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Chapter 10

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Thirty years evolution of block caving in Chile

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Abstract

An analytical account is made of the evolution of Mass Caving of the Chilean mines in the last thirty years. For this, the cases of El Teniente, Salvador and Andina (Río Blanco) mines are reviewed. Because the driving force of the mentioned evolution was the change of the geo-mechanical properties of the ore bodies while their exploitation advanced and became deeper, reference is made to the characterization of the rock masses on which the mining designs were based on. The evolution is analyzed describing the effects on designs and equipment of the different mining levels and unit operations characteristic of mining by Mass Caving: undercut, extraction, secondary breakage, ore transfer and intermediate haulage. Based on the analysis of the evolution of these three decades, a projection of the possible developments of Mass Caving is made for the future and a balance of some pending problems with this type of mining is presented.

1 INTRODUCTION

At present, three of the five Codelco-Chile producing mines are underground and use the mining method known as *Block Caving*: El Teniente, Río Blanco (Andina) and El Salvador. Fine copper recovered from these operations is today in the order of 570.000 tpy, out of a total of around 1.600.000 tpy produced by Codelco. There are no other mines at present in the country that use this mining method, even though some isolated efforts have been tried in the past.

This method was first used in Chile in 1924 at the Potrerillos mine of Andes Copper Mining Co., branch of Anaconda Co. Then El Teniente Mine of Braden Copper Co., branch of Kennecot Copper Corporation, after a long evolution process, applied the *block caving* method as such in the late 30's. Years later two other caving mines join the *brotherhood*, El Salvador mine of Anaconda Co. (1959) as replacement of Potrerillos and, finally the Río Blanco mine (1970) of Cerro Corporation.

The method, in its traditional form *-chute tappers*, grizzlies, and gravity transfer to a transport level- had reached through the years, in

Potrerillos and in El Teniente, a high degree of standardization and efficiency (Figure 1).

A similar design was adopted at the Río Blanco mine of Andina, but with an intermediate ore transport level with belt conveyors; while at El Salvador, because of the ore body geometry, the utilization of *scrapers* was preferred for ore extraction.

This was the technical setting when in the year 1971 nationalization of the big copper mines took place. Besides the political impact and the transfer of technical and managerial responsibilities from US companies to Chilean professionals, this also meant the concentration of the property of all the mines in the hands of only one owner.

Coinciding with this situation, –almost simultaneously and because of different reasons in the three mines– the appearance of sectors with harder rock and bigger fragmentation in the production programs started taking place, with much lower productivities using the traditional *block caving* design.

The case of El Teniente mine illustrates what was going to happen in the short to medium range term in the three mines: as reserves in the upper or secondary enrichment zones deplete (which fragments very well producing fine grained material), the continuity of mining necessarily required initiating the extraction of the primary ore zones, with much harder and resistant rocks. These types of rock cave with more difficulty and generate a coarser product, which is impossible to handle with the standard designs and mining practices.

From this start point, and for the next two decades, the concepts and designs which are involved in mining of hard rock evolved to what is now known as *panel caving* with LHD, with subsequent variations and refinements. The main aspects of this evolution are summarized in this paper.

It is important to recognize the contribution of the numerous professionals who with their creativity and effort achieved conceptual solutions and intelligent designs that allowed the referred evolution to be successful, and acknowledgement is made to all those who dedicated long extra hours to synthesize their findings in papers, without which this chronicle would have not been possible. Each one deserves to be mentioned, but faced with the possibility to forget a few, we feel it is more just not to name anybody and we trust that each will recognize his mark in this re-count.

As usual, a tally of this sort has deficiencies that arise from the reduced space available, from the fragility of memory despite abundant references, from the difficulty to sort out the essentials from the accessory, and also from the bias introduced by the personal interpretation and experience of the chroniclers. The authors declare that they have aimed to be faithful to the available sources and hope to count with the indulgence and compre-hension of those that may have a different view of the relevant facts of these thirty years of mass caving with LHD in Chile.

2 THE ROCK MASS

Given an ore body with its own metal values and defined geometry, the main conditioning variable to determine the

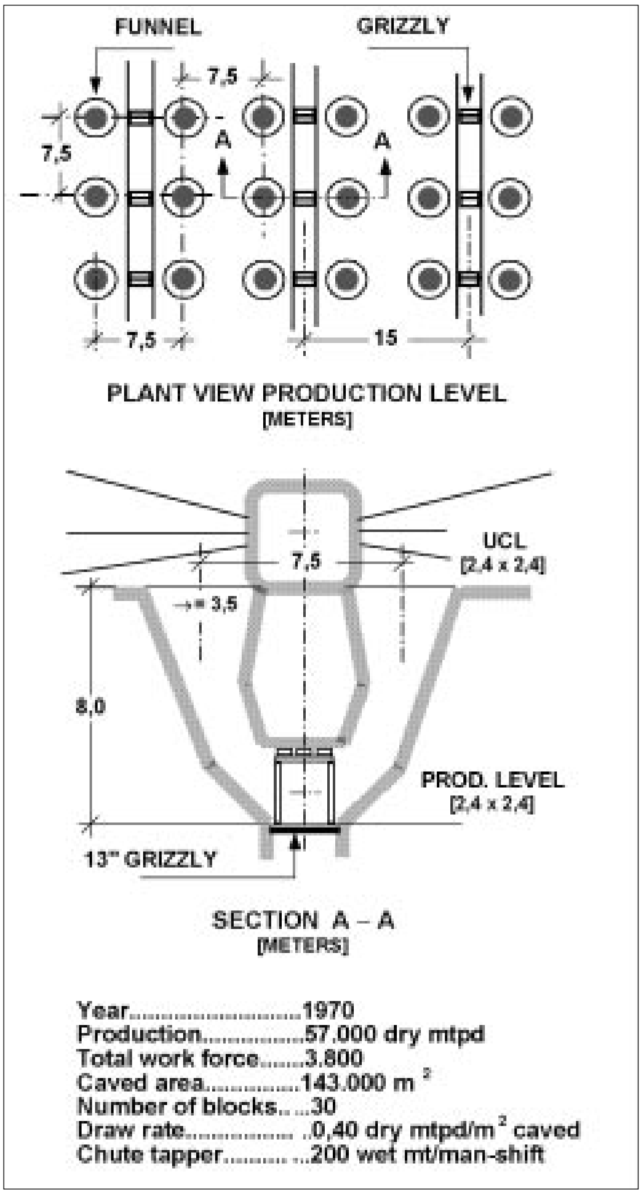

Figure 1: Block Caving with chute tappers, El Teniente mine.

design parameters of a *block caving* is the set of geomechanical pro-perties of the rock mass.

As stated in the introduction, the trend in the thirty years covered by this paper, has been the exploitation of deeper sectors of the mines, with bigger stress fields and harder rock.

If we take the First Latin American Mining and Extractive Metallurgy Congress of 1973 as a milestone, we can appreciate how the compre-hension and treatment of the subject has evolved in all relevant aspects of the mining method, among which it is worthwhile noting:

- Cavability (base area and weakening developments);
- Gravity flow (dilution and recovery);
- Stress fields (extraction sequence, orientation of mine workings and reinforcement);
- Fragmentation (extraction grid and equipment).

Regarding the natural characteristics of the rock mass, in 1970 the RQD and fracture frequency were started to be logged at El Teniente in primary rock. It is worth mentioning that at that time in the secondary rock at El Teniente, four geotechnical parameters were mapped (type of rock, fracturing, hardness and water filtrations), with the purpose of defining reinforcement and to design induction of caving and explosive usage. But the first registered attempt to quantitatively predict geotechnical rock quality in hard rock is in Andina and dates back to 1974. On the basis of RQD and FF, a prognosis of cavability, reinforcement, fragmentation and productivity is made for a sector of Río Blanco mine with turmaline breccia. This was the first of a long sequence of contributions to the numerical characterization of the rock mass. Between 1980 and 1985, the three mines adopt geomechanical rock classification systems based on the scheme developed for mining by Laubscher from Bieniawski´s work. With minor modifications derived both from the evolution of the definition of the Laubscher index and from local adjustments, the same classification system is still in use in order to define design parameters such as cavability, fragmentation and reinforcement.

Complementing the rock mass characterization, advancement in stress measurement was started. Starting in 1972 and for the first time in Chile, in situ stress measurements were taken at El Teniente mine, using the "overcoring" system with the USBM gage. Since that time the "overcoring" and the "doorstopper" systems have been used at various locations in the three mines (and also at other locations), so there is now an extensive data base of the natural stress field in the country. This information has been used for the global design of the undercutting and mining sequences, to define orientation of mine openings, and to design resistant pillars.

As has been pointed out, the deepening of the mines has implied that mining has been of harder rocks subject to more aggressive stress fields. Because of this, the occurrence of violent liberation of energy, has been an ever more frequent phenomenom (induced seismicity). In the late 70´s, these phenomena started at El Teniente mine, –with more intense expressions corres-ponding to rock burst– constituting a permanent threat to the exploitation of primary rock, which has meant toll in lives and also has had an important impact on costs.

The way in which this situation has been dealt with in El Teniente considers microseismic monitoring of the mine, which has been done since 1980 and is able to give early warning to evacuate parts of the mine. It also helps to understand the phenomena in order to regulate draw rate, to alter undercutting sequence and even to redesign fortification. Similar to many other aspects, the problem is far from solved: only the learning of the cause-effect relationship has taken almost a decade. But as far as the phenomenom has been able to be characterized and understood, there has been advancement regarding the mitigation and control of effects.

An important subject related to the rock mass characterization is fragmentation. In 1973, a well known colleague stated the general belief of the time: "avoiding the productions of boulders in a block caving is like squaring the circle". Through the years, ever coarser fragmentation has required more expensive designs, smaller draw rates, bigger capital expenditure in infrastructure and equipment for fragmentation and ore handling, and in the bottom line, has meant a negative impact on the profitability of the operations. Up to some time ago, the only aim was to improve fragmentation as an additional advantage of designs which main objective was another one: forced caving with explosives to induce caving; the adjustment of undercutting sequence and mining progress to control damage in the production level openings; the control of draw rate to manage extraction and dilution. In the last three years there has been an effort to modify the in-situ characteristics of the rock mass, which has been termed as pre-conditioning of the ore, using special techniques with explosives or with hydraulic fracturing. Hopefully we are in the eve of another major change in cave mining, as was the introduction of LHD equipment in its time.

3 FIRST DESIGNS

El Salvador Mine: In the year 1970, still under Anaconda management, for the first time in Chile *block caving* with LHD equipment was utilized. In a sector planned to be extracted with the standard system, with *chute tappers*, grizzlies and branched orepasses, because of the poor production rates achieved and because of serious problems with ore pass maintenance, it was decided to place a few well fortified orepasses outside the blocks and introduce LHD equipment for the extraction and haulage of ore in the production level.

Shown in Figure 2 is the first design adopted for the Production Level, with a *herringbone* design, where the *loading accesses* concurred from either side to only one central *draw point*. These central loading points aligned every 12,5 m.

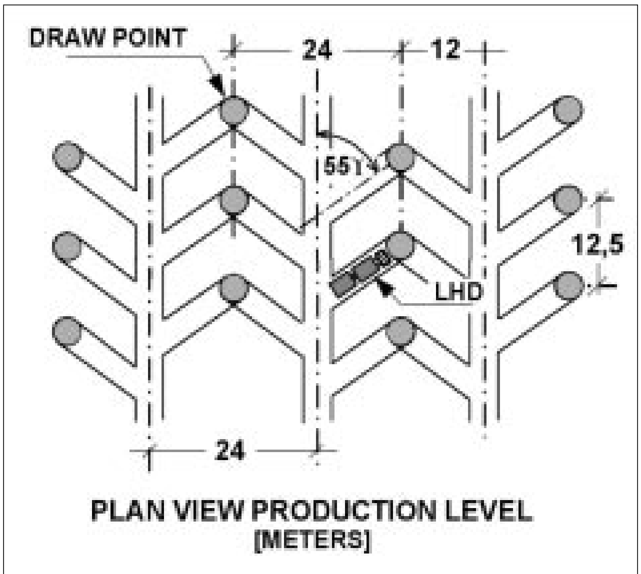

Figure 2: El Salvador Mine, original design with mechanized LHD extraction.

Probably the main design criteria considered, was to give the 5 yd^3 LHD's enough space to face the heap for loading in a straight position, a position strongly recommended at the time by equipment manufactures. The resulting *extraction grid* was then 24,0 x 12,5 m, defined as the distance between rows of loading points and the distance between two consecutive loading points in the same row.

Unconfirmed information, because of the change of administration at the time, indicate that results of that experience, mainly regarding ore recovery, were not good. Chilean engineers that took the technical control of the operation, in light of the publications about *gravity flow* models by Mc Cormick, Janelid and others, concluded that the problem originated in the excessive distance between rows of draw points (24 m).

The design was corrected and the next block had an *extraction grid* of 16,0 x 12,5 m (Figure 3), that later evolved to 14,3 x 16,0 m. .The idea was to maintain the length of the *loading accesses* to allow straight LHD´s, offsetting the draw points from the *extraction points* by means of a raise that climbs backs up from the *loading access*.

Conceptually it was a good solution, in the sense that it yielded an almost equilateral extraction *grid*, but there were operational problems associated to the weakness of the brow of the draw points and to the labour intensive type of development required. It also turned out complicated to maintain the stability of the intersection between the loading

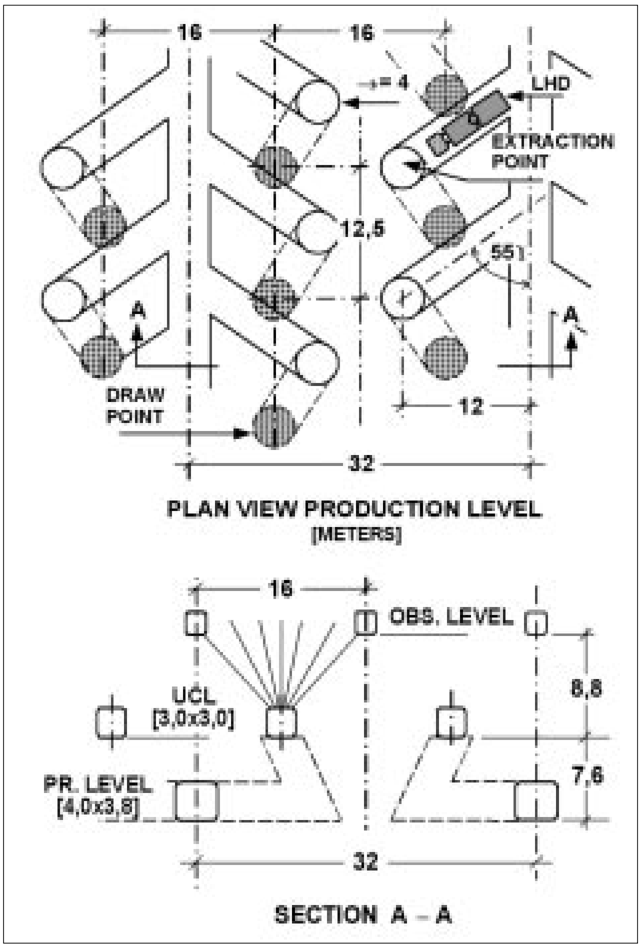

Figure 3: Block caving with LHD extraction, El Salvador mine.

access and the tramming drift, requiring heavy steel and concrete structures. In relation with these three problems, other design criteria and parameters were incorporated, such as the ratio between voids and total area, and the angle between the loading access and the tramming drift.

In this first successful block caving experience with LHD's in Chile, loading rates around 400 to 600 t/shift per equipment were obtained with 5 effective hours per shift and a tramming distance of between 50 and 150 m.

Río Blanco Mine: In the mid 70's, in this mine of the Andina Division of Codelco-Chile, in the south sector of the first Production Level, more than 200.000 m2 rock of a different characteristic to what had been successfully exploited with a traditional block caving (chute tappers, grizzlies, gravity ore transfer) had to be mined. It was mainly turmaline breccia that presented cavability problems and generated coarse fragmentation.

After the results of the first block in this area, -the productivity of the chute tappers decreased by 30% and the powder factor in secondary blasting increased 3,5 times- it was decided to modify the mining system. Three alternatives were analysed:

- Block caving with scrapers and haulage by railroad.
- Block caving with LHD's.
- Forced caving with big diameter long hole blasting and chute tappers.

The trade-off analysis favored the second option of block caving with LHD and the herringbone type design chosen is shown in Figure 4. The main design criteria considered were related to parameters such as the length of the loading access and the dimensions of the extraction grid. There

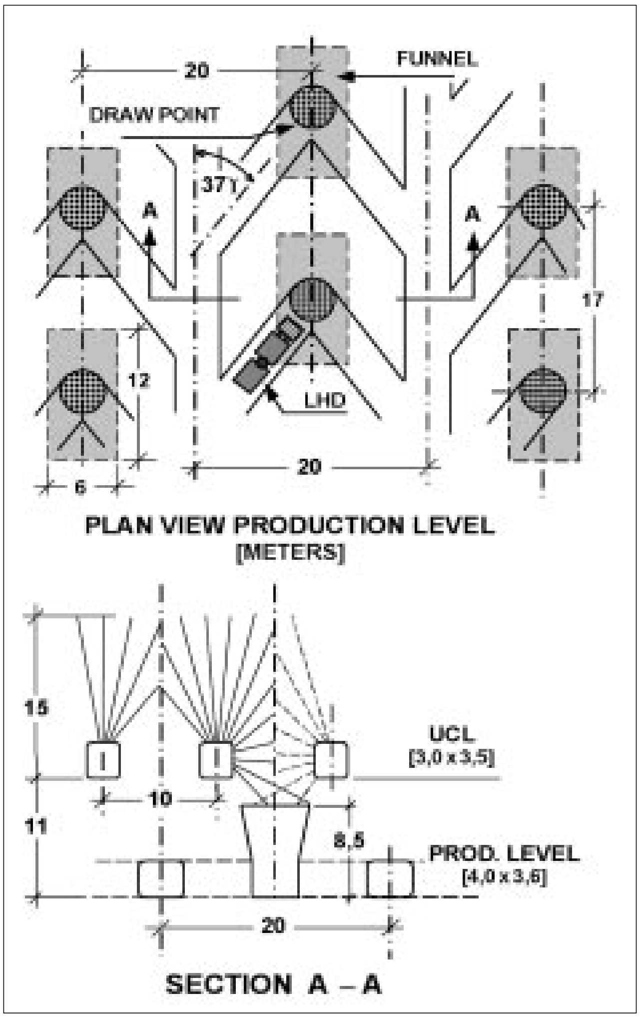

Figure 4: Block caving with LHD, Río Blanco mine, Andina.

were also some local conditions such as the lack of barren overburden and no dilution problems. The reason not to mine by open pit, even though there was no overburden, was because of extreme climatic winter conditions.

El Teniente Mine: The year 1970, coincidental with the change of administration, the Mine Department starts the first discussions about the change in rock conditions. In the central sector of the Teniente 4 Production Level, numerous blocks already prepared with the traditional layout were emplaced in the primary ore zone of the deposit, in some cases only at the base and in others to a considerable height.

In 1972 the first block in primary rock was undercut using a slightly modified standard system (4 million t) and the results obtained highlighted the real magnitude of the problem: chute tapper productivity was reduced to between 20 and 30 t/man-shift, as compared to an average of 200 in secondary ore. The conclusion was that there was no alternative but to introduce radical modifications to the method or change it altogether.

With the assistance of swedish professor and consultant I. Janelid, internationally reputed in massive mining at the time, the first conceptual studies were started. His approach points to the dynamics of gravity flow and to materials handling of coarse ore. His contribution in this respect was conceptually of great importance, even if swedish praxis and theory were oriented to sub-level caving, which has a different extraction dynamic. At that time, and for obvious reasons, the possibility to seek advise from US consultants, with ample experience in block caving, was not an scenario.

At the outset of these preliminary studies, it was concluded that the rock would cave, even for very competent rock conditions and for "normal" base areas, and that the coarse fragmentation was manageable with diesel LHD equipment, pick hammers for secondary reduction and with an underground crusher. As a synthesis, the block caving method was still the best solution.

After this conclusion, the final conceptual engineering of the primary ore project is started in 1974. The analysis focused first on the configu-ration of the Production Level, specifically on the design of the extraction grid. The clue of the problem was to reconcile design parameters where the optimization of one of them affected others in a negative way. For example:

- The extraction grid had to be as equilateral as possible and also ample enough to have loading accesses long enough to allow LHD equipment to load straight.
- The spacing between draw points had to allow the interaction of the draw volumes: it cannot be too big.
- Reducing the distance between rows of draw points augments the ratio between voids and total area, affecting the stability of the Production Level.
- A smaller angle between the tramming opening and the loading accesses, allows increasing the length of the latter one, but generates instability conditions difficult to control.

The most important subject, the spacing of the extraction grid, was uncertain. Even though some qualitatively approaches to the problem were known, originated in gravity flow models, the scaling of these models to real conditions was then and is still an unresolved question. The only certainty was that as the ore gets coarser, the diameter of the volume that flows also increases, and therefore the distance between draw points could be enlarged considerably.

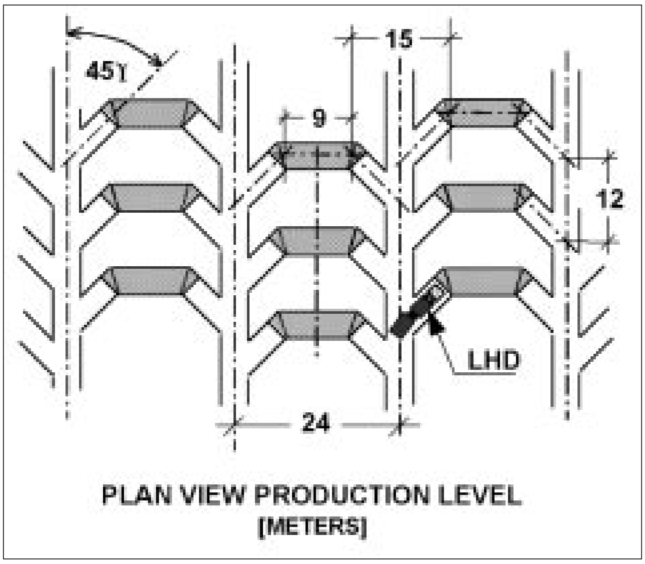

Figure 5: Block caving with LHD´s, Henderson mine, original design

The experiences of El Salvador and Andina were extensively analysed, and also careful attention was given to the Henderson mine in the US, that had started operations with LHD recently (Figure 5). It was concluded that the herringbone type configuration was the limiting factor of these designs.

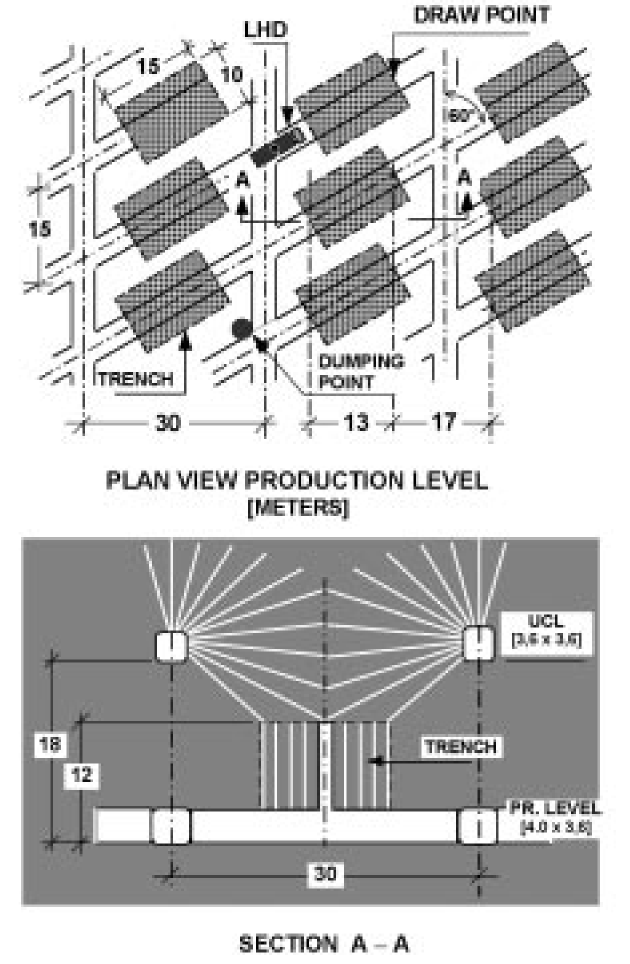

Figure 6: Block caving with LHD´s, El Teniente mine.

The new proposed configuration (Figure 6) consisted in confronting the loading accesses in opposite directions, and aligned along the same axis. The idea was to take advantage of the space provided by both loading accesses for the manoeuvring of the LHD's. The design was validated by marking down the ground plan on surface to duplicate the design geometry, and test driving the first LHD equipment that had been acquired by the mine. Results spoke for themselves: the cycle time of equipment increased in only a few seconds, which were irrelevant in the total cycle time. The adopted design is shown in Figure 6.

The first block undercut with this new design started production in May, 1982. Two years later, after steady state production and with a continuous modality of undercutting (panel caving), 5 yd3 LHD productivity reached 850 t/shift, with a daily draw down rate in the order of 0,5 to 0,6 t/m2 (185 to 222 mm/day).

5 PRESENT DAY DESIGNS

In the mid 80's Andina starts studying its third Production Level (Third Panel Project) with the participation of D. Laubscher as consultant. A new design methodology was incorporated. The distance between draw points was refined with respect to the expected fragmentation produced by the undercutting; also the interactive draw concept was definitely introduced, postulating that the diameter of the active material can attain 1,5 times the diameter of a column with isolated draw. Nonetheless, the results of recent investigations by the IM2 group of Codelco and by the Mine Department of the University of Chile seem to indicate that the final "paper" about the subject has not been written.

Eventually, with minor differences, the three Codelco mines ended up applying this methodology for the design of the new production sectors, adopting variations of what has been termed the "Teniente Type Design", with different spacing between rows of draw points, as a function of the expected fragmentation according to the local conditions of each mine or sector. Also, even though it may seem a detail, this greater flexibility has been possible because of better mechanical conditions of equipment, which has made it possible to ease the restriction imposed on them to load on a straight line.

6 THE FUTURE AND PENDING PROBLEMS

The mining method which we have termed mass caving with LHD, and in particular the "Teniente Type Design", has been successful for more than 20 years and may well continue to be a good option for mass mining in the future. It is a productive and low cost method, which makes it the logical continuation for deep open pit mines. Nevertheless, there are still many challenges to face.

The main pending problems are related to the following:

- forced caving and/or pre-conditioning
- caving height
- secondary fragmentation
- seismic activity and collapse of openings
- draw control and reserve recovery
- undercutting rate

Forced caving and/or pre-conditioning: One of the effective ways to control the occurrence of rock bursts has been to maintain a low draw down rate for the initial area of a project, until it can break through to surface or the previous level, which usually happens after one third of the rock column has been extracted. After this precaution, practice has shown that draw down rates can be accelerated. It is possible that there exists a trade-off between the cost to force the caving or pre-condition the rock mass of an important initial area and, on the other hand, the benefit of obtaining a more productive rate and a safer undercut.

Undercutting height: The trend in under-cutting height in hard rock, at least in El Teniente, has been to decrease. From the initial 16,6 m used in sector Teniente 4 when it started production in 1982, it has evolved to the actual 3,6 m in the pre-undercut modality being used in the Esmeralda sector. Even though this design has some opera-tional advantages, the doubt remains whether such a low undercutting height will cause the settling of huge blocks, pressure on pillars and collapses of openings in the production level.

Secondary fragmentation: The amount of secondary blasting required by natural caving of hard rock can be very significant. It is necessary to make a good prediction of this unit operation and compare it to the convenience of making a forced caving, as has been successfully done for example in the west part of Teniente 4 South. The normal behaviour of rock is that secondary blasting will decrease as the extraction column increases. This unit operation must be carefully planned, designed and executed. After secondary blasting, there is a materials handling design for coarse ore, which depends upon the particular characteristics of each mine. There must be a match between bucket size of the LHD, grizzly size at the dump points, pickhammer at the production level or at the reduction level, sizers or crushers if to load conveyor belts, type and size of chutes if to load trucks or trains, bins, primary crushers, etc.

Seismic activity and collapse of openings: The collapse of openings in the production level is a problem to deal with. The main reasons for this problem are settling of huge blocks, high abute-ment stresses, improper design, poor construction, and inadequate undercutting sequence. High stress concentrations can also produce induced seismi-city, with violent effects such as rockburts.

Examples of these are: 18% collapse of the total undercut area in the production level of Teniente 4 South sector; 5 major seismic events, between 3,2 and 4,0 in the Richter scale, in Teniente Sub 6 sector from Jan 90 to Mar 92, with great damage and extensive stoppage of activities.

A mitigation measure for these situations has been to change the undercutting modality to pre-undercutting, which consists in making the production level openings and constructions "under shadow", that is, after the abutement stress has passed, which is accomplished by doing the undercut before the development of the production level openings and constructions. This has been successfully done in the Esmeralda sector of Teniente, even though not exempt of problems.

High magnitude seismic events occur mainly at the start of mining a virgin sector in highly competent rock, while subsidence is propagating to surface or to the previous level. As a control measure, strict restrictions to the drawing rates are imposed up to one third extraction of the column, after which the restriction is eased. As mitigating measures for rock projections and collapses caused by rockbursts, special reinforcement has been designed, where yielding characteristics are important.

Draw control and reserve recovery: In some which use block caving with LHD's, there is a trend of uneven draw. For instance, in Teniente 4 South sector, an effective LHD productive daily rate varying between 0,1 and 9 t/m2, for an average of 2,27 has been reported. Furthermore the daily draw rate for the whole sector was 0,59 t/m2 as an average. This would indicate a deficiency in the draw control, which is also reflected in the low reserve recovery shown as compared to higher figures for the standard chute tapper system. For the first 66 million t extracted, recovery was +19% of the in-situ tonnage and -34% of the in-situ grade, with a resulting 10% loss in recovery in terms of fine copper.

Undercutting rate: The pre-undercut moda-lity, which apparently has been a solution to preserve the integrity of openings and deve-lopments of the production level, has important difficulties regarding accesses and coordination of work in a much restricted area. This limits the undercutting rate, and therefore the capacity to produce from the sector. Some challenges ahead visualized to solve this problem are: uncouple production faces; adopt advanced undercut instead of pre-undercut and redesign fortification of accesses to allow for rockburst, and industrial engineering analysis to improve work organi-zation and coordination in the confined areas.

7 CONCLUSIONS

The evolution of block caving in Chile over the last thirty tears shows how the mining industry has been able to adapt to changing natural conditions, keeping its competitiveness in spite of an increasingly complex environment. This has been possible thanks to the ingenuity, open mindedness and effort of the professional teams both at the mines and in supporting outside groups.

Among the different improvements which were introduced during the three decades, the "Teniente Type Design" of the production level has probably had the biggest impact on the successful lay-out of the ore extraction scheme and has hence been introduced in all three chilean operations.

Although there have been significant advances both in knowledge and in design and operation of Codelco's block caving mines, several issues still have to be addressed in order to solve the many problems that remain, and most of which are related to the geotechnical nature and behavior of the rock in the mines as they progressively get deeper.

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