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Geotechnical challenges in development of El Soldado open pit

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Abstract

During the development of Phase 3 of El Soldado open pit, structurally controlled instabilities at the bench level were detected. The operational strategy was to scale down the blocks in order to leave a clean wall, free of loose rocks. As background, it was known the California Fault was close to the slope (Regional Fault, subparallel to the orientation of the slope). As the development of the phase continued, there were identified unstable conditions at bench level. A detailed structural analysis of the observed condition detected an area of convergence of faults that generated an area of greater damage in the central sector of the wall of the phase, causing the continuous instabilities observed. With the updated structural information it was determined that instability belonged to a wedge that did not daylight, it was called the Central Wedge.

The trace of the California Fault was re-interpreted very close to the pit wall design. Because of this, and knowing the behaviour in areas of convergence of faults, it was decided to modify the pit design to ensure that the wall (or slope) was behind the plane of the California Fault. The decision was to increase the inter-ramp angle from 55 to 65° at a height of 105 m and a length of 400 m.

To successfully develop a stack of benches with inter-ramp angle of 65° operational practices had to be changed and a working protocol was defined, involving operational areas (drilling and blasting, loading and transport and mine services) and technical areas (planning, geology and geomechanics).

As the development was getting closer to the central sector, a new potential instability was detected that could affect a stack of benches below, so it was decided to scale down this instability. Due to this, the Central Wedge was likely to be reactivated with toppling type faulting in the upper blocks, which made it too risky to keep the design of 65° under the Central Wedge.

Due to the above, it was decided to change the pit wall design moving away from the Central Wedge. Many alternatives were analysed. It was finally decided to develop the mine exposing the lying plane of the California Fault at a height of 90 m, then pass behind the exposed fault plane and continue the bench berm design.

Currently the mine is developed in three sectors: north sector of the 65° phase inter-ramp angle; the South Central Sector scaling down the California Fault plane at 53°, which corresponds to the dip of the fault; and, the southern sector with a 55° inter-ramp angle, all developed successfully. This has only been possible with a joint effort between the technical and operational areas.

1 Introduction

El Soldado, one of AngloAmerican operations in Chile, is located in the V region, in the district of Nogales, 132 km northeast of the Santiago city. El Soldado open pit is a stratabound copper deposit, where the mineralising channel corresponds to a north-south orientation Subregional Fault, with a 47 to 53° dip, subparallel to the pit design, which is known as the California Fault. The criteria used for designs considering the location of the California Fault, is always to buttress by 60 m to ensure a minimum rock bridge at the base, or remove 20 m behind it, to ensure complete extraction (Figures 1 and 2).

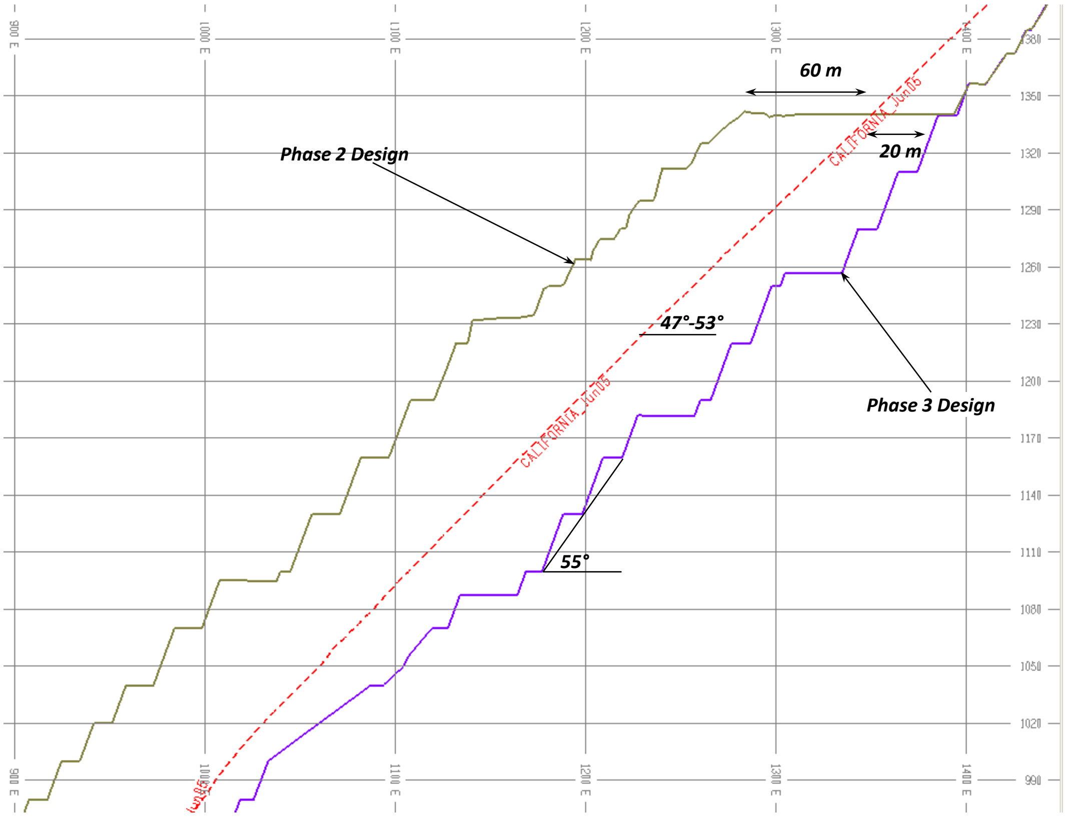

Figure 1 Criteria design with affectation of the California Fault

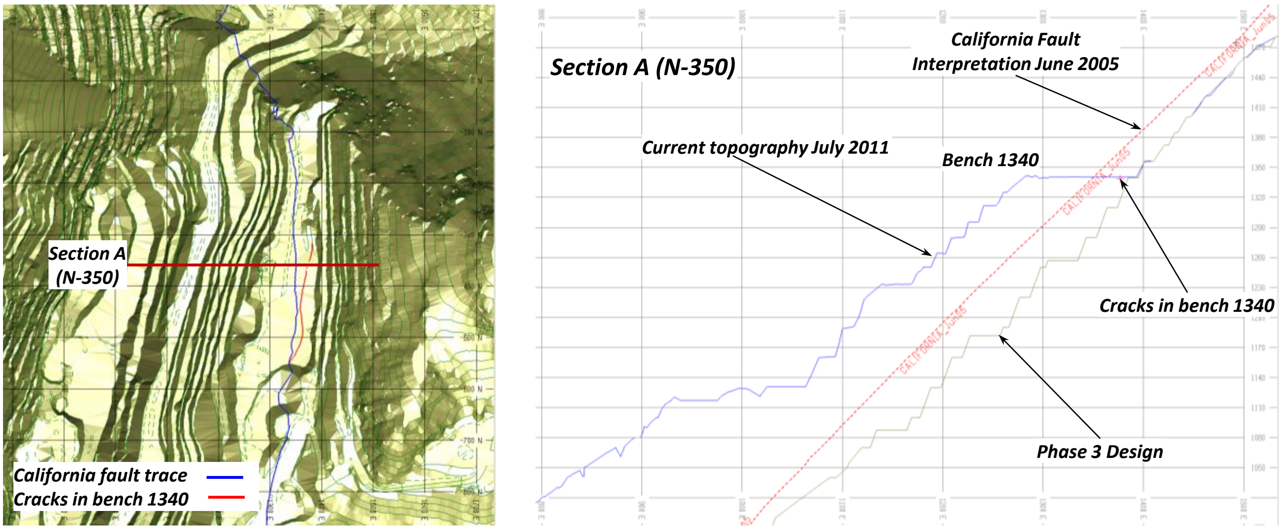

Figure 2 Plan view and section to show the nearness of the California Fault to Phase 3 design

During the development of the first benches of Phase 3, structurally controlled instabilities were observed at the bench level (Figure 3), they were scaling with mechanised equipment as they emerged. It was not possible to generate a predictive analysis of potential instability that would compromise the development of Phase 3 because bench mapping and structural modelling had not been performed nor updated since 2006. From the operational point-of-view, the wall control blasting techniques were deficient because design lines in the foot of the bench were not achieved and generated excessive damage on the crest (Figure 4). Typically, the losses were between 4 to 6 m in the foot and 2 to 5 m on the crests, this meant a reduction of the width of the berm. On the other hand, there were no operational practices to clean benches with preformed blocks located on the crests of benches.

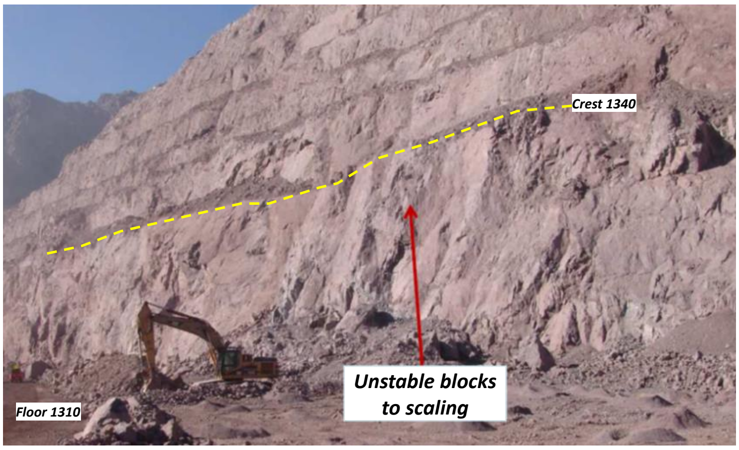

Figure 3 Initial observed condition in the development of Phase 3

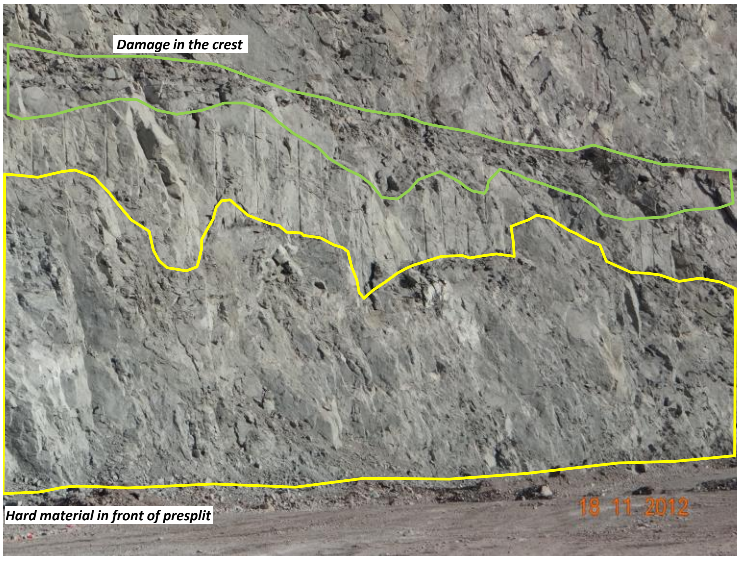

Figure 4 Final wall condition in 2012

The development of Phase 3 continued to bench 1280, as it had been assumed that the observed instability could be caused by its proximity to the California Fault. However, in bench 1280, a non-daylighting wedge type instability was observed in the central part of Phase 3 between the coordinates N-300 and N-500, named Central Wedge (Figure 5).

Figure 5 Central Wedge in bench 1280

2 Action plans

In order to continue the development of Phase 3, action plans were defined that allowed a change to the current strategy, it considered the below various sequential stages:

- Structural model update of the sector.
- Scaling down and cleaning material Central Wedge until bench 1280.
- Modification of designs to mitigate the California Fault hazard.
- Improve contour blasting.
- Improve operational practices.

2.1 Structural model update of the sector

The structural model focused on updating the California Fault and local structure models controlling the Central Wedge. Ten drillholes were performed (8 Diamond Drill Hole (DDH), and 2 Reverse Circulation (RC)), with televiewer logging and surface mapping using ShapeMetrix3D system.

In addition, the models indicated that in the north sector of the Central Wedge the convergence of California and Arauco Fault occurs. This convergence creates an area of greater damage to the environment, which locally modifies the trace of the California Fault, bringing it closer to the wall design Phase 3 (Figure 6).

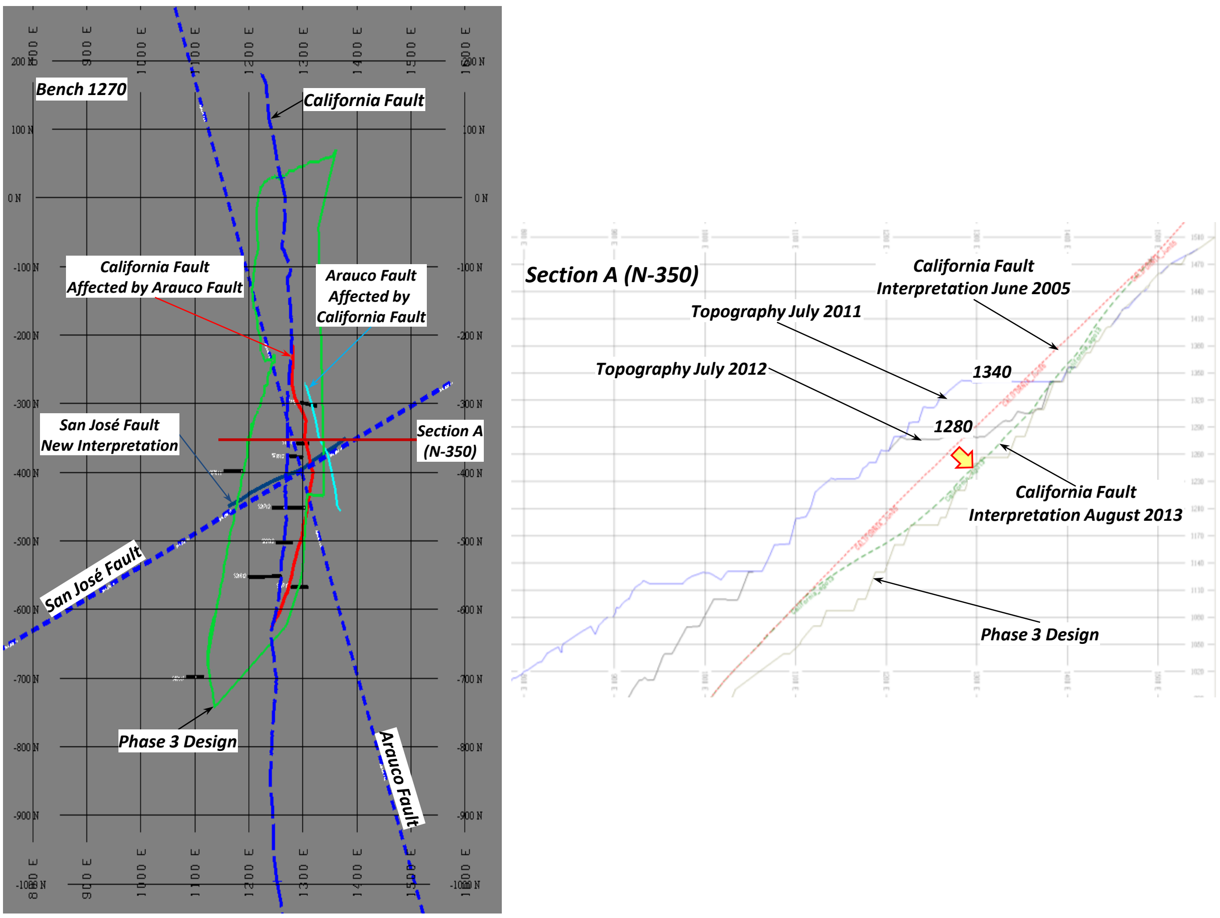

Figure 6 California, Arauco and San José Faults updated (Gonzalez 2013)

This new interpretation of the California Fault was the main base for the new design of Phase 3.

2.2 Scaling down and cleaning material, Central Wedge until bench 1280

In parallel with the update of the major structures and proposals for alternative designs, the wedge was mined out and the wall cleaned between elevation 1280 and 1355 (Figure 5), the final condition achieved in March 2013 (Figure 7).

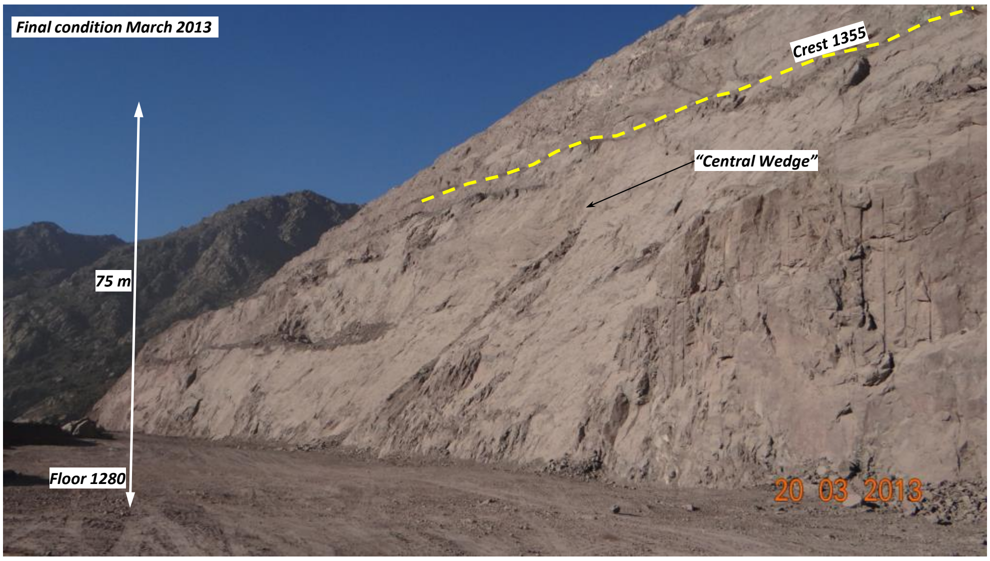

Figure 7 Final condition achieved March 2013

This was achieved by defining a strategy for scaling by shovel excavator PC-5500 (operated by remote control to prevent human exposure to falling material), with continued support of geomechanics onsite. The support radar was focused on monitoring the deformation and deformation rates. When, during works, the monitoring shows an acceleration of this sector, people and equipment were evacuated from the affected area. An example is shown in Figure 8, wherein point 1 indicates an increase in the sector monitored deformations, point 2 marks the evacuation and point 3 indicates the collapse of block deformation.

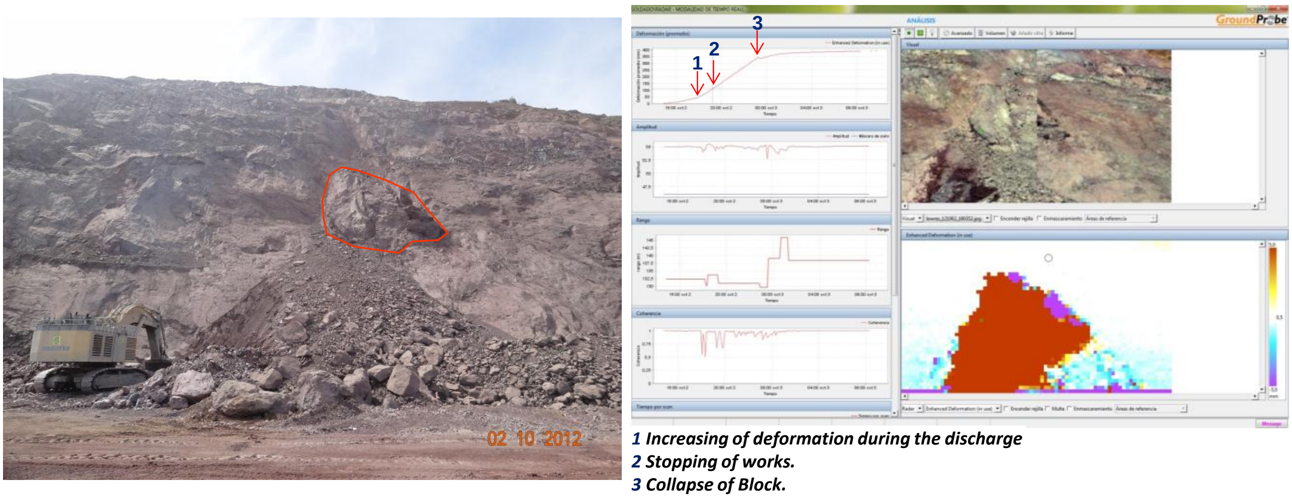

Figure 8 Activation of geomechanics monitoring during discharge

2.3 Modification designs to get away from California Fault

After evaluating different design alternatives to increase/decrease the inter-ramp angle, including: a platform, developing a new phase behind the current design etc., it was decided to adopt an aggressive design from the geomechanical point-of-view, considering the increased inter-ramp angle in the first stack of benches from 55 to 65° between the coordinates N-100 to N-500 and between elevations 1280 to 1175. This meant that the width of the berm design would decrease from 21 to 14 m but would guarantee development of the wall behind of the California Fault (Figure 9).

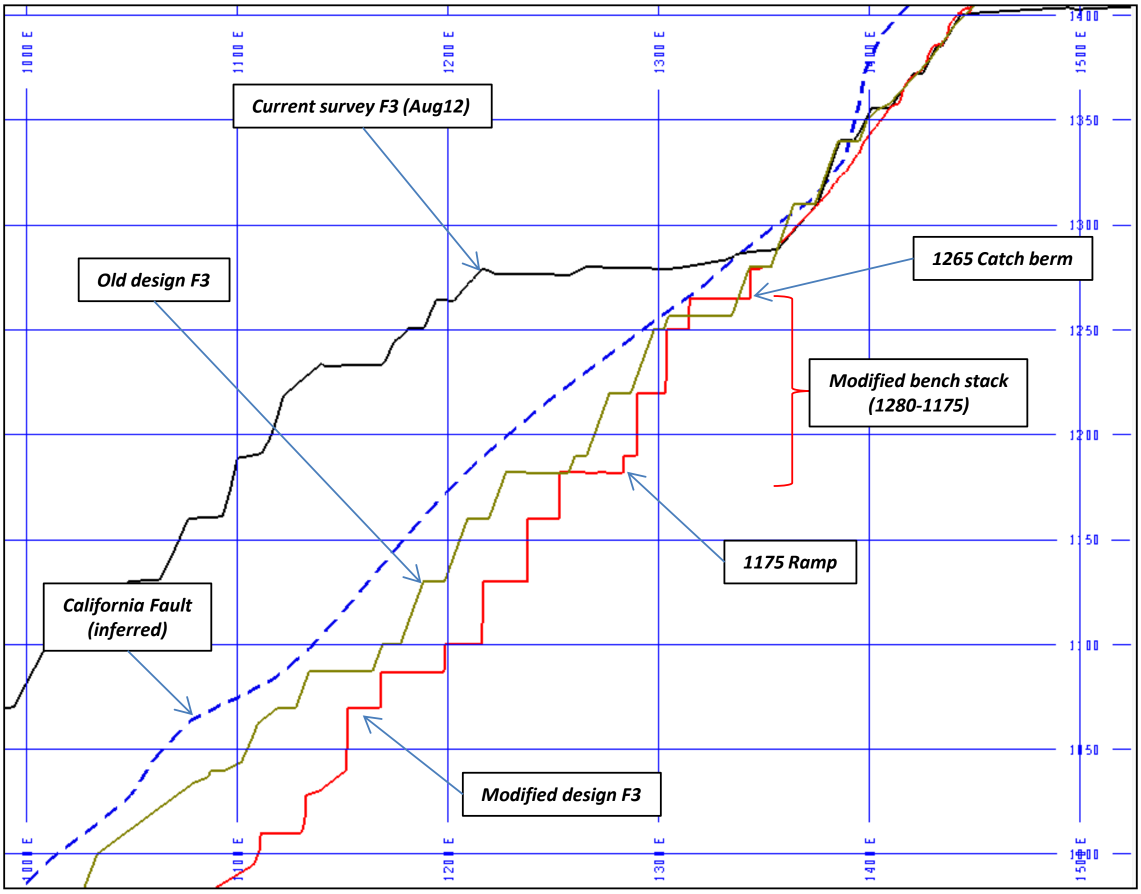

Figure 9 Phase 3 modified design

The stability of this alternative would not be affected because the strength of the intact rock present in El Soldado is very high so that an increase of 10° in the inter-ramp angle and a stack height of 105 m does not affect overall stability.

2.4 Improve contour blasting

The new design reduces the berms from 21 to 14 m, so berm loss associated with blasting had to be minimised.

Studies and tests were conducted, in conjunction with external consultants, to validate pre-split and optimisation of wall-control blasting to minimise damage to the crest of the bench and achieve the design line in the foot. In total, 12 blasting tests were performed during a period of four months in sectors of temporary walls so as not to risk the final face. The way in which damage was quantified in a standardised and unified approach was by using evaluation protocol, an evaluation sheet, which includes condition factor (Fc) and design factor (Fd). The sheets were modified and calibrated for the El Soldado site.

Test 1 was the baseline and the authors used current wall-control blasting geometries for drill pattern (burden and spacing) and loading holes (charging). Post-blasting observed that the foot had not been achieved and there was excessive damage at the crest of the wall. The Fc and Fd are 34 and 0, respectively, indicating a bad condition of the final wall (Figure 10). Modifications continued with the tests until optimised blasting, which allowed achievement of the design lines of the foot and minimised damage in the crest. The final results are shown in Figure 11, including the Fc and Fd.

Figure 10 Results of contour blasting test 1

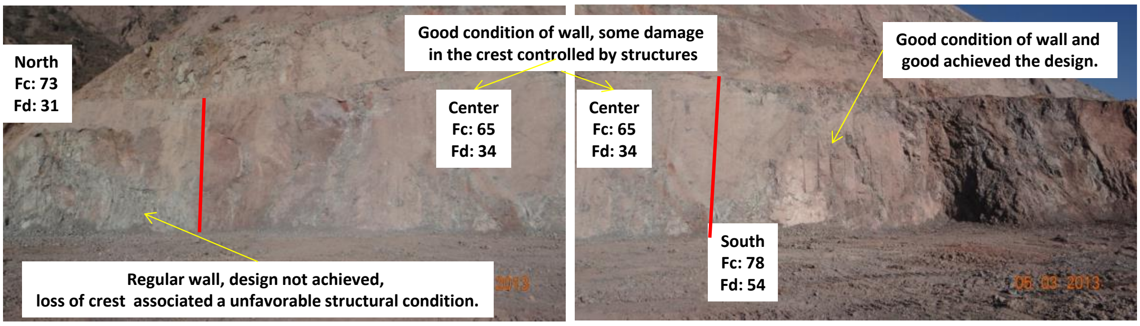

Figure 11 Results of contour blasting test 10

Finally, in Figure 12 is a graph showing the evolution of the Fc and Fd as the tests were developed.

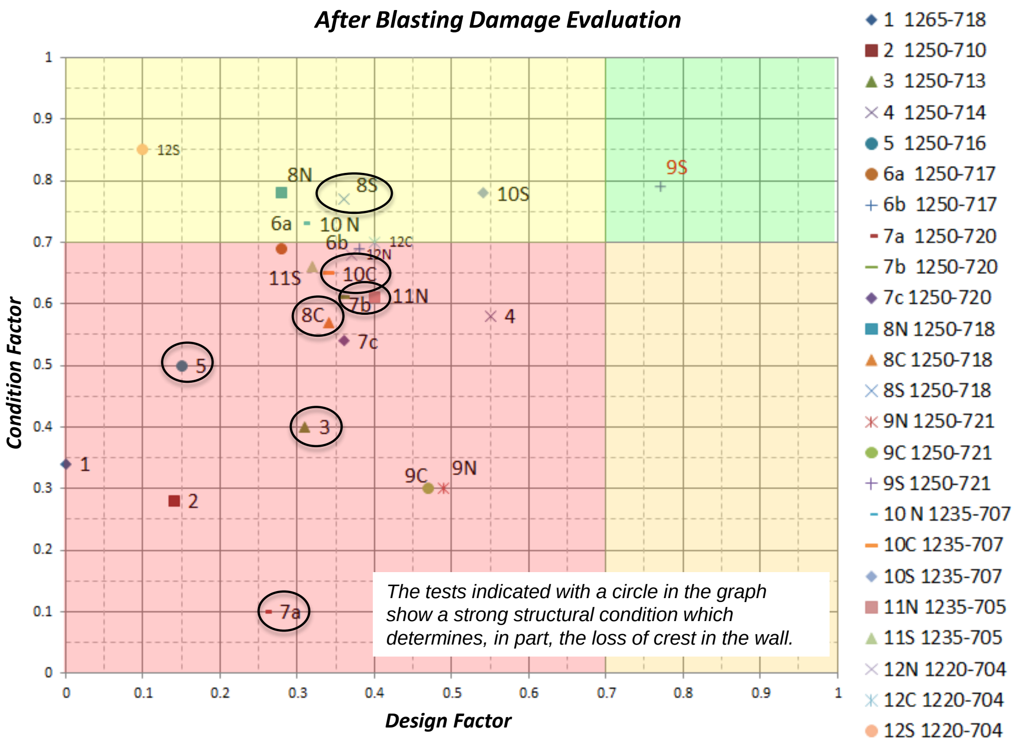

Figure 12 Summary of contour blasting test evolution

2.5 Improve operational practices

Although the improvement in contour blasting practices allowed the authors to minimise damage in the crest and achieve foot lines, it was complemented by an improvement to the whole process, including: drilling and blasting, loading, mine services, geomechanics, geology and planning. To accomplish this work, a strict protocol was created that regulated all activities and considered a strict sequence to be met to achieve the ultimate goal of developing a wall inter-ramp angle of 65°, this is shown in Table 1.

Table 1 Summary of operational practices

Process	Description	Responsible
Review of previous signatures in the protocol	You cannot run any field work until you have finished reviewing the protocol for the immediately preceding blast	Geomechanics/operation chief
Drilling polygon design	Delivered by short-term planning and marking in the field for their preparation. Design includes structural information	Short term planning/ operation chief
Acceptance of drilling platform	Platform clear of loose rock and levelled, accessible and marked. Slope without unstable blocks, crest and foot achieved, and without material in front of pre-split	Geomechanics/operation chief
Drilling	Maximum error of 5 cm between drill holes designed and physically marked in the field; maximum permissible errors for pre-split and buffer holes are 0.5 and 1 drilling diameter respectively; maximum angular deviation is 1%; no deviations in depth	Drilling and blasting
Blasting	Pre-split fired minimum 1 day before the rest of the shot. Geomechanics review pre-split (berm condition and backbreak). Effective free face	Drilling and blasting/ loading/geomechanics
Post-blasting	Geomechanics review the blasting performed (berm width implications, backbreak); surveying staff should mark the design line every 2 m maximum spacing. Only after this will construction of the trench commence (2 m deep)	Geomechanics/operation chief
Trench in crest	Post topographical marking, geomechanics review the remaining berm, should topographically mark the design crest line prior to loading out	Geomechanics/operation chief
Loading	Ensure that the loading design achieves compliance (foot lines, floor, bench face angle etc.). Survey should support whenever necessary	Chief of mine/operation chief/slopes coordinator
Scaling	Geomechanics review if scaling down is necessary, after the scaling geomechanics review to release the area	Geomechanics/operation chief/slopes coordinator
Bench mapping	Once the area is free, geology staff must perform bench mapping	Geology
Geotechnical conciliation	I-site scanning of the sector and reconciliation of compliance to design. This task will eventually determine the need for installation of prisms and/or radar	Geomechanics
Fortification	Mesh installation on the crest of bench with counterweights on the foot. No work on the lower bench if this activity is not complete. This item was not considered for the testing stages, subject to geomechanical assessment	Geomechanics/ operation chief/slopes coordinator
Closing protocol of current blasting	Review all activities are properly closed to continue the development of phase	Geomechanics/ operation chief

Importantly, subsequent activity cannot commence if the above has not been finalised, with the corresponding signatures.

3 Obtained results and new challenges

Wall-control blasting commenced for the final Phase 3 considering an inter-ramp angle of 65 °. The results of this development on the north side of the stage were excellent, as shown in Figure 13.

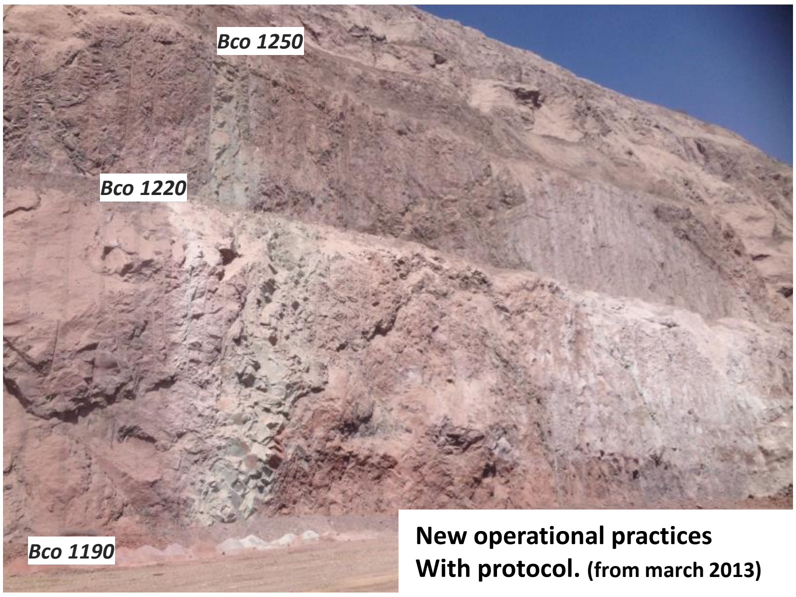

Figure 13 East wall development to 65° inter-ramp angle, north of Phase 3 with protocol

New operational practices allowed the authors to develop the stack of benches with an inter-ramp angle of 65°, without problems, in the north sector. The updating of the geology information herein and review of this information by geomechanics allowed potential instabilities to be visualise and action plans to be implemented to control these risks.

One example was the detection of a potential daylighting wedge between benches 1190 and 1265, controlled by Arauco 105 Fault and San José 17 Fault. After geomechanical analysis, it was determined that, to reduce the risk of this wedge, it should be removed in higher benches. This would download the 1265 and 1220 benches between the faults planes controlling this wedge, this is shown in Figure 14.

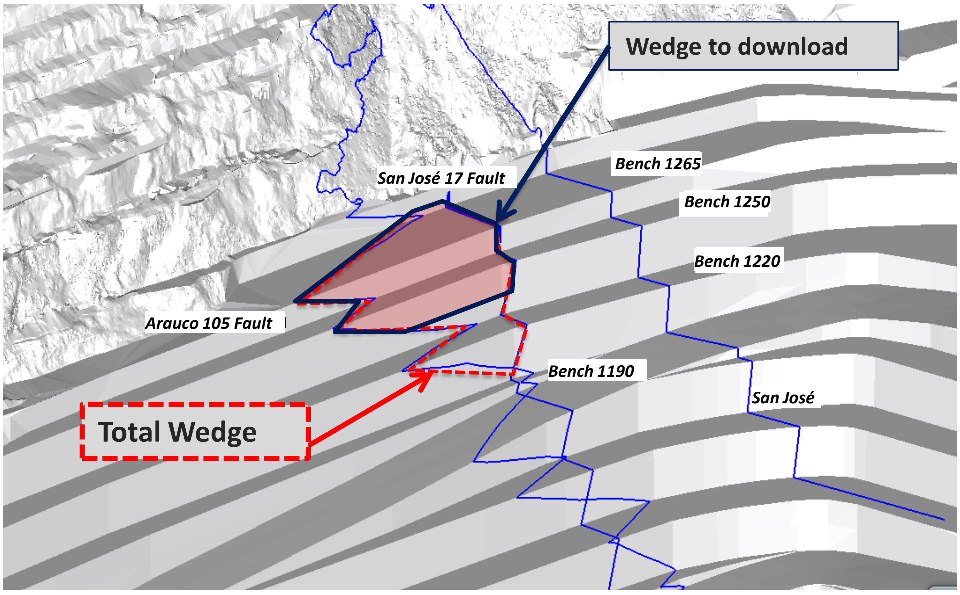

Figure 14 Potential wedge to discharge

4 Central Wedge reactivation

After the first blasting to discharge instability, identified in Figure 14 under the Central Wedge, the sector was reactivated due to the presence of another San José subparallel fault system south of the first (Figure 15).

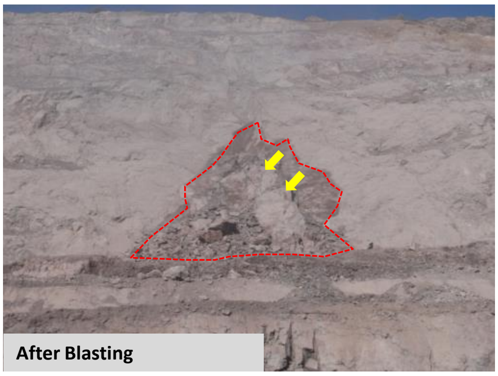

Figure 15 Comparison before and after discharge blasting

The behaviour after the blast activated the south Central Wedge, limited by another San José system, (SJ_S3_Ajust) this involved changing the original strategy stopping development under the Central Wedge.

In order to be able to resume development, stabilisation of the upper section was required (ensuring the collapse of the unstable zone). For this, a strategy was defined including:

- Water discharge from upper benches and by helicopter.
- Blasting sub-horizontal at the base to accelerate collapse.
- Scale down the material in the foot wedge with autonomous equipment (remote control shovel).

All this was undertaken with in situ geomechanical support, i.e. radar.

In January 2014, the condition of the Central Wedge was stable. There were cracks in the upper benches, however, monitoring showed no relevant activity. Due to the condition previously mentioned, the current design (inter-ramp angle of 65° in the central area) is not possible to achieve. This implied that design must be positioned under the wedge again and that would mean reactivating the instability of the wedge that would threaten the development of Phase 3.

Therefore, to ensure operational continuity of El Soldado, an alternative design was made to unload the California Fault between the coordinates N-250 and N-650 and between 1235-1175 levels, leaving the clean-up on the slope (Figure 16). Under the 1175 elevation, bench berm design began in order to begin movement behind the California Fault.

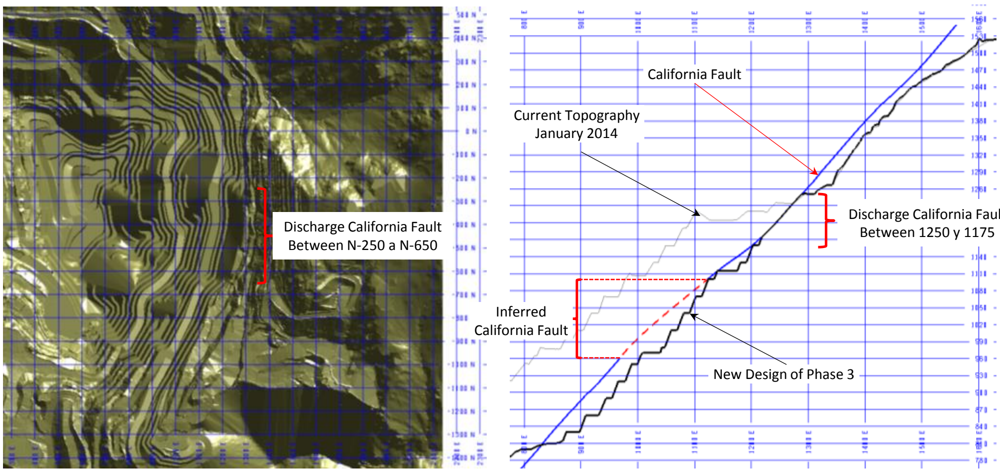

Figure 16 Phase 3 new design considering clean-up of the California Fault

To ensure the success of this strategy, a new drilling campaign focused on giving greater certainty to the location of the California Fault at depth, and the protocol used for the development of the 65° inter-ramp angle was modified to include this situation.

The strategy for the mitigation of the California Fault plane hazard considered blasting controlled vertical drilling, while maintaining a minimum of 5 m offset from the plane of the California Fault (Figure 17).

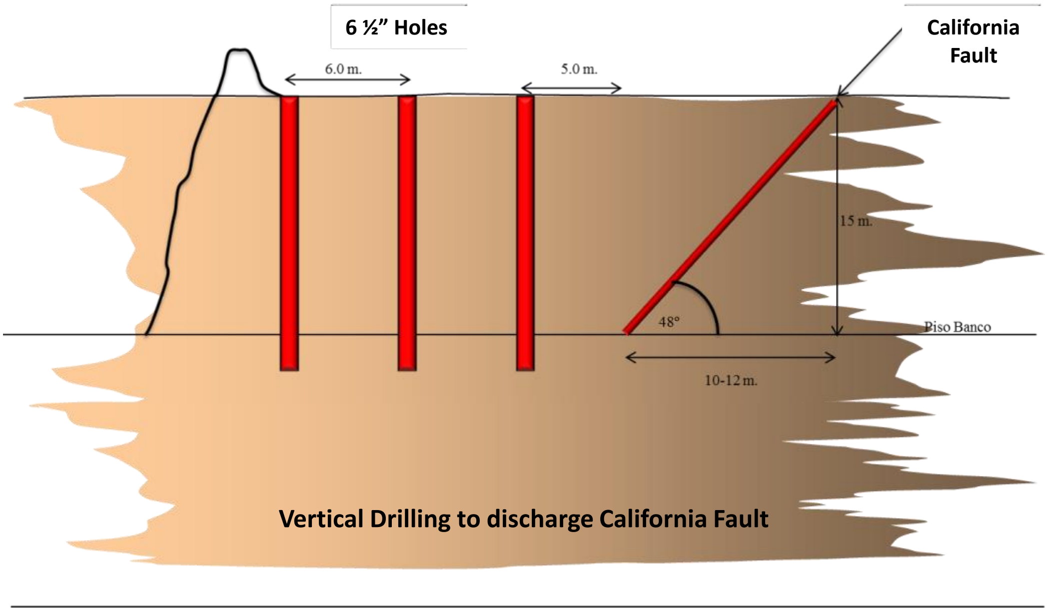

Figure 17 Drilling diagram showing contour blasting in California Fault discharge area

Throughout the development of the work under the Central Wedge, radar monitoring was connected online to the fleet management control room and geomechanics offices, with the aim of alerting any change in the condition of stability of the sector.

During the month of April 2014, the mining of California Fault plane between elevations 1250 and 1175 was completed, and the first double bench was developed behind the fault plane. The results of this are shown in Figure 18.

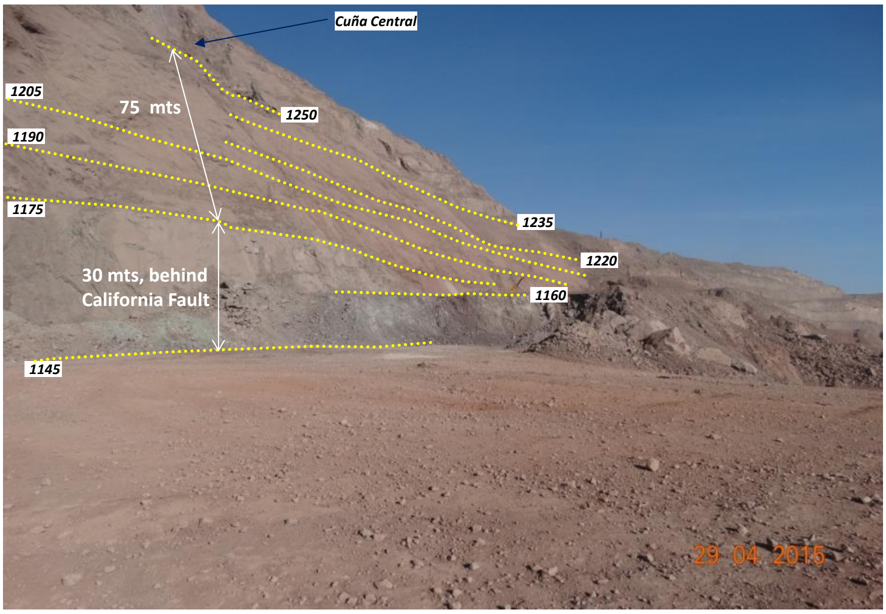

Figure 18 Final results of discharge in California Fault Plane, April 2014

The successful mining at the California Fault plane, was primarily based on the excellent operational discipline and allowed the North wall of this sector to achieve an inter-ramp angle of 65°. This was a challenging design that would give operational continuity.

5 Lessons learned

The challenges the authors faced helped them to look back and think 'why did it fail?', 'why did this happen?', 'what could have been done differently?' With these questions in mind, the main lessons learned were:

- The updated model of major structures must be continuous.
- Continuous and systematic bench mapping.
- Permanent drilling campaigns for structural recognition and validation.
- Operational discipline and good operational practices in drilling, blasting, loading and scaling.
- Monitoring and geomechanics instrumentation.

6 Conclusion

The Phase 3 development of El Soldado was not free from challenges and each was tackled with a multidisciplinary high performance team. The results speak for themselves, considering that the Central Wedge today has 155 m of height, and the team developed and executed a challenging design (inter-ramp angle of 65°, California Fault plane as a continuous batter at 75 m height, Figure 19).

Figure 19 Development of 65° inter-ramp angle in the north sector of Phase 3 and Discharge California Fault plane between 1250 to 1175

The successful development of Phase 3 was not because of one person or a particular area but rather, it was only possible, due to a high performance, multi-disciplinary team that is accustomed to working together to achieve a common goal.

Reference

Gonzalez, J 2013, Reporte Condición Estructural Fase 3, El Soldado, AngloAmerican Chile.