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Modeling Coal Seam Damage in Cast Blasting*

Dale S. Preece
Sandia National Laboratories

Stephen H. Chung
Orica Inc. Canada

Abstract

A discrete element computer program named DMC_BLAST (Distinct Motion Code) has been under development since 1987 for modeling rock blasting (Preece & Taylor, 1989). This program employs explicit time integration and uses spherical or cylindrical elements that are represented as circles in two dimensions. DMC_BLAST calculations compare favorably with data from actual bench blasts (Preece et al, 1993).

Coal seam chilling refers to the shattering of a significant portion of the coal leaving unusable fines. It is also refered to as coal damage. Chilling is caused during a blast by a combination of explosive shock energy and movement of the adjacent rock. Chilling can be minimized by leaving a buffer zone between the bottom of the blastholes and the coal seam or by changing the blast design to decrease the powder factor or by a combination of both. Blast design in coal mine cast blasting is usually a compromise between coal damage and rock fragmentation and movement (heave). In this paper the damage to coal seams from rock movement is examined using the discrete element computer code DMC_BLAST.

A rock material strength option has been incorporated into DMC_BLAST by placing bonds/links between the spherical particles used to model the rock. These bonds tie the particles together but can be broken when the tensile, compressive or shear stress in the bond exceeds the defined strength. This capability has been applied to predict coal seam damage, particularly at the toe of a cast blast where drag forces exerted by movement of the overlying rock can adversely effect the top of the coal at the bench face. A simulation of coal mine cast blasting has been performed with special attention being paid to the strength of the coal and its behavior at the bench face during movement of the overlying material.

Bench Cast Blasting

Cast blasting in surface coal mines employs explosives to not only break the rock but to also move the rock. Cast blasting utilizes significantly more explosives to move the rock than is necessary just for fragmentation. A typical cast blast is shown in Figure 1 several seconds into the blast. This particular blast consisted of 525 blastholes, 320mm in diameter, an average of 90 feet deep and utilized approximately

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DISCLAIMER

two million lbs. of ANFO. It is now accepted in the industry that muck movement through cast blasting is more economical than using mechanical equipment. Current cast blast designs employ high benches (30 to 50 m), large blastholes (300+ mm) with burdens and spacings on the order of 10 m. Powder factors for cast blast designs are typically 1.0 Kg/m^3 and higher. The object of these designs is to move the maximum amount of muck possible into its' final resting place to eliminate reprocessing with earth moving equipment. These designs work because the high powder factors result in the application of significant explosive energy to the rock. The high benches also allow conversion of significant potential energy into kinetic energy to move the rock further.

A common conflict in cast blasting is between rock movement and maintaining the integrity of the coal seam. Blast designs resulting in very large powder factors (on the order of 1.5 Kg/m^3) can move the rock very well but will also cause significant coal chilling or damage. Coal damage can be controlled to some extent by increasing the buffer between the bottom of the blasthole and the top of the coal seam. However, buffers that are too large will result in unbroken and undiggable rock above the coal. Cast blast design is usually a compromise between rock movement and coal damage. Even with balancing these factors cast blasting has revolutionized surface coal mining over the past 15 years making it more efficient.

Modeling of Bench Cast Blasting Using DMC_BLAST

The cast blast design for the example calculation that will be presented in this paper is given in Table 1. Figure 2 shows the 2-D discrete element model created to represent this design. This model has 3797 spherical discrete elements and five layers of rock represented in gray scale. The model also has eight rows of explosives that are not visible in Figure 2 but the effects of which are visible in Figure 3. Detonation of each row of explosives is modeled with a coupled explosive gas flow and particle motion calculation. Flow of the explosive gases outward from the blasthole through the rock is modeled with a finite difference technique (Preece et al, 1993). Loading of the rock particles by the explosive gas is done by integrating the gas pressure across each particle (Preece, 1993).

A material strength capability has been added to DMC_BLAST and has seen several applications (Preece, 1995). Rock strength is incorporated in DMC_BLAST simulations by adding links or bonds between discrete elements as shown in Figure 4. These links are used during the discrete element simulation to hold particles together and thus maintain the geometrical integrity of the particles and simulate material strength. These links can be broken which allows the discrete elements to move without restriction and thus simulate material disaggregation. Links can be broken based on simple tension, compression or shear stress in the link exceeding the strength of the material. In this calculation links were only allowed to break in tension since this mode had previously been determined to dominate failure during blasting simulations (Preece, 1995). The tensile strength of the coal layer in this simulation was set at 6.5 MPa (942 psi). Laboratory tensile strength data for coal could not be located. This value is based on an average unconfined compressive strength for coal of 40 MPa (Touloukian et al, 1981). In this calculation only the strength of the coal seam was modeled with interparticle links. It is assumed that the material above the coal seam has a high enough powder factor to totally fragment the rock and thus it is unnecessary to model rock strength in these layers.

Simulating Coal Seam Damage

Predicted rock movement for this blast is shown in Figure 3. Close examination of the top of the coal seam at the bench face shows a shear failure and movement of the top corner of the coal seam. It is proposed that this is the dominant mechanism for coal damage in current cast blasting practice. This region and the interparticle links are shown in more detail in Figure 5 at times of 0.3 s and 1.2 s. As seen at 0.3 s in Figure 5, a triangular region is broken at the face and toe of the coal by the detonation of the first row of blastholes. This is caused by compressive transient stress waves emanating from the bottom of the blasthole and reflecting off the surface of the coal at the face producing a tensile wave that breaks a triangular corner at the toe. This phenomenon occurs quite early in the blast and undermines the coal seam to allow a shear failure plane to propagate from the toe of the coal diagonally up to the top surface as shown at 1.2 s This shear failure plane in the coal allows the top corner of the coal at the face to slide into the pit and be lost.

In addition to displaying the intact links between particles, the particles can be colored according to the percentage of links to the particle that are broken. This variable, which is the ratio of the number of links broken to the original number of links is called *damage*. Plots of damage at the same location and times as Figure 5 are shown in Figure 6. The relationship between the link pattern and damage is obvious. It is often more illustrative to plot damage in color or gray shading because the intact links tend to blend together when the plotting scale is large making it difficult to discern areas of damage. Figure 7 illustrates six frames from the blast simulation with the variable damage being displayed in gray shades. This large view again shows the front/top corner of the coal seam being damaged and sliding into the pit where it will be lost. Figure 7 also indicates minor coal damage along the top of the coal seam induced by the detonation of each row of blastholes.

Conclusions

A study has been performed to demonstrate the ability of DMC_BLAST to model chilling/damage of the coal seam during surface coal mine cast blasting. With a good cast blast design the dominant damage mechanism is removal of only the top corner at the face of the coal seam. The fracture plane allowing removal of this corner extends diagonally upward from the damaged zone at the toe of the coal on the existing face created by reflected transient stress waves emanating from the first row of blastholes. Some damage of the top surface of the coal by the explosives in blastholes above is also evident. This damage is minimized by the buffer zone left between the bottom of the blastholes and the top of the coal seam.

This computational capability will be utilized to compare coal seam damage induced by different cast blast designs. Special emphasis will be placed on reducing the coal damage at the face. One obvious solution that is sometimes employed is to leave a buffer of broken rock at the face of the coal instead of a free face. Powder factors and buffer zone thickness can also be varied to determine the effect they have on coal damage.

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Table 1: Blast Design Parameters

Parameter	Value
Hole Diameter	311 mm
Hole Depth	45 m
Hole Angle	25^o
Stemming Length	9 m
Explosive Length	36 m
Explosive Type	Heavy ANFO 50/50
Explosive Density	1.3 g/cm^3
Number of Rows / Delay	8 / 100 ms
Tensile Strength	6.5 MPa
Buffer Zone between Bottom of Blastholes and Top of Coal Seam	4 m

Figure 1: Surface coal mine bench cast blast

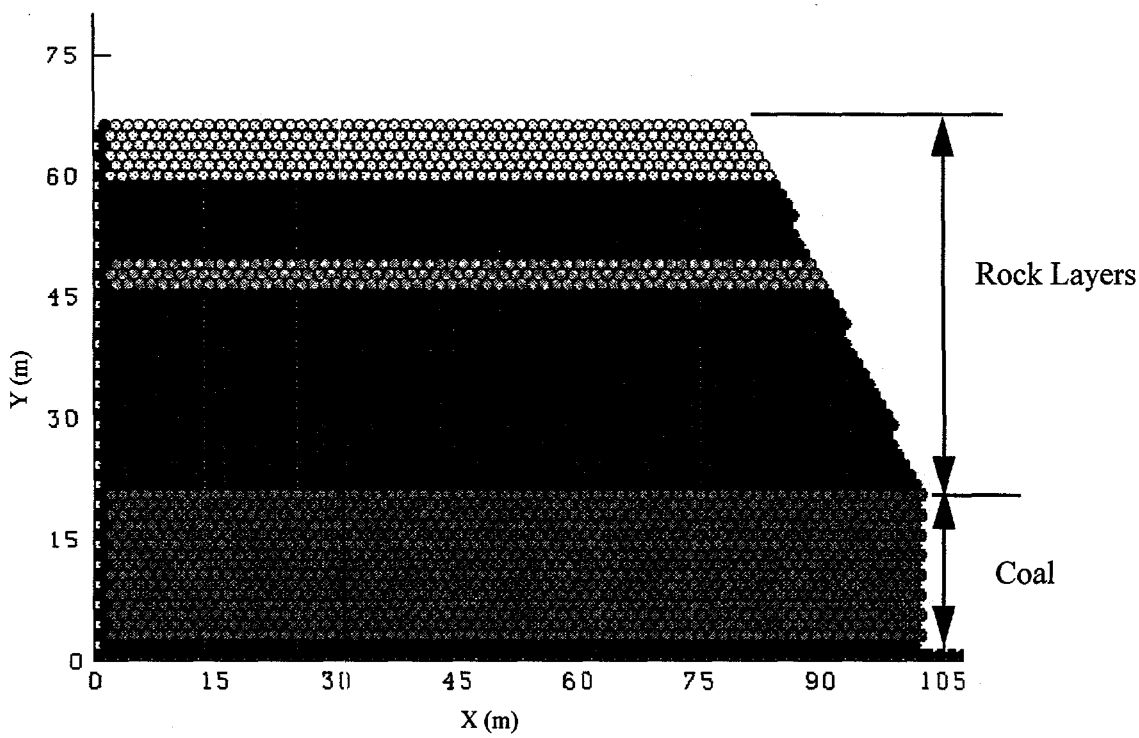

Figure 2: Discrete element model of surface coal mine cast blast.

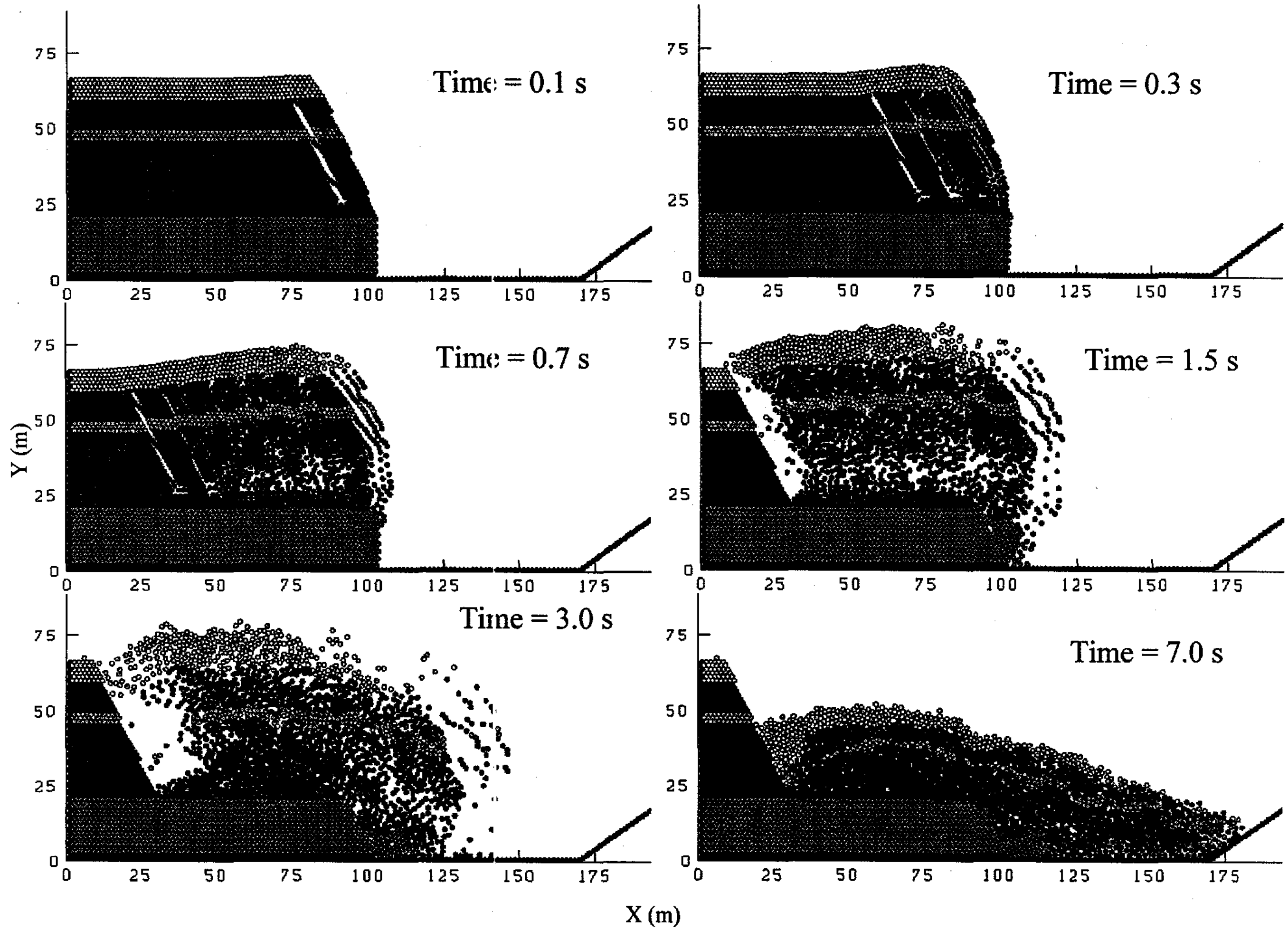

Figure 3: Coal mine cast blast simulation using DMC_BLAST.

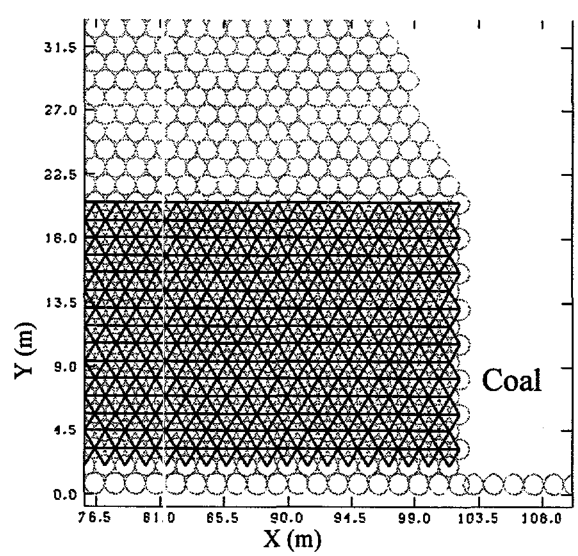

Figure 4: Links between spheres in the coal layer used to model coal strength.

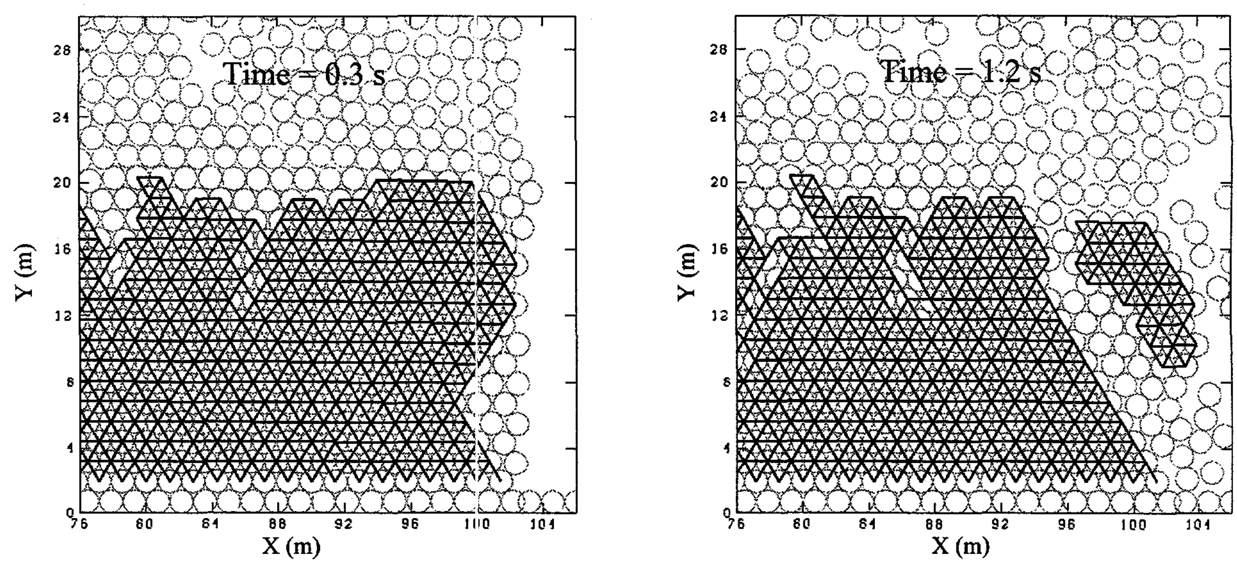

Figure 5: Links broken by tensile stress indicating coal damage in the vicinity of the face of the coal seam. Compare with Figure 3.

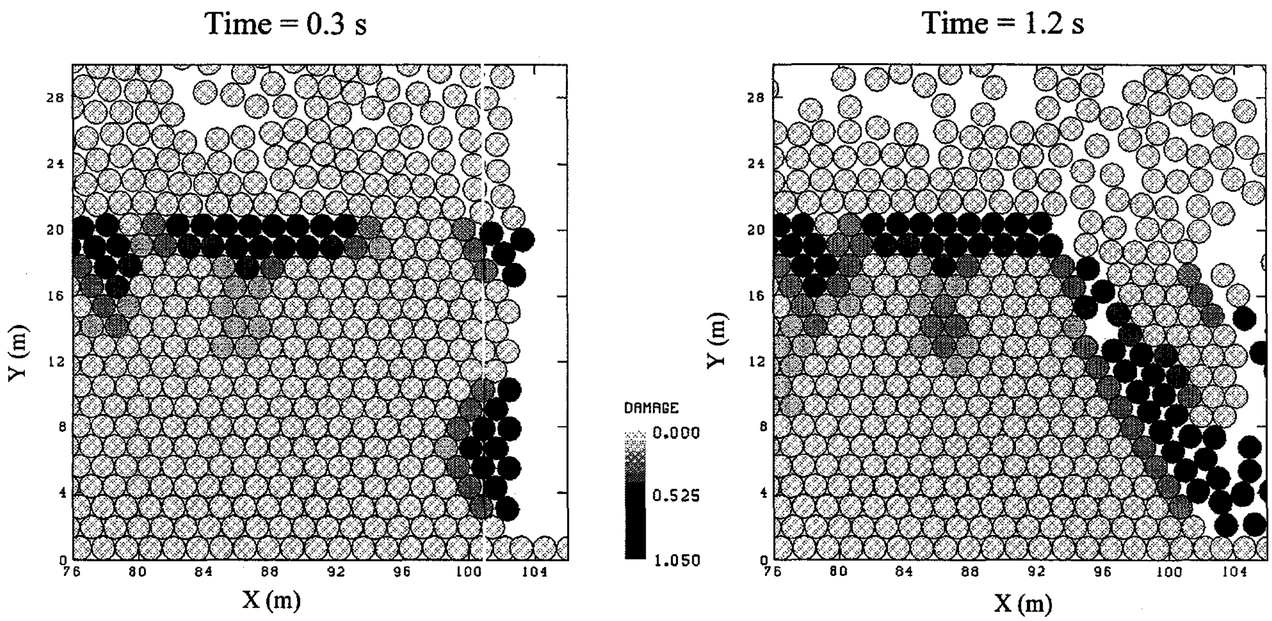

Figure 6: Damage in coal calculated as the percentage of broken links for each sphere. The times and locations for these figures are the same as for Figure 5.

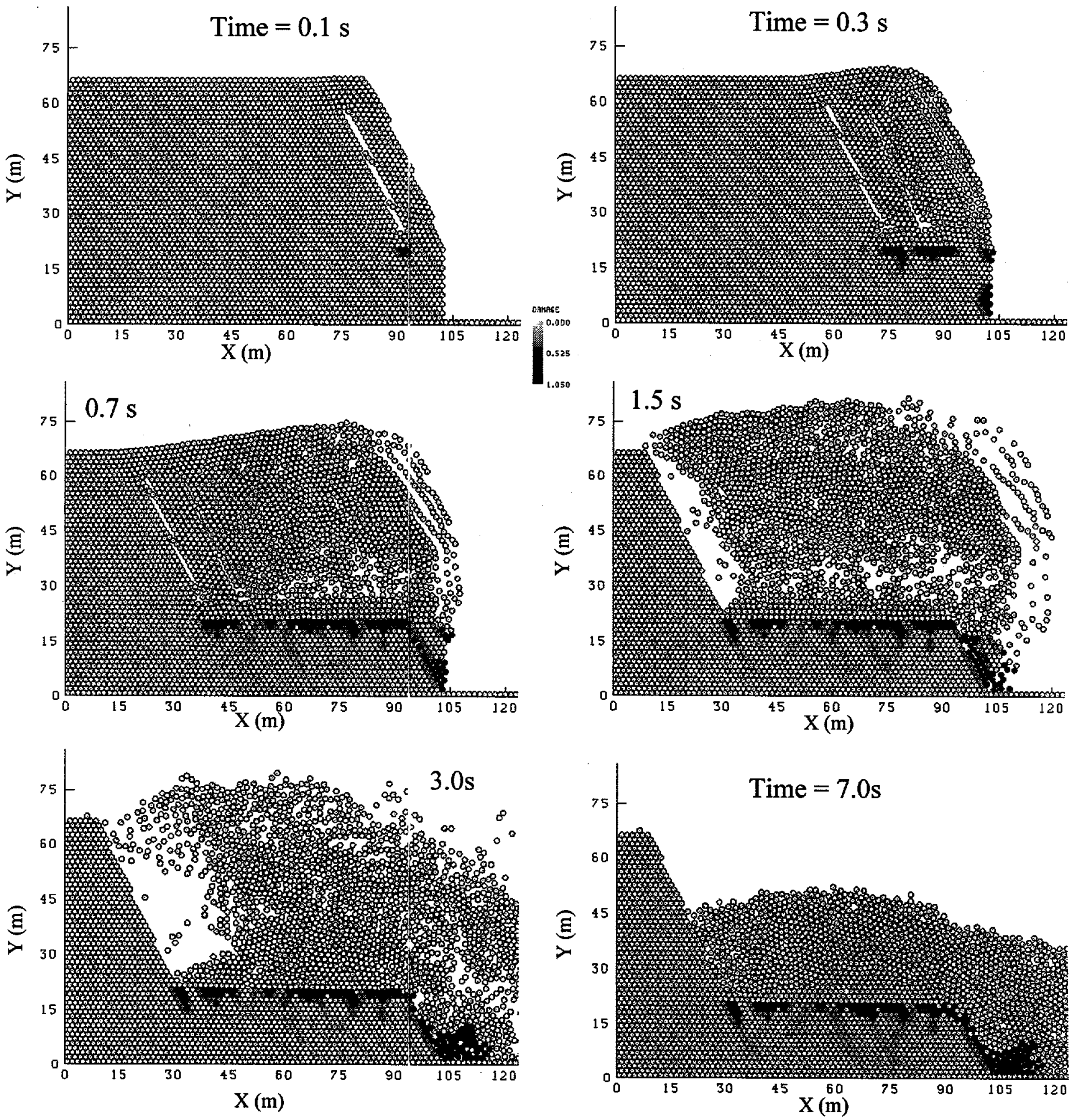

Figure 7: Calculated coal seam damage due to the applied explosive loading.