The blasting used to recover a dozer from a highwall

by Tristan Worsey and Tyler Acron

A dozer operator at a surface gold mine accidentally drove a D10 off the side of a highwall during a night shift. The blade of the dozer caught on the lip of a catch bench 18.3 m (60 ft) down, stopping its descent. The operator was able to exit the dozer and climb to safety.

The highwall the dozer drove off was at a 65° angle but the dozer sat on the catch bench at a 40° angle. Figure 1 shows the dozer caught on the catch bench.

Engineering and management evaluated multiple dozer recovery options, with safety as the overriding consideration. The initial plan was to rent a crane to lift the dozer out. However, the dozer manufacturer would not sanction tying off on the tool bar. This meant that personnel would have to remove the tool bar on the highwall, which was deemed unsafe. For work to be done at the dozer level, an access bench was necessary. Mechanical excavation was initially attempted, but only had success several feet down before the rock was no longer digable. The only option, other than abandoning the dozer, was blasting the access bench down to the elevation of the dozer blade.

Figure 1

Day after the dozer drove off the highwall.

The drill and blast team had discussed blasting solutions and came up with a sound approach that was presented when mechanical excavation failed. Normal mine production blasts use 200-mm (7.875-in.) holes drilled 7 m (23 ft) apart and loaded with 2.1 m (7 ft) of powder, with 30 to 40 percent hole utilization and a powder factor (PF) of 0.2 kg/t (0.4 lbs/st). Down the hole detcord and surface delays are used and blasts can be violent.

The potential risks were:

- Damaging the dozer with flying rock.
- Knocking the dozer down the highwall.
- Vibrations causing cascading material to bury and damage the dozer.

Fortunately, the ground was mostly waste rock, which meant there were few constraints on blasting. The plan involved increasing both powder factor and hole utilization to send more of the energy into breaking the rock and casting it away from the dozer while eliminating flyrock and minimizing ground vibrations. Blasts as near as 24 m (80 ft) away from the dozer were designed using one of the highest powder factors ever used at the mine, of 0.4 kg/t (0.8 lbs/st) or 0.9 kg/m^3 (1.6 lbs/cu yd) and a 63-percent hole utilization using the timing precision of electronic detonators with the process, philosophy and designs described in detail in this article. The process was documented using video, seismograph and laser profiling movement monitoring.

The D10 dozer was successfully extracted with none of the windows damaged and no

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Table 1

Pattern designs.

Shot type	Burden (ft)	Spacing (ft)	Hole depth (ft)	Hole diameter (in)	Bench height (ft)	PF lbs/ ton	PF lbs/ cyd	Stem-ming (ft)	lbs/ hole	Blend (% emulsion)
40 ft drop	17	18	43	7.875	40	0.54	1.10	24	500	15
20 ft drop	16	18	23	7.875	20	0.34	0.84	16	180	15
60 ft panel	13	15	63	6.75	60	0.8	1.62	23	700	15
Metric	(m)	(m)	(m)	(mm)	(m)	Kg/ tonne	Kg/m^3	(m)	Kg/ hole	%
40 ft drop	5.2	5.5	13.1	200	12.2	0.27	0.61	7.3	227	15
20 ft drop	4.9	5.5	7	200	6	0.17	0.43	4.9	82	15
60 ft panel	4	4.6	19.2	171	18.3	0.4	0.90	7	318	15

damage to the dozer from the blasting. It was back in operation at the mine after a thorough inspection and maintenance.

Methodology

The idea of the design was to put as much of the explosive energy into breaking and casting the rock as possible to reduce the amount of vibrations escaping the blast pattern. Explosive energy will take the path of least resistance. The less contained a blast is, the more energy goes into breaking and casting the rock in the direction of the free face than goes into the material behind the blast. The bigger the bench height to burden ratio is, the more tensile stress is exerted onto the rock. Rock tends to break the best under tensile stress. This is like trying to break a tall skinny pencil in half and a short fat pencil in half. The tall skinny pencil is a lot easier to break. The plan was to increase the powder factor by decreasing burden and spacing and increasing face height. This, in theory, would increase movement of the material, increase fragmentation and decrease ground vibrations.

Design

The bench elevation that the dozer drove off was on the 1,750 m (5,740 ft) elevation. The front dozer blade caught on the 1,731 m (5,680 ft) catch bench below. This meant the blast would have to fragment 18.3 m (60 ft) of material to be excavated to create a pad to work on the dozer. Two types of blasting were designed for creating the pad, one being for the initial drop and the other for removing the material closest to the dozer.

As it was necessary to drop down 60 ft (18.3 m), the drop cut was made by shooting two levels. The first level was drilled to 1,736 m (5,697 ft) and the second was drilled to the 1,730 m (5,677 ft). Normal production design was used for the drop as it was far enough away to minimize concern with moving or damaging the dozer. This also helped the speed of the mining cycle.

Signature hole analysis was done on a 12.2-m (40-ft) bench using normal production practice of down hole cord and on an 18.3-m (60-ft) bench using a down hole electronic detonator. An explosives supplier was used to analyze the signature hole data and recommended 33 meters hole-to-hole and 62 meters row-to-row for the 12.2-m (40-ft) bench and 25 meters hole-to-hole and 53 meters row-to-row for the 18.3-m (60-ft) bench. These situations simulated well at 30.5 m (100 ft) and 61 m (200 ft) locations from the blast hole.

Normal production patterns used at the mine site are 4.9 x 5.5 x 7 m (16 x 18 x 23 ft) (burden x spacing x depth) in ore and 5.5 x 5.5 x 13.4 m (18 x 18 x 44 ft) in overburden. The average powder factor on site is around 0.2 kg/t (0.4 lbs/st) of explosives. The decision was made to double the powder factor to 0.4 kg/t (0.8 lbs/st) for the special panel shots by decreasing the burden and spacing to 4 x 4.6 m (13 x 15 ft) and increasing depth to 19.2 m (63 ft). The pounds of explosives were limited in the 19.2 m (63 ft) face by using a 171-mm (6.75-in.) hole instead of normal 200-mm (7.875-in.) hole. A buffered blend with a density of 1.15 g/cc was used due to reactive ground potential. Unfortunately, appropriately sized crushed stone was not an option for stemming, so drill cuttings were used for stemming the holes. The quality of the drill cuttings for stemming was decent due to the damp conditions of winter and stemming ejection was minimal.

The panel shots were limited to three rows to minimize constipation of the shot. After three rows, relief caused by the row timing and material moving starts to decrease. This caused an increase in vibrations going back into the wall. The pattern designs of the drop cuts and panel shots are shown in Table 1. Figures 2 and 3 show a plane view of the pattern designs.

Figure 2

5,700 bench shot map.

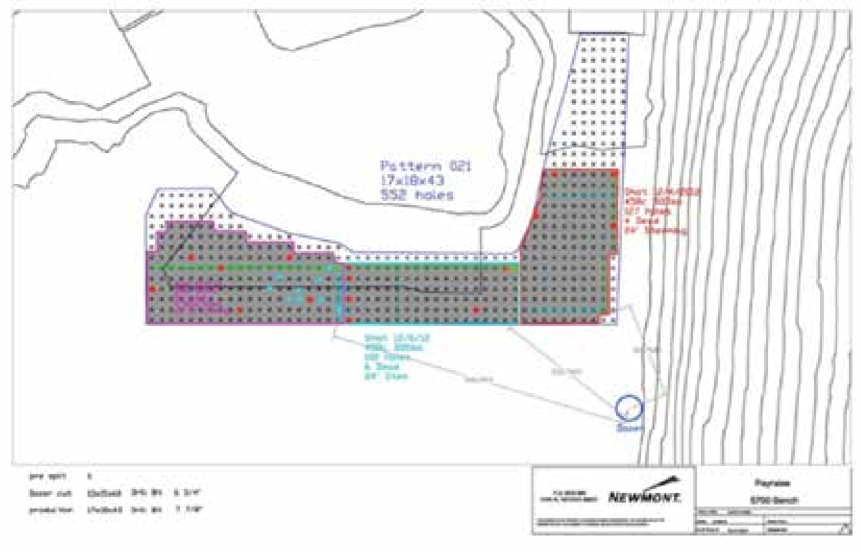


Figure 3

5,680 shot map.

Results

Unfortunately, there are no regulations on the maximum vibrations for a D10 dozer sitting on the edge of a high wall. The engineers had no starting place besides trial and error. Since the material with the dozer did not fail due to weather conditions changing, it was assumed that the dozer could take quite a bit more than the regulation for structures of 50.8 mm/s (2 in./s). Table 2 shows the distances away from the blast of the seismographs and seismograph data. Notice that the last three blasts had significantly more ground vibrations. This was due to the proximity of the blasts. From data collected vs. what was estimated, vibrations near the dozer were significantly reduced by using signature hole data and increasing powder factor by decreasing burden and spacing and increasing hole length. In a perfect world, the hole diameter would have been drastically reduced. This would have decreased pounds per hole to be less than production and still doubled the powder factor. However, with this operation going lower than 171 mm (6.75 in.) diameter, this was not an option.

The first blast went well. Laser profile scans were taken before and after the blast and showed minimal movement. Figure 4 shows a picture of the blast with the dozer in the lower right hand corner. The dozer was 50.6 m (166 ft) away from the blast. It was decided to bring the next pattern back from the crest edge because the scans didn't show any movement in the material between the dozer and the blast. The blast had 127 13.1-m (43-ft) holes, and 227 kg (500 lbs) of explosives per hole. The seismograph reading next to the dozer had a peak reading of 53.848 mm/s (2.120 in.s) at 26.9 Hz with the lowest frequency of 21.3 Hz at 46.736 mm/s (1.840 in./s). It was noted that normal blasting practices did send a lot of material down the high wall. If this design was shot by the dozer, it would have covered the dozer with material and potentially dislodged the dozer. Figure 2 shows the location of the 12-

Table 2

Seismograph distance from blast and data.

Blast	Seis distance (ft)	Seis Distance (m)	PPV (ips)	PPV (mm/s)	Frequency (Hz)	calculated PPV (ips) (k factor of 1140)	Calculated PPV (mm/s)
1st (12-4-12)	157	48	2.12	53.85	26.9	47.23	1199.64
2nd(12-5-12)	493	150	0.21	5.33	9.3	7.57	192.28
3rd(12-6-12)	220	67	1.36	35.54	17	27.53	699.26
4th(1-2-13)	153	47	1.52	38.61	22.2	22.14	562.36
5th(1-24-13)	170	52	1.88	47.75	13.4	58.95	1483.23
6th(2-1-13)	72	22	ips>5	mm/3>127	N/A	233.05	5919.47
7th(2-14-13)	92	28	N/A	N/A	N/A	157.44	3998.98
8th(2-27-13)	84	26	8.8	223.52	28.4	182.11	4625.59

Figure 4

First dozer shot.

4-2012 blast bordered in red.

The next two blasts were on the same bench as the first with the same design and timing. These blasts are outlined in pink (12-5-2013) and teal (12-6-2012) in Fig. 2. The second shot had 161 holes (8 dead) and was 161 m (529 ft) away from the dozer. This shot had a peak particle velocity of 5.334 mm/s (0.210 in./s) at 9.3 Hz with the lowest frequency being 8.9 Hz at 4.572 mm/s (0.180 in./s). Little to no movement was reported from the scans for the material around the dozer and the dozer itself. In Fig. 5, the blast shows a little stemming ejection. This is very common when using detcord down the hole as an initiator. The stemming ejection caused quite a bit of fly material that was unwanted as blasting progressed closer to the dozer. The third shot had 102 holes (six dead) and was 77 m (251 ft) away from the dozer. This shot had a PPV of 34.544 mm/s (1.360 in./s) at 17.0 Hz with the lowest frequency being 10.2 Hz at 1.360 in./s (34.544 mm/s). The scans reported little to no movement of the dozer from before the blast. In Fig. 6, the blast shows a little more violent stemming ejection.

Blast number four next to the dozer was a 6-m (20-ft) drop pattern to get the 1,737 m (5,700 ft) down to the 1,731 m (5,680 ft) elevation to fully free face the panel shot. Since this shot had less than half the explosives per hole than the 12 m (40 ft) drop, it was decided to shoot all 402 holes (11 dead) in one shot. This is the blast shot on 1-2-13 outlined in red in Fig. 3. The closest hole to the dozer was 158 ft (48 m) and gave a seismic reading of 38.608 mm/s (1.520 in./s) max at 22.2 Hz and the lowest frequency 13 Hz at 32.512 mm/s (1.280 in./s). The dozer scans did not show any significant movement near or

Figure 5

Second dozer shot.

Figure 6

Third dozer shot.

around the dozer. This blast (1-2-13) is outlined in red in Fig. 3. This blast had less ground vibrations than the first shot that was similar in distance but this shot had less than half the lbs per delay. This blast had a lot of stemming ejection and was also quite violent as can be seen in Fig. 7. A lot of material was cascaded down the side of the highwall and there was some fly material that could have hit the dozer if it had been closer. There was a little bit of snow that fell down the high wall in front of the dozer but no actual material fell.

Shot number five next to the dozer was the first panel shot. There was a failure in the wall that split the pattern up into two shots. In Fig. 3, there is a gap in-between the pink and teal shots that was the area that failed. The pink pattern (1-24-13) was the panel shot first. The blast had 53, 19 m (63 ft) holes, and 318 kg (700 lbs) of explosives per hole. The closest hole to the dozer was 67 m (219 ft). This shot gave a PPV of 47.752 mm/s (1.880 in./s) at 13.4 Hz which was the lowest frequency. As shown in Fig. 8, the before and after dozer scans came back negative for significant movement. All of the scans looked similar except for one so only two scans are included here. In the scan, anything that is in blue is up to 0.3 m (1 ft) of material gain, gray is zero movement and orange is up to 0.3 m (1 ft) of lost material. The green color means it went out of the range of -0.3 m (-1 ft) to 0.3 m (1 ft). The scan shows that the material near the dozer was basically unaffected. The material that is right next to the free face shows a little bit of loss but it was right in front of the blast and was expected to see a little bit of movement. One thing to note from this scan is that the material next to where the blast was located was unaffected. This meant that it was a safe distance (43 m or 140 ft) from the highwall to put the blast once patterns were placed directly behind the dozer. This blast, shown in Fig. 9, had the least amount of fly material and only one stemming ejection that was from a hole plugged during stemming.

Shot number six was the second panel shot next to the dozer. The blast had 12, 19 m (63 ft) holes (0 dead), and 318 kg (700 lbs) of explosives per hole. The teal pattern (2-1-13) in Fig. 3 shows shot number six. This pattern was only 33 m (108 ft) away from the dozer and had more burden than designed due to the failure. This pattern also had some short holes in the middle of the pattern. This shot gave a PPV greater than 127 mm/s (5 in./s). Unfortunately, the seismograph was set to a max of 127 mm/s (5 in./s), so data was not received. The scan showed little to no movement on and around the dozer. This was a good sign that the dozer was pretty well set in the catch bench and, as long as the material in the catch bench didn't get casted, the dozer would be fine. One observation from this blast was that the material in between the dozer and the blast did show a little bit of movement, as seen in Fig. 10. It was then decided to pull the rest of the panels 15 m (50 ft) back. Figure 11

Figure 7

Fourth dozer shot.

Figure 8

Before and after scan of the first panel shot.

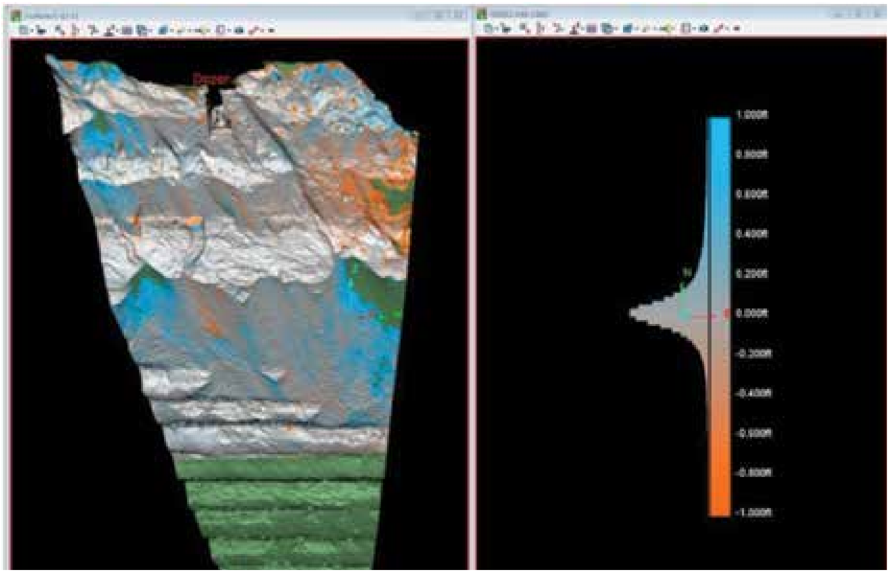
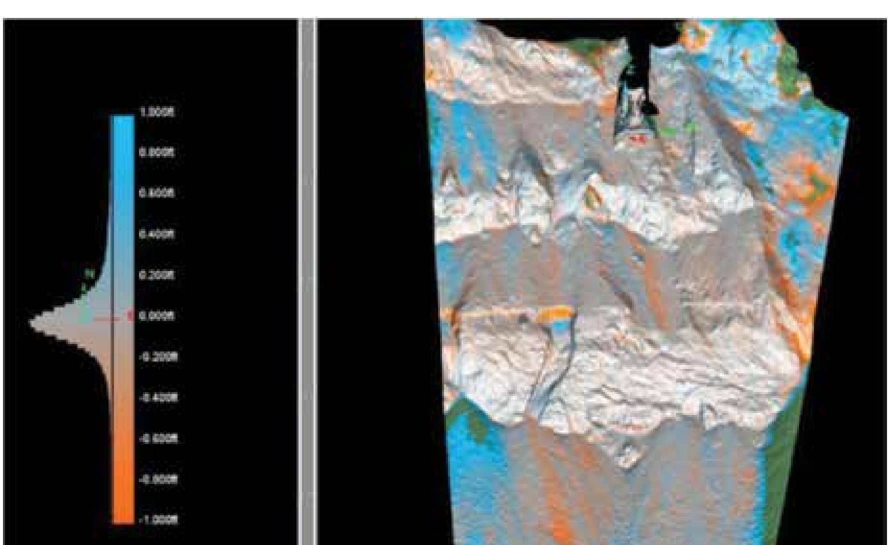


Figure 9

Fifth dozer shot.

Figure 10

Dozer scan of the sixth shot.



shows a photo of the shot that had no fly material and no stemming ejection.

Shots seven (2-14-13) and eight (2-27-13) were similar in design to the first panel shot and can be seen in Fig. 3 in green and yellow, respectively. Shot seven was 39 m (128 ft) away from the dozer and occurred while the blasting engineers were unavailable. The seismograph monitors were improperly set up and a valid reading was not obtained. The video was also missed, but the before and after dozer scans showed little to no movement of the dozer and the surrounding material. This shot was slightly north of being behind the dozer. Shot eight was the last dozer shoot needed for equipment space to retrieve the dozer and was slightly south of being behind the dozer. This shot had 53 19-m (63-ft) holes (0 dead), and 318 kg (700 lbs) of explosives. This shot gave a PPV of 223.52 mm/s (8.80 in./s) at 28.4 Hz with the lowest frequency of 4.7 Hz at 152.4 mm/s (6.00 in./s). The scans showed little to no movement of the dozer or the material around it. Figure 12 shows a photograph of the eighth dozer blast. This shot had some stemming ejection that was caused by using drill cuttings and hole plugging.

After the eighth shot, the bench was down to the dozer blade elevation and there was enough room for equipment to operate. The 15-m (50-ft) buffer zone ended up being easy to dig due to the shock wave from the blast creating microfractures in the rock. This was expected but not as well as it did. Figure 13 shows the dozer after final excavation of the buffer zone. The removal of the dozer was done by strapping onto the tool bar with the shovel and digging the material out from under it with a backhoe and then dragging it to more stable ground. The dozer had no blast damage and all of the glass was intact. Once the dozer was inspected and the fluids changed, it was out in the pit again working.

Conclusion

The dozer rescue using blasting

to excavate the bench to the level of the dozer was a success. Although vibrations were significantly more at the dozer with the panel shots than the drop cuts, using regular production blasting design would have caused even more vibrations in the same location and casted material onto the dozer. This could have disturbed the catch bench material that the dozer was sitting on, resulting in dozer loss. Using the technique of increasing powder factor by decreasing burden and spacing and increasing face height and casting the rock away from the dozer did significantly reduce the impact of blasting near the dozer. ■

Figure 11

Sixth dozer shot.

Figure 12

Eighth dozer shot.

References

2012. *Service Manual for a Cat D10 Dozer.* Peoria, IL, Caterpillar Inc.

2012, *Orica Pocket Blast Guide.* Melbourne, VIC, Australia: Orica Mining Services.

Walker, J. 2010, *AutoCAD Civil 3D.* San Rafael, CA, Autodesk.

[Don't miss the video, How to Blast a Bench Access.]

Figure 13

Dozer after final excavation.