Wall Control by Blasting Optimization at “Las Cruces” Open Pit Copper Mine (Spain)

M. Rocha
Mining Engineer

I. Carrasco
Mine Planning Manager. Cobre Las Cruces, S.A., Seville, Spain

J. Castilla
Universidad Politécnica de Madrid, Madrid, Spain

S. Cooper & M.D. Rodríguez
Geotechnical Division at Cobre Las Cruces, S.A., Seville, Spain

ABSTRACT: Slope stability is one of the most important challenges in open pit mining. Blasting can be considered a principal cause of induced damage to these slopes. This induced damage has repercussions with respect to design and maintenance, additional support costs and above all mining safety. Nevertheless, a firm control on design and implementation of contour blasting can help to minimize damage and other adverse blast effects. This project deals with the optimization of contour blasting in the copper mining project Las Cruces (Inmet Mining), located in Seville, Spain. It develops the concept of continued improvement of contour blasting to minimize induced damage to slopes, analyzing the effects of energy distribution during rock blasting exercises. In this way, through a merging of energy data and geotechnical rock characteristics, it may be possible to obtain, for a particular rock, characteristic damage energy and, consequently, an optimum blast design. The final objective of the project is to minimize damage to the rock mass, achieving a more precise excavation face, minimization of maintenance costs and overall an optimum slope stability. During the evolution of the mining pit, blast design at Las Cruces Mine has evolved, utilizing a variety of known techniques as considered appropriate with reference to rock quality, water ingress, joint setting and required geometry. This project is divided into four different stages. Firstly, blasting data has been collected and analyzed using bespoke blasting software. The second stage comprises the analysis of the blasting energy data and rock mass joint distribution combined with geotechnical data to estimate the energy blasting effects on each material. Stage 3 deals with the design contour blasting. These blasts take into account the available energy limits obtained as a result of studying previous blasting activities and geotechnical characteristics together. Then, in the final stage different designs and implementation changes are formulated and trialed in situ to achieve results and meaningful conclusions. In summary, the results to date, and their evolution in this project will be highly beneficial for the mining operation, obtaining better and more efficient results in slope accuracy and stability.

1 INTRODUCTION

Las Cruces is a copper open pit mine located 20 km. northwest of Seville, Spain and fully owned by Inmet Mining Corporation (Toronto, Canada). Las Cruces project is located in the eastern part of the prolific Iberian Pyrite Belt VMS district and is one of the highest grade copper deposits in the world. Original resource outlined was 17.6 million tonnes @6.2% Cu, equivalent to 1 million tonnes of contained copper. The Las Cruces mine has been in operation since 2009, having processed 1.4M tonnes in total as of December 31, 2011. The hydrometallurgical plant uses atmospheric ferric leaching technology, followed by SX – EW to produce copper cathode at a design production rate of 72,000 tonnes per year with a 91% recovery. An ongoing stockpile blending program helps smooth the plant feed grade. The deposit is a secondary sulphide mineral deposit formed by supergene enrichment in the up dip part of a massive primary sulphide zone. Near surface oxidation of the sulphide minerals to an iron oxide gossan, transport and precipitation of copper and finally replacement of unoxidized primary massive sulphides at depth formed the orebody. Subsequent submarine deposition buried the deposit under 100 to 150 meters of sandstone and calcareous mudstone (marl). The deposit has a general strike to the east and a dip to the north at about a 71º angle. The current ultimate pit design is approximately 240 meters deep, 1.5 kilometers long (east - west), and 0.9 kilometers wide (north - south). Contour blasting techniques are implemented to minimize induced damage to slopes and other adverse blast effects. Slope stability has a very important, positive and absolutely necessary consequence: safety. Clearly, all these improvements can be translated into profits for the operation. Contour blasting allows a more precise excavation face to be achieved and subsequently reduces dilution issues and risks of material fall-off; it also contributes to minimization of slope maintenance costs and, in some cases, additional slope support can be reduced or eliminated. Blast energy that does not result in rock fragmentation and displacement induces damage to the rock mass, opening new fractures and creating weak planes. In consequence, what can remain is a potentially hazardous fractured rock mass. The best way to minimize the induced damage from blasts areas to adjacent slopes is by controlling blast energy release. Nevertheless, it is important to take into account the balance between contour blasting costs and slope maintenance costs.

2 GEOLOGY AND GEOTECHNICAL DATA OF THE MINE

Geological and geotechnical information is essential to slope design and optimized blasting design. At Las Cruces the general geological profile predominately comprises tertiary Guadalquivir Blue Marls over a Paleozoic Volcano-sedimentary sequence hosting the poly-metallic ore body. The Table 1 below provides a summary of rock types encountered as work progressed within the mine pit:

Table 1. Paleozoic Rock Strengths.

SLOPE	VOLCANICS		SHALE		GOSSAN	
	U.C.S. (MPa)	R.M.R.	U.C.S. (MPa)	R.M.R.	U.C.S. (MPa)	R.M.R.
SE	107	55	57	46	-	-
E	80	44	73	45	103	47
NE	104	48	90	50	113	51
N	119	51	-	-	141	69
NW	75	50	82	48	127	63
SW	137	60	79	48	132	59
MEAN	104	51	76	47	123	58

As can be seen from the data in Table 1, rock strength and rock mass rating is variable. Weak rocks are especially prevalent in the contact zones between ore and shale, and other areas closely associated with post-formation faulting.

3 BACKDROP OF THE MINING OPERATIONS

The Las Cruces Mine is a moderately sized open pit mining operation utilizing contract drilling and blasting, loading with hydraulic excavators, and transport by trucks. The overall pit slope angle is 28º in the marls and sandstone, and 43º in the Paleozoic bedrock. Trucks haul the ore to blending stockpiles prior to introduction into the crusher. Current mining rate is 1.2 Mt ore and 7 Mm^3 waste per year. An option for underground extension of the operations exists at the end of the life of mine.

Bench parameters are provided in the Table 2 shown below. Operational bench height is reduced down to 5 m in Paleozoic rocks to improve grade control and selective mining.

Table 2. Pit design parameters.

	Tertiary	Paleozoic
Batters	50º	70º- 75º
Berms	4 m - 10 m	5 m
Bench High	10 m	5 m / 10 m
Ramps	8%	10%

Pit development comprised 6 consecutive pushbacks. Currently, ore production comes from phase 2. Phase 3 stripping is well advanced and ore is expected to be excavated in this Phase in second quarter of 2013.

The overburden layer is free-dig to 90 m depth. Preblasting with ANFO is then used (0.15 Kg/m^3). Blasting starts when marls and sandstone interphase is reached. Dope emulsions are used systematically due to the presence of water.

4 CONTOUR BLASTING FUNDAMENTALS

The purpose of contour blasting is to produce stable and homogeneous surfaces, easy to clean and maintain, by reducing damage and cracking in the remaining rock mass. This kind of blast helps to achieve an increase in slope angle, with economic benefits such as increased ore reserves or decreased ore to waste ratio. Also, a minimization of fall-rock risk associated with slopes could reduce berm width improving the productivity and the operation safety.

In contour blasting techniques, the principal characteristic is that the spacing in the last row (near the wall) is less than the spacing in a production blast or a modified production blast. Therefore, cracking progresses towards the lower strength path, that is to say, from hole to hole to create a cutting plane with decreasing radial fractures creation. The fundamental conditions of the slope row in contour blasts are:

- The relation between burden and spacing is inverted. Now, burden is bigger than spacing.

- Reduced charge concentrations, to use only sufficient energy to open a cutting plane between the holes. Different explosive loading techniques can be considered to achieve this effect such as decoupled charges, decking or air decking.
- Appropriate stemming material (1/10 drilling diameter and angular shape) to achieve the necessary timing of the explosive gases inside the hole to make use of all the possible energy whilst avoiding over confinement.
- Reduction of inter hole surface delays, even detonating them simultaneously.

There are 3 fundamental ideas needed to be clear for a better control of the blasts:

1. The explosive energy in its movement will always travel along a preferred lower strength path so there must be sufficient distance from the required slope location. Blast relief is critical.
2. Productivity decreases in slope control zones.
3. Considering the geotechnical structure of the site, there are 4 types of blast to control the energy in the slopes, pre/post-splitting, buffer blasting, trim blasting and line drilling.

Contour blasting is based on a balance between the keys of the efficient blast design that link several aspects of explosive energy with blast results. These keys are the base and guide to the optimization process. They are: Energy Distribution, Confinement and Energy Amount. (Floyd, 2009)

Detailed information is needed to achieve an accurate blast design adjusted to the site conditions and to the goal:

- Seismic characteristics of the site. Sometimes, vibration data is only taken into account if there exists local restrictions such as third parties buildings or structures close to the mine. Slope responses to blast vibrations should be considered in contour blast design process.
- Free faces available. Ensuring a good blast release with one or two free faces is critical to facilitate the blast displacement away the slope.
- Water conditions. The presence of water in the site reduces the effective strain and, therefore, the cutting strength of the discontinuities of the rock mass.
- Slope design. Occurrence of alteration zones will impact on the rock mass strength and, subsequently, slope stability and design parameters. It is important to identify these potential hazardous areas prior to short term planning and blast design processes.
- Geology and Geotechnical data. No doubt, this is the most important information needed to achieve a good contour blast. Design parameters will change depending on the geotechnical properties of the rock mass.

5 PREVIOS STUDY OF THE PIT SITUATION

Prior to develop the optimization process itself, an analysis was carried on site to evaluate current blasting procedures and their effects on pit slopes. The study comprises different stages: geotechnical and geometrical study, blast modeling and analysis, KPIs identification and blast performance evaluation. Based on this study, a series of recommendations were proposed to the Mines Department staff to improve contour blasting.

5.1 *Planned pit design*

The initial pit design of Las Cruces pit implemented studied dimensions to achieve project continuity, not only from an operational level but for safety as well. The design of the mineralization area of the pit is shown in Figure 1.

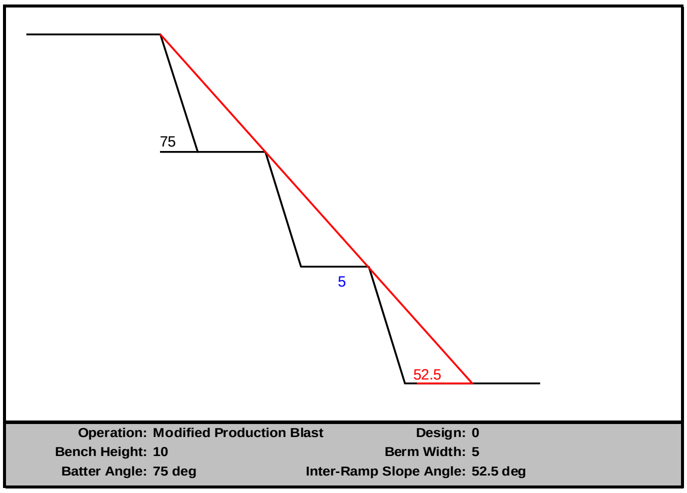

Figure 1. Open pit slope design (Paleozoic area).

5.2 *Contour blasting practices at Las Cruces*

During the mining operation and related to slope stability and contour blasting, there have been different blasting designs looking for the optimal results and improvement. The stages followed are:

a) Production blasting: damage to the final slope as shown in Figure 2.

b) Modified production blasting (Figure 3): is a first approach to the problem but is not properly a contour blast.
The modified production blast has a few differences with a normal production blast. The most important changes between both blasts are:

- Short sequence times between rows.
- Improves berm definition by eliminating subdrill in the holes close to future berm areas.
- Ensures blast relief by limiting the number of rows to 3 or 4.

- The slope row is located with a designed offset to the toe of the projected final slope, to avoid damage but to guarantee ease whilst excavating the slope toe. This distance changes depending of the geotechnical domain in the pit.

The explosive charge of the modified contour blast is the same as in a production blast. The stemming material is the drilling detritus and the pattern is 4 x 4.5 m. The damage caused to the remaining rock mass is still important in certain areas of the pit, as showed in the Figure 4.

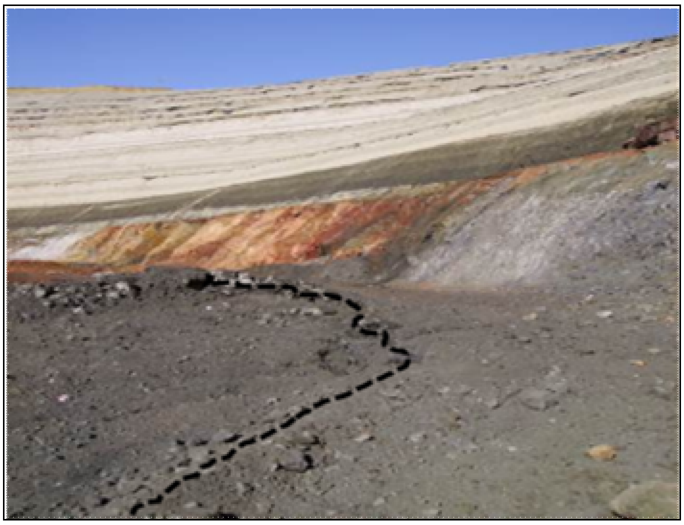

Figure 2. Induced cracking due to high confinement and excessive energy levels.

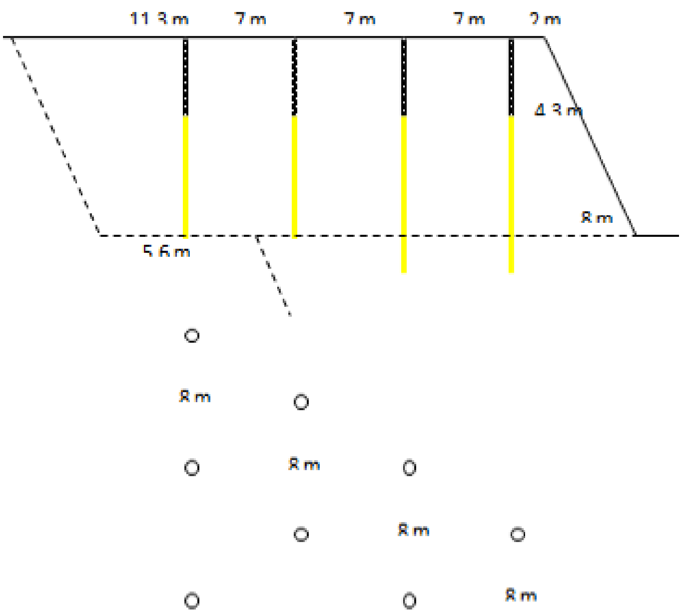

Figure 3. Design of “Modified Production Blasting”.

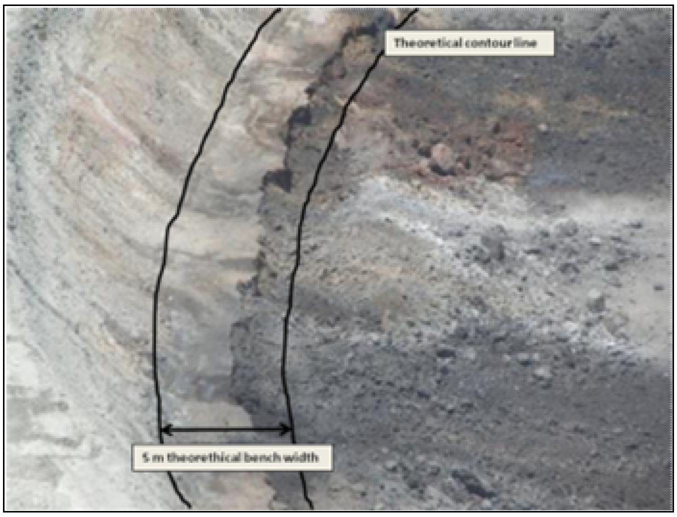

Figure 4. Backbreak caused by modified production blasting.

c) Contour blasting: optimization.

6 PRE-OPTIMIZATION BLASTING STUDY

After modeling 9 modified production blasts (pre-optimization blasting) several results are shown in different subjects: field measurements of the real situation of slopes and berms in the pit and results of the simulation with JKSimBlast software, using 2DBench module.

6.1 *Berm situation*

Perhaps the most important issue in the pit is the deviation of actual berm widths related to the planned design. An example is given for -125 level (Figure 5).

The average berm width is 3.14 m compares to planned 5 m. Only the 6% of 100 measurements are between +10% and -10% (4.5 m and 5.5 m) of the required dimension.

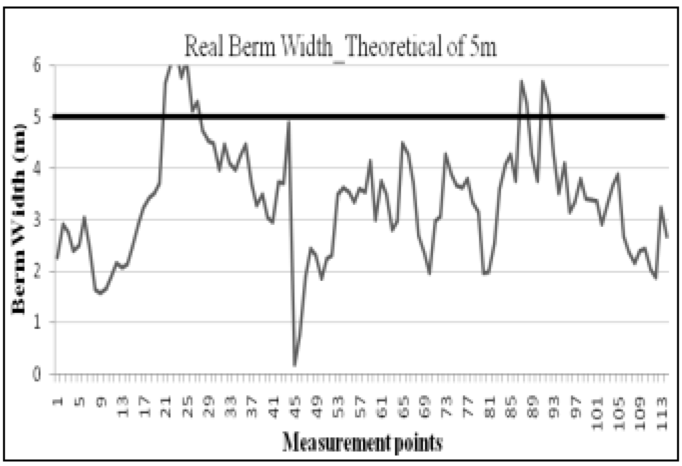

Figure 5. Real vs. theoretical berm widths at -125 level.

Over excavation of catch berms is the most important problem, overall in the gossan area.

6.2 *Slope situation*

The study of the real situation of slopes in the pit is done by measuring and comparing actual and projected crests and toes of the benches.

The analysis of more than 140 surveyed points showed that over than 92% of bench toe was more than 0.20 m out of design. The average difference between actual and projected toe was approximately 1 m.

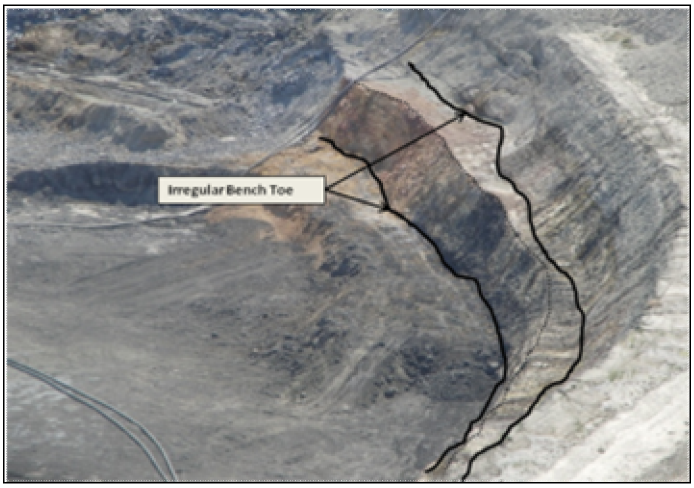

Figure 6. Bench toe is out of design.

The problem with bench head is almost the same. More than 93% of bench head was out of design for more than 0.20 m, with an average difference of 1.30 m. An over excavation in crests appeared and considering the problems with the toe, this explains the berm width issue as shown before. Secondary effects of this situation were that hazards increased for non-operative catch berms. Figures 6 and 7 show the problem.

Figure 7. Bench head is out of design.

6.3 *Energy distribution analysis*

Blast simulation with JKSimBlast software allows quantification of the energy range in which the blast creates a break, damage or no effect in the rock mass. It is possible to estimate the response of the rock mass given a certain energy level.

Nine contour blasts were modeled and the energy distribution analyzed and joined with the pre and post blasting topography, taking into account the heterogeneity of the geology. It is possible to adjust the energy range needed in the design step to guarantee the appropriate cutting and the minimization of induced damage to the surrounding rock mass.

The energy distribution analysis was checked in different ranges between 40 MJ/m^3 and 3 MJ/m^3.

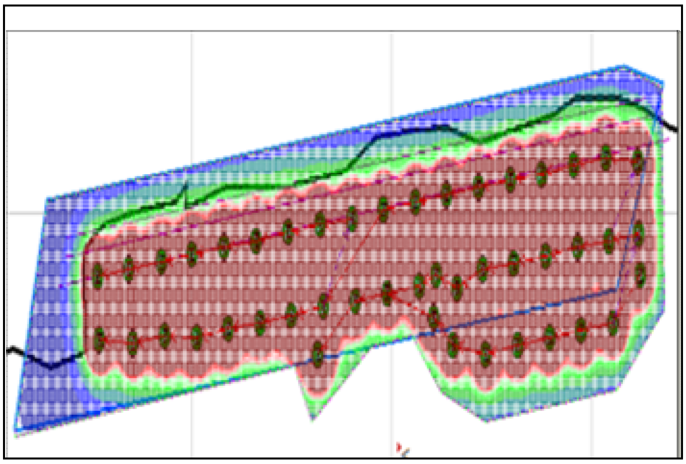

Figure 8. Energy distribution analysis with the real topography of the slope loaded.

With the results of the analysis, a confirmation of the studied pit area is obtained: the cutting plane in the slope blasting is created with energy levels over 5 MJ/m^3. The Figure 8 shows the energy distribution and the topography of the final slope. The dominant energy of cracking and cutting is all over 5 MJ/m^3, being the energy that creates the slope (the red color marks 5 MJ/m^3 energy limit). (Scott, A. et al, 1996)

7 PRE-OPTIMIZATION STUDY RESULTS

The study above concluded that fragmentation problems can be caused by many factors, that heterogeneous blasting material should be taken into account and affects subsequent blast energy distribution. The principal effects of blasting in the slopes of the pit are:

7.1 *Blasting domains*

After the development of energy distribution analysis all around the pit, blasting domains were established related to the behavior of the different existing material. Pit domains are:

1. Shale zone (Figure 9): this is the most problematic area. Jointing dips into the pit and water inflow and rock mass weakness makes it a real challenge for the engineers. Following feasibility trials, this area is now loaded directly without drilling and blasting.

Figure 9. Shale zone.

2. Fault zone (Figure 10): more consistent than the shale area but its highly weather condition makes over excavation very easy. It is necessary, therefore, to pay close attention at design stage and during subsequent loading of this material. The energy pathways need to be tightly controlled.

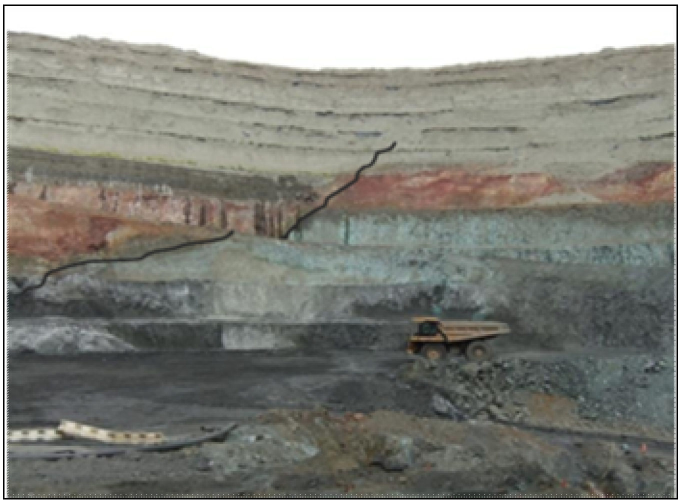

Figure 10. Fault zone.

3. Mineral-gossan zone (Figure 11): this is the most competent and consistent geotechnical area of the pit but, the contour blasting results can be improved with an accurate control of the energy distribution. The trial blasting will be in this zone.

Figure 11. Mineral-gossan zone.

In general, the entire pit needs an accurate and appropriate blasting energy control depending of the zone sensitivity.

7.2 *No continuity in the open pit design*

The damage is caused by an inappropriate energy level and an incorrect energy distribution. As shown in the Figures 6 and 7, the implemented energy in the slope, for the geological conditions, isn´t appropriate in related to the distribution. Loading and slope cleaning operations are very important in this stage and they need to be undertaken with care.

7.3 *Berm width reduction*

An incorrect energy distribution was found in this study. That is why toes were out of design and it implies that future slope crest rock quality could be worst and weaker than expected. It causes an overbreaking that, if the loading of the muckpile and bench scaling are not carried out accurately, width berm could be reduced and, in some cases, berm width could be lost. This effect has to be eliminated to improve the safety of the pit.

7.4 *Increased of damage in weak zones*

An excess of energy and vibration induced to the rock mass can increase the accumulated stress in weak material, compromising staff safety and the operation as well. Because this material is susceptible to movement and with the situation of the berms, the retaining of this material is not guaranteed. Figure 12 shows the weak material with a very close contour blast.

Figure 12. Increase of stress in weak areas by induced blast damage.

7.5 *Costs increase*

Maintenance, clean operations and support costs increase when the blast is less consistent or is poorly located. Loading and transport costs are increased as well because more material is been blasted for an uncontrolled backbreak.

8 TRIAL BLAST

With the collected data registered during the study of contour blasting and its effects, a new contour blasting design is suggested to improve and optimize the wall control.

8.1 *Design*

For the design of the trial blast, the most important data to take into account is the energy needed to cut the slope (Scott et al. 1996). As said before, this energy is $5 MJ/m^3$ so, designing and simulating different patterns and explosives charges to leave this energy in the cutting plane is desirable. Figure 13 shows an energy distribution simulation of the new contour design.

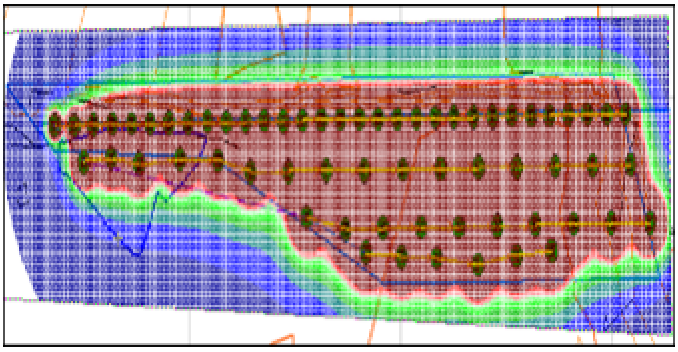

Figure 13. Energy distribution simulation of the trial contour blasting.

This blast design is called trim blasting. The trial was done in a simulated slope in the middle of the pit, with the geology parallel to the real slope to be similar to the real geological structures (Figure 14), to test the results and effects with the goal of continued improvement method.

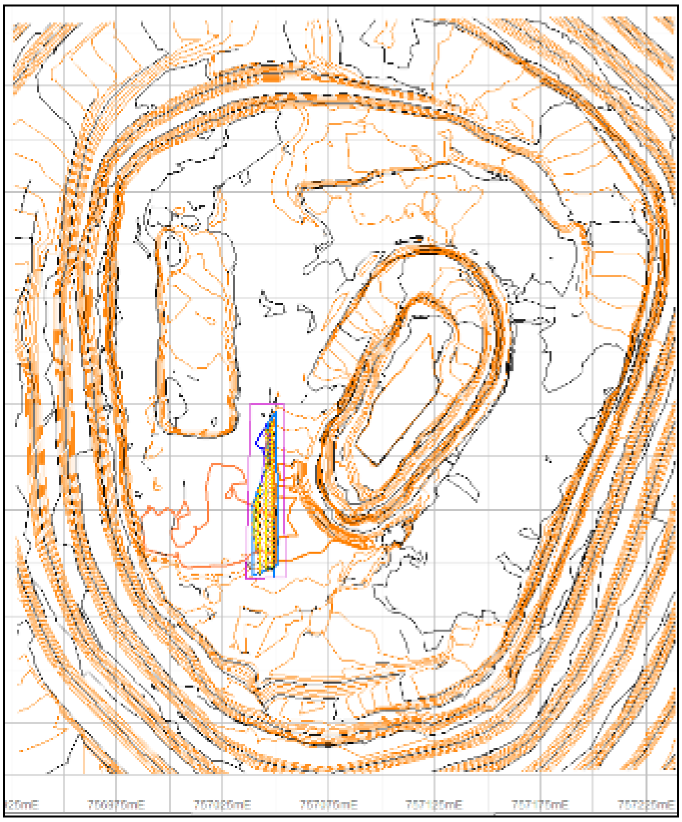

Figure 14. Trial contour blast located in the middle of the pit.

The outlined blast design is shown in the Table 3 and Figure 15.

Table 3. Trial trim blast characteristics.

Blast 394	Slope Row	Buffer Row	Production Row
Drilling Diameter	140 mm	140 mm	140 mm
Subdrilling	no	no	yes
Pattern (m x m)	3.00 x 2.25	3.50 x 4.50	4.00 x 4.50
Loading	HANFO (80/20)+ airdeck+ stemming	HANFO (80/20) +deck+ HANFO (80/20) +stemming	HANFO (80/20)+ stemming
Stemming	Cuttings	Cuttings	Cuttings
Offset to final slope	1m / 3m	-	-

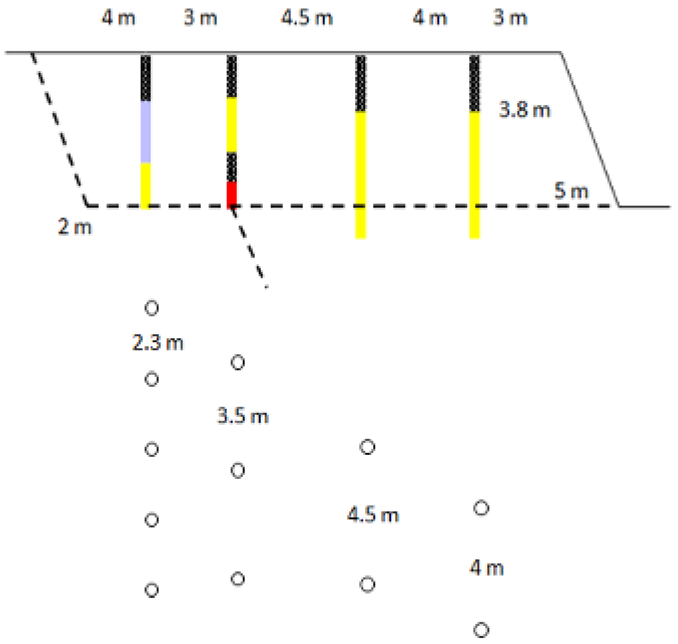

Figure 15. Trial contour blast located in the middle of the pit.

8.2 *Implementation*

Implementation is, after a consistent and logic design, the most important stage for a successful blasting.

The bench preparation begins with a good cleaning of the face and the floor of the bench. The implementation of the pattern is fundamental for an appropriate drilling operation.

In this case, every stage of the design implementation is done with care, accurate procedures and in accordance with best practice (Cebrián, 2007).

The pattern and general data of the design is as shown above, and the explosive charges of Table 4, are the result of many tests and simulations to achieve conditions to guarantee successful blasting.

Table 4. Explosive charge characteristics of trial trim blast.

Slope Row	Buffer Row	Production Row
Stemming	Stemming	Stemming
Airdeck	20 kg HANFO (80/20)	55 kg HANFO (80/20)
	Middle deck	
20 kg HANFO	22 kg HANFO (80/20)	

After an adequate preparation of the bench and an accurate drilling operation as shown in the Figure 16, the charge of the explosive is placed with precision.

Figure 16. Preparation and drilling of blast bench 394.

When the explosive is charged a single person makes the sequence connection. The timing is 100ms between rows and 17 ms between holes. In this case, 150ms are implemented between production row and buffer row to guarantee a better burden relief of the material previous to the detonation of slope row.

Once all blasts are connected, all staff exit the area and a last review is done by the blast manager in charge. Then the blasting protocol starts.

With distance as the best safety rule with blast detonation, the pit is cleared, all access closed and the radio channel is only open for the blasting team and emergency.

The blast is iniciated.

Following a checkup of complete denotation of the blast, access and activity returns to normal for the mine.

9 TRIAL BLAST RESULTS

The results of this trial trim blast were highly satisfactory. The aims achieved were:

- Accurate cutting for future slope excavation. Backbreak was significantly reduced compared to modified production blasting.
- Good displacement with a high fragmentation rate.
- No flyrock problems.

Figure 17 shows the result post blasting.

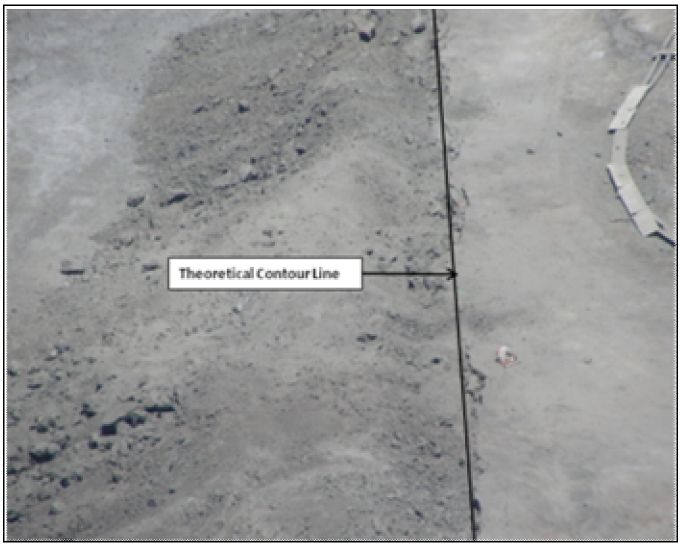

Figure 17. Trial blast back cut and pile fragmentation.

Figure 18 shows how the simulation and the energy distribution established in the previous study are correctly predicted.

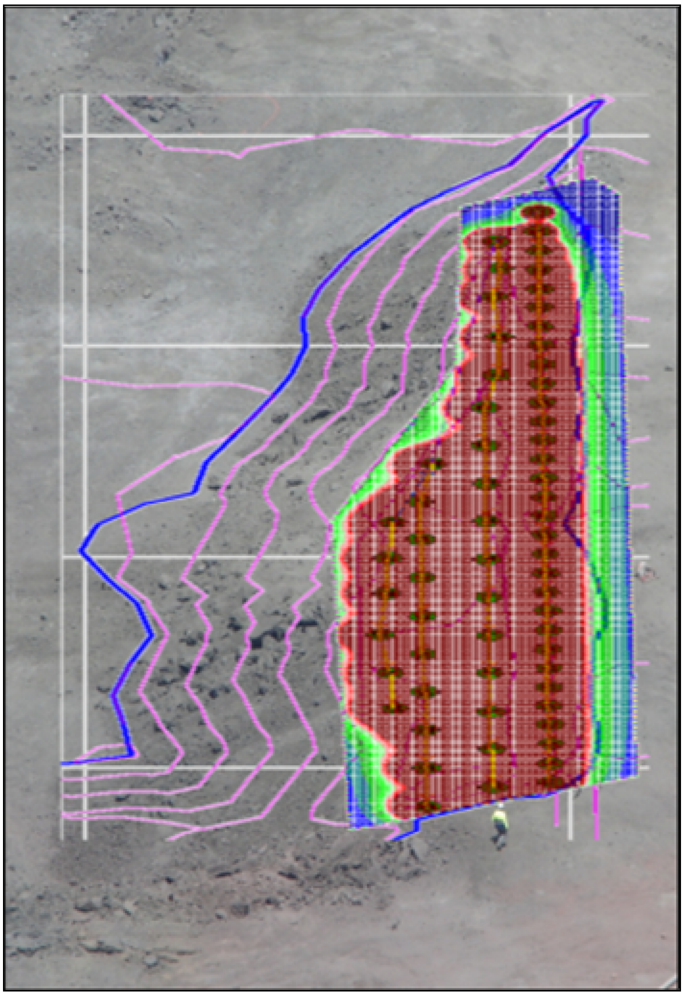

Figure 18. Energy distribution analysis with the real topography post blasting.

After completion of the loading of the blasted material and cleaning final slope accurately following the survey limits of the bench crest, a consistent slope was achieved closely matching design, as shown in Figure 19.

Figure 19. Final slope achieved by trial blast 394.

10 CONCLUSIONS

One of the most important concepts obtained is that an accurate implementation of the blast is essential for this energy-based method. The commitment of all the staff involved in each stage is the key to achieve the best results.

Figure 20. Las Cruces pit.

The process of improvement and optimization of contour blasting continues at Las Cruces. Different factors that affect the blasting operations are still been classified as the pit deepens and reaches new areas and rock classes (Figure 20). In this sense, nowadays the approach to contour blasting design in Las Cruces mine covers different categories:

a) Hard rock mass: trim blasting.
b) Medium-hard rock mass: modified trim blasting (Slope row: spacing increased up to 3 m with an offset of 1 m).
c) Soft rock mass: modified production blasting. The contour blasting area is opened from 3 to 4 rows (i.e. 14 - 16 m) to increase the distance of high energy production blasts from the final slopes.
d) Very soft rock mass: direct excavation.
e) In localized pit areas where there is not enough space to separate contour and production blasting, a “mixed blast design” is now in evolution. In this case a good timing sequence is essential to ensure sufficient relief of both toe and inner buffer rows.

As a final conclusion, a proper blast design, following a systematic procedure, improve blast results, mainly regarding blast contour. It has been check that using an average energy distribution, fixed at 5 MJ/kg, blast result implies a better stability of the bench head. This energy factor makes easier blast design and, above all, provides a quick and easy reference to design blasts properly.

ACKNOWLEDGEMENTS

The authors wish to thank the Management of Cobre Las Cruces, S.A. for the permission to publish this paper. Our gratitude to all the personnel from the Mining Department directly involved in this project, with special dedication to the Drilling & Blasting Team.

REFERENCES

Cebrián, B. (2007). Wall control by contour blasting-airdeck. XII International Congress of Energy and Natural Resources, Oviedo, 7-11 October 2007

Floyd, J. (2009). Guidelines for Open Pit Slope Design: 276-304

Scott, A., Cocker, A., Djordjevic, N., Higgins, M., La Rosa, D. Sarma, K.S. & Wedmaier, R. 1996. *Open Pit blasting analysts and optimization*. Indooroopilly, Queensland, Australia: Julius Kruttschnitt Mineral Research Centre.