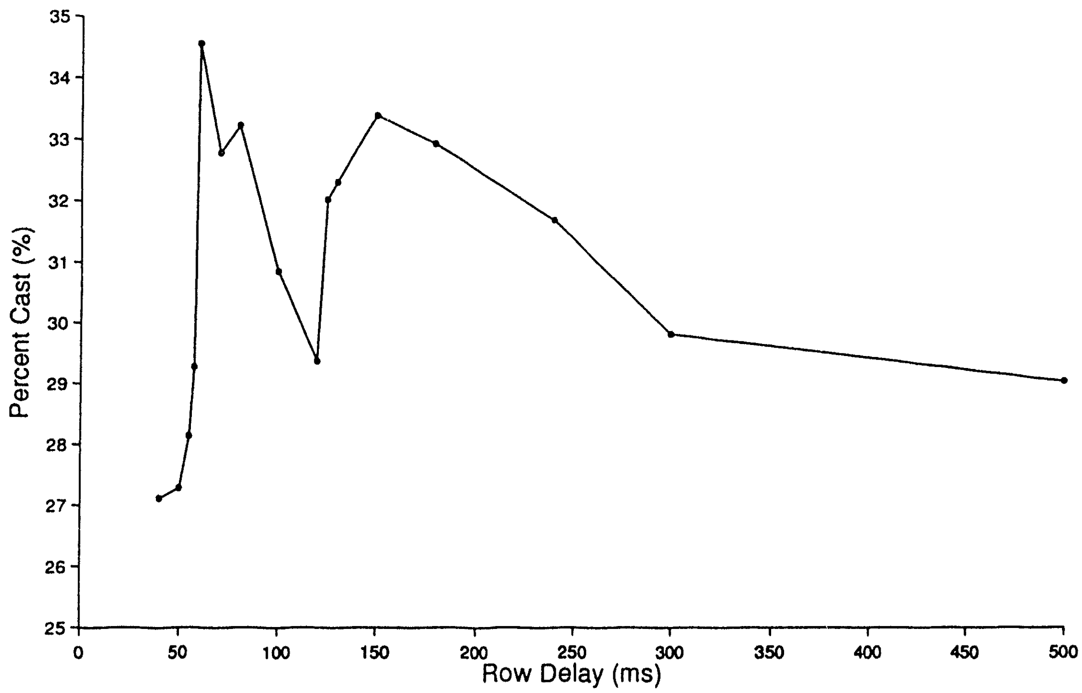

Figure 8: Percent-Cast Versus Row Delay.

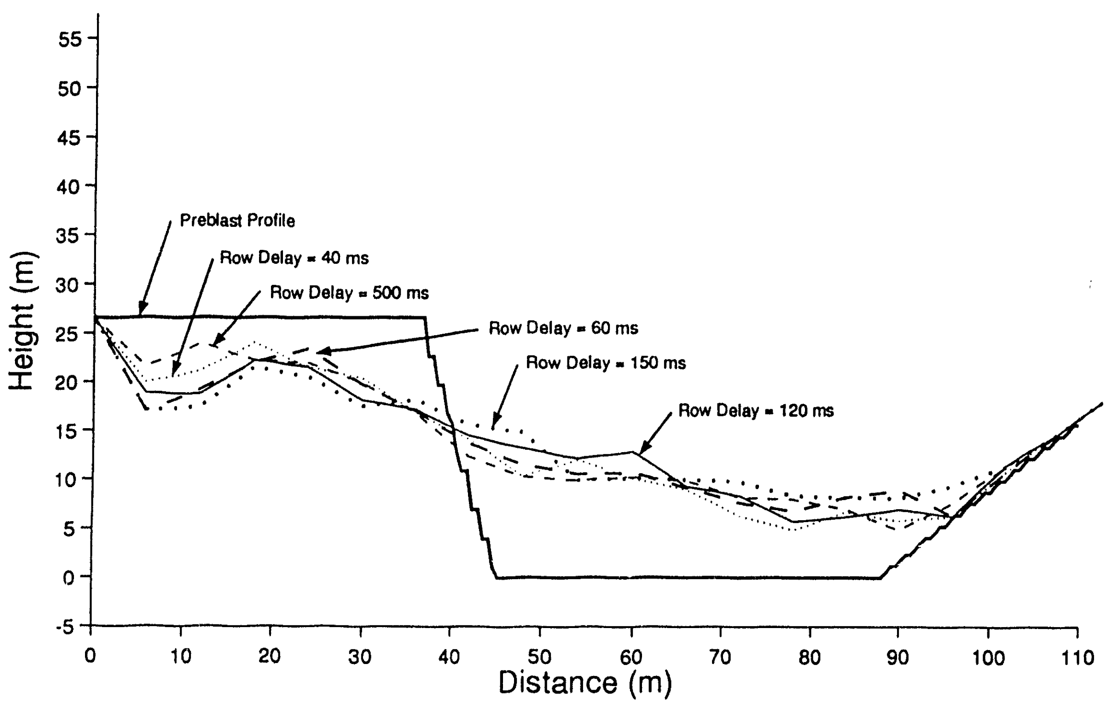

Figure 9: Comparison of Muck Piles for Several Different Row Delay Timings.

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