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New approach for rapid preparation of block caving mines

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Abstract

Block and panel caving is one of the most suitable methods for exploitation of large massive ore bodies where a high rate of extraction is required. However, many authors have studied the rate of extraction and concluded that it may be limited by the ability to prepare mines at high rates.

Different approaches, to increasing the rate of extraction, tend towards the introduction of some kind of continuous draw and materials handling on production levels, which apparently are close to reaching a practical solution. However, corresponding studies to match the rate of mine preparation to high extraction rate operations have not been discussed or published to any great depth.

This paper describes some layouts and constructive techniques compatible with rapid mine preparation demand. A significant reduction of time in mine preparation, in both underground drifting and construction is expected as a consequence of the introduction of non-blasting excavation methods and using pre-cast concrete modules to build up underground mine construction.

The main advantage of non-blasting drifting, is the predictability of finishing underground drifts, such that it is possible to standardise all the components of single underground mine constructions (i.e. drawpoint, dump points).

The solution requires adapting and developing both new equipment and new layouts, because neither standard full face boring machines nor current layouts for conventional block/panel caving are suitable to high speed development of caving levels.

The layouts discussed focus on conventional load–haul–dump units (LHD) and on mechanised continuous drawing system (MCDS) arrangements. In each case, the general arrangement presented has been developed by JRI Ingeniería S.A as part of its technological innovation policy.

Finally, an evaluation of the impact upon scheduling and costs, are presented in comparison with conventional methods. New approaches are also mentioned about other issues such as logistics and commissioning, with new actors in the business, which may produce additional benefits for project and operation management.

1 Introduction

As part of its innovation policy, JRI Ingeniería S.A. encourages their professional staff to develop internal projects concerning different problems of mining and metallurgical industry. This work is one such project and deals with rapid development of underground mines, which is one of the issues where progress is demanded by the users of block/panel caving.

Increased rates of extraction in block/panel caving are close to success following the industrial tests of preconditioning (van As et al., 2004) and MCDS (Encina et al., 2008), but no similar initiatives have been dealing with preparation rates.

Considering that undercutting rate is one of the key variables controlling production capacity of massive caving mines (Pesce and Ovalle, 2004), mine preparation rate becomes the bottleneck, to raise production rates of underground mines to the scale of open pit mines.

Mine preparation comprises drift development and different concrete works underground. Both types of works have made significant progress in civil works applications, examples of which include tunnel boring machines (TBM) and pre-cast concrete modules used as standard practice in modern construction, but mines have not taken advantage yet of these technologies.

TBM application suits well wherever long and large tunnels have to be built, as the main accesses and transport infrastructure of new mines, but it is not practical for mine preparation, where drift extension is usually less than 200 m and cross sections are less than 30 m^2. On the other hand, rock headers would fit better than TBM for developing short and small drifts, but they require relatively soft and non-abrasive rock.

Non-blasting development is well known in vertical development, where, for reasons of safety, drill and blast methods were abandoned two decades ago and replaced by raise borers and blind hole borers. Both techniques bore raises from the bottom up in such a way that detritus material falls down to the bottom where mucking may be done at the operator's convenience.

The central idea in this work, which is not original (Departamento de Construcción y Estructuras, 2001), takes advantage of the experience in underground mines using raise borers, by extending the concept to horizontal development, consisting of doing the same work as raise borers, but horizontally, called now 'drift borer'.

Drift boring application is restricted to hard and competent rock environment, which is exactly the case in Chilean mines, where most of production and undercut level of currently running block caving mines are located on primary rock, which is mostly characterised as Class II of Bieniawski rock mass rating (RMR).

Starting with two parallel access drives, the machine would be located in one of them, fixed horizontally to drill the pilot hole just in the centre of the new drift and then from the other access install the cutter head that would be pulled and rotated by the machine until the head could be extracted.

The difference between raise boring and drift boring, is in the way the detritus would be mucked. A drift borer needs a system as used by TBM equipment, that is to say the reamer head has to have channels to collect spoil material and direct it to a conveyor.

The project comprises three parts:

- design of block caving layout with 'round drifts'
- design of modifications to an old raise borer machine, both the positioning device and cutter head for mucking system
- implementation of the drift borer and test on-site.

This paper deals with the first part, which was developed to justify an application to get government funds to develop parts two and three.

2 Conventional block/panel caving mine layout

For the purpose of this study, a theoretical ore body approximately 1,500 m in length, 200 m in width and 300 m in height is considered for exploitation by conventional LHD block/panel caving with drawpoints spaced on 15 m centres.

A mine layout is proposed based on current trends, especially with respect to coarse material handling, using underground crushing on the production level, to avoid passing large boulders through ore passes. Small ore passes in length and diameter, are less exposed to deformation by stress or wedge slippage. Also, crushed material is less prone to the occurrence of hang-ups.

Figure 1 shows the arrangement where LHDs can extract the ore from drawpoints and haul it to a crosscut, where it can dump the ore over a chain conveyor.

Finally the conveyor transports the ore directly to a crusher. After the ore is crushed to a convenient size, it can be transferred through small ore passes to belt conveyors and/or skips.

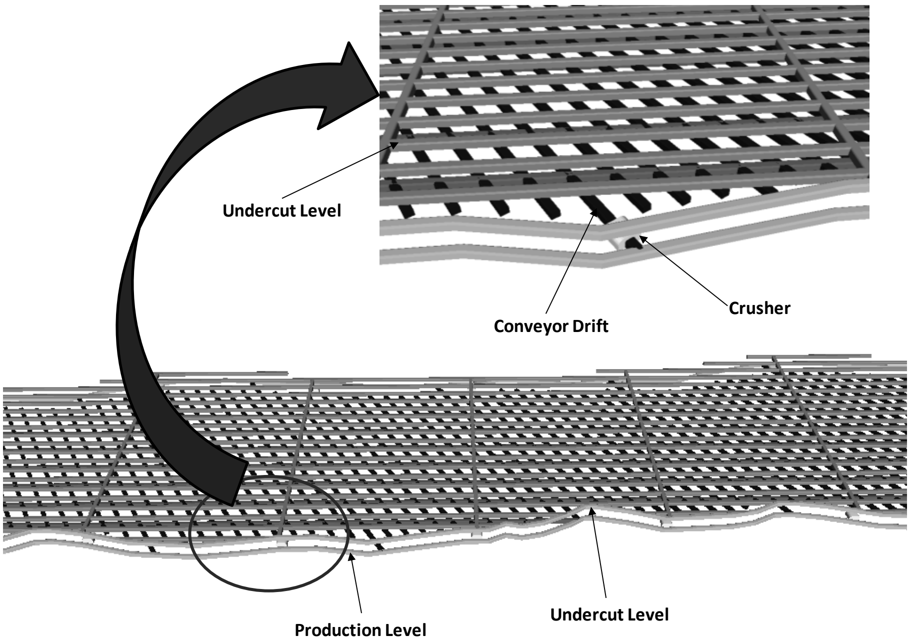

Figure 1 Conventional LHD block/panel caving layout

Figure 2 shows the dump point over a chain conveyor. A bridge allows the LHD to pass from one side to another depending if it arrives from the front or rear end. Dumping also may be done from both sides of the bridge. Notice that the conveyor drift is located in the future position of draw point drift, the floor of which has been lowered to install the chain conveyor. When they are used as drawpoint drifts, bridges are removed and the floor is filled with muck.

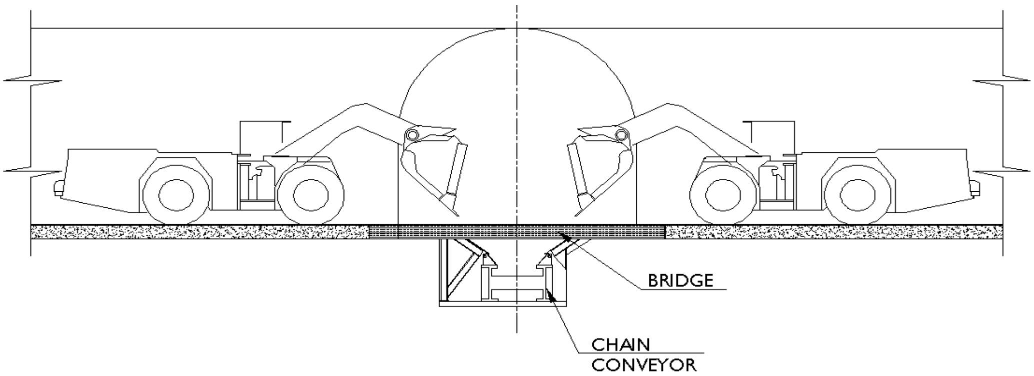

Figure 2 Dump station at production drifts

Undercut design is the so called ‘crinkle cut’ (a combination of flat and inclined narrow cut) usually to be blasted after the production level is completely built. Drawbells are blasted just before the undercut advances. In the case of pre-undercutting, the same arrangement can be adapted by completing the fan drilling to develop a V-shaped cut and extending the length of the drawbell drill holes.

Considering that crosscuts are usually pre-developed, preparation of the production level comprises drawbell drifts and production drifts (LHD) and the undercut level comprises only undercut drifts plus all the construction works on roadways, drawpoints and dump points.

2.1 Conventional drill and blast development

Conventional tunnelling by drill and blasting with shotcrete and rockbolt support, and ‘tailored’ in situ construction work adapted to the shape of walls, roofs and floor, is a long established and most common method of mine preparation.

A simple exercise of scheduling the preparation of approximately 30,000 m^2 (144 drawpoints) which is close to the maximum area experienced undercut by year without rockburst events looks like Table 1.

Table 1 Conventional tunnelling and construction practice

Conventional LHD with Chain Conveyor	Units	Year 1 Qrt 1	Qrt 2	Qrt 3	Qrt 4	Year 2 Qrt 1	Qrt 2	Qrt 3	Qrt 4	Total
LHD Drifts	m	301	301	301	301					**1204**
Drawbell Drifts	m					600	600	600		**1800**
Undercut Drifts	m					516	516	516	516	**2064**
Drawpoint Construction	each						48	48	48	**144**
Total	**m/Qrt**	**301**	**301**	**301**	**301**	**1116**	**1116**	**1116**	**516**	
Development Groups	each	1	1	1	1	4	4	4	2	
Rate of development	m/Qrt-Group	301	301	301	301	279	279	279	258	
Rate of development	m/Month-Group	100	100	100	100	93	93	93	86	
Construction Groups	each						8	8	8	
Rate of Construction	Units/Qrt-Group						6	6	6	
Rate of Construction	Units/Month-Group						2	2	2	

This means that preparation takes two years involving one group of development in the first year and four groups in the second year. Also in the second year eight construction groups are considered. Therefore, every year is required to have five groups of development and eight groups of construction.

Groups are formed by a set of equipment and the correspondent labour to work three shifts (8 hours) per day and 30 days per month. Table 2 gives a list of components for development and construction.

Table 2 Groups composition for conventional tunnelling and construction

Development Group		Construction Group	
	Qty		**Qty**
Equipment		**Equipment**	
Drifting jumbo	1	1 Boom jumbo	1
Blasting utility	1	Concrete mixer	1
Mucking LHD	1	Concrete pump	1
Scaler	1	Scaler	1
Rockbolting jumbo	1	Mucking LHD	1
Shotcrete utility	1	Construction utility	1
Labour		**Labour**	
Operators	16	Welder/reinforcer	12
Mechanics	12	Concrete crew	16
Electrician	8	Mechanics	8
Crew supervisor	4	Crew supervisor	4

2.2 Preparation with drift borer

The same general arrangement for conventional LHD mucking with chain conveyor has been developed replacing rectangular drifts with circular drifts. A tunnel section of 3.6 m diameter, would be developed in such a way that roadway can be supported using pre-cast concrete pans as shown in Figure 3. The flat road surface of 2.5 m wide would allow an LHD to pass.

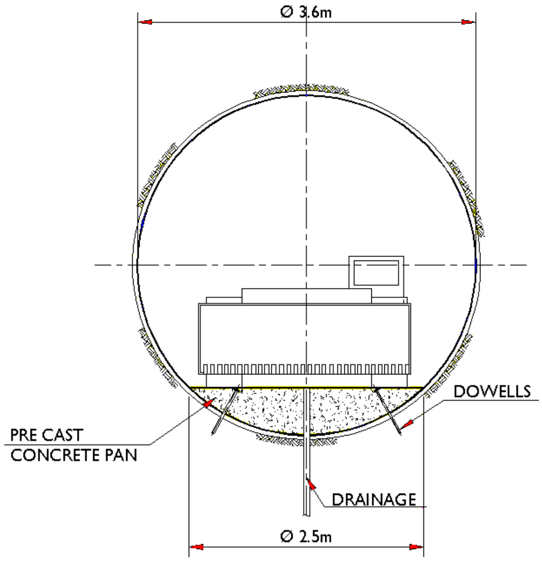

Figure 3 Circular section with pre-cast roadway

The summary of preparation using drift boring and pre-cast concrete plans for construction is presented in Table 3.

Table 3 Drift boring and pre-cast concrete modules

Conventional LHD with Chain Conveyor		Year 1								
	Units	M1	M2	M3	M4	M5	M6	M7	M8	Total
LHD Drifts	m	482	482	241						**1204**
Drawbell Drifts	m	360	360	360	360	360				**1800**
Undercut Drifts	m						688	688	688	**2064**
Drawpoint Construction	each			24	24	24	24	24	24	**144**
Total	**m/MONTH**	**842**	**842**	**601**	**360**	**360**	**688**	**688**	**688**	
Drift Borer Groups	each	2	2	2	1	1	2	2	2	
Rate of development	m/Month-DB Group	421	421	300	360	360	344	344	344	
	m/day-DB Group	14	14	10	12	12	11	11	11	
Construction Groups	each			4	4	4	4	4	4	
Rate of Construction	Units/Month-Group			6	6	6	6	6	6	

It can be seen that only eight months are required to prepare the same area using only two drift borers groups and four construction groups, based upon rates of advance higher than conventional drifting.

In this case, the groups are conformed as presented in Table 4.

Table 4 Groups composition for drift boring and pre-cast concrete modules

Development Group		Construction Group	
	Qty		**Qty**
Equipment		**Equipment**	
Drift borer	1	1 Boom jumbo	1
Mucking system	1	Hyster boom	1
Scaler	1	Scaler	1
Rockbolting jumbo	1	Mortar pump	1
Shotcrete utility	1	Construction utility	1
Labour		**Labour**	
Operators	16	Operators	12
Mechanics	12	Modules assembler	12
Electrician	8	Mechanics	8
Crew supervisor	4	Crew supervisor	4

3 Mechanised continuous drawing system

Considering the same area of exploitation, Figure 4 shows the layout for MCDS (see Encina et al., 2008), composed by one dozer feeder per drawpoint to feed chain conveyors on each production drift. Also a gathering conveyor system is located on a future drawpoint drift.

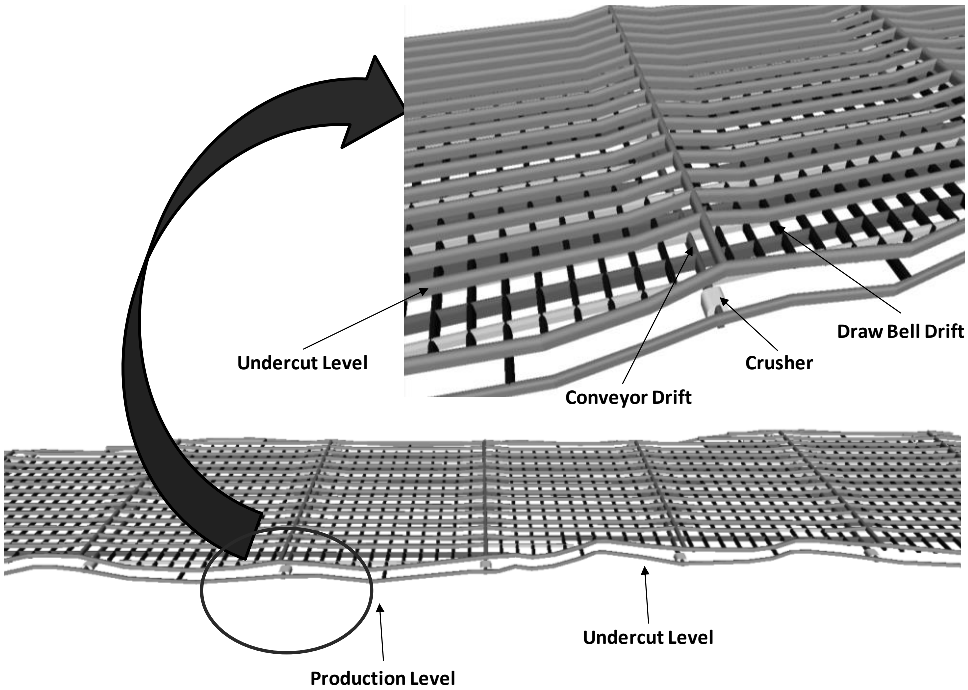

Figure 4 MCDS layout

3.1 Conventional drill and blast development

Table 5 summarises the schedule to prepare the same area of 144 drawpoints with conventional drill and blast tunnelling with shotcrete and rockbolts support and conventional in situ construction works.

Table 5 Conventional tunnelling and construction practice

Continuous Mechanized Drawing System		Year 1				Year 2				
	Units	Qrt 1	Qrt 2	Qrt 3	Qrt 4	Qrt 1	Qrt 2	Qrt 3	Qrt 4	Total
Service Drifts	m	303	303	303	303					**1211**
Conveying Drifts	m	260	260	260	260					**1038**
Drawbell Drifts	m					460	460	460		**1380**
Undercut Drifts	m					519	519	519	519	**2076**
Drawpoint Construction	each						48	48	48	**144**
Total	**m/Qrt**	**562**	**562**	**562**	**562**	**979**	**979**	**979**	**519**	
Development Groups	each	2	2	2	2	4	4	4	4	
Rate of development	m/Qrt-Group	281	281	281	281	245	245	245	260	
Rate of development	m/Month-Group	94	94	94	94	82	82	82	87	
Construction Groups	each						8	8	8	
Rate of Construction	Units/Qrt-Group						6	6	6	
Rate of Construction	Units/Month-Group						2	2	2	

Preparation takes two years involving two groups of development in the first year and four groups in the second year. Also in the second year eight construction groups are considered. Therefore, every year six groups of development and eight groups of construction are required.

Groups are the same as presented previously in Table 2.

3.2 Preparation with drift borer

The same mine layout was adapted to utilise a drift borer of 3.6 m diameter as for a conventional LHD layout.

As production and gathering conveyor drifts have to be higher than draw point and service drifts, to bore them, two pilot holes and reaming would have to be done. An ‘eight shape’ drift of 6.1 m height was designed as showed in Figure 5.

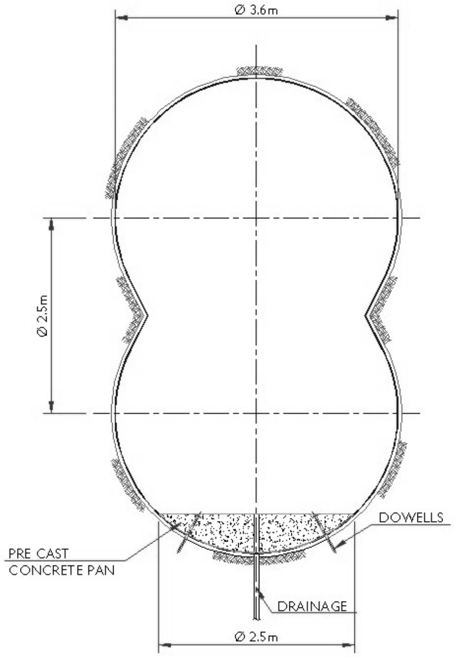

Figure 5 Eight shape of conveyor drifts developed by drift borer

A summary of the preparation work using drift boring and pre-cast concrete plans for construction is presented in Table 6. Notice that double length is considered for conveyor drifts because they have to be developed twice.

Table 6 Drift boring and pre-cast concrete modules

Continuous Mechanized Drawing System		Year 1								
	Units	M1	M2	M3	M4	M5	M6	M7	M8	Total
Service Drifts	m	484	484	242						**1211**
Conveying Drifts	m	415	415	415	415	415				**2076**
Drawbell Drifts	m						460	460	460	**1380**
Undercut Drifts	m			208	415	415	415	415	208	**2076**
Drawpoint Construction	each			24	24	24	24	24	24	**144**
Total	**m/MONTH**	**900**	**900**	**865**	**830**	**830**	**875**	**875**	**668**	
Drift Borer Groups	each	2	2	2	2	2	2	2	2	
Rate of development	m/Month-DB Group	450	450	433	415	415	438	438	334	
	m/day-DB Group	15	15	14	14	14	15	15	11	
Construction Groups	each			4	4	4	4	4	4	
Rate of Construction	Units/Month-Group			6	6	6	6	6	6	

Again, the time is eight months as well as in conventional LHD layout, but in this case, the two drift borers groups are always busy. Four groups of construction are also enough. Groups are formed as presented in Table 4.

4 Cost comparison

Preliminary assessments of unit costs of mine preparation for both methods are presented in Tables 7 and 8.

Table 7 Unitary cost of preparation for conventional LHD with chain conveyor

Conventional LHD	Drill & Blast			Drift Borer		
with	Development	Construction	Total	Development	Construction	Total
Chain Conveyor	US$/m2	US$/m2	US$/m2	US$/m2	US$/m2	US$/m2
Capital Cost	61	75	136	72	24	96
Equipment Operation	41	26	67	110	16	126
Materials	123	95	218	503	48	550
Labour	266	429	695	106	194	300
Indirect	74	94	167	119	42	161
Total	564	720	1.283	910	324	1.233

Table 8 Unitary cost of preparation for MCDS

Mechanized	Drill & Blast			Drift Borer		
Continuous Drawing	Development	Construction	Total	Development	Construction	Total
System	US$/m2	US$/m2	US$/m2	US$/m2	US$/m2	US$/m2
Capital Cost	97	75	172	95	24	119
Equipment Operation	54	26	81	147	16	163
Materials	163	95	258	668	48	715
Labour	319	429	748	106	194	300
Indirect	95	94	189	152	42	195
Total	728	720	1.448	1.169	324	1.492

Simple comparison shows that, in terms of unitary cost of preparation, very similar figures are expected using drift borer and pre-cast concrete technology instead of drilling and blasting.

5 Conclusions

The main conclusions of this analysis may be summarised as follows:

- Simple adaptations to block and panel cave mining layouts are needed to introduce drift boring development and pre-cast concrete modules for mine concrete works.
- By using drift boring methods, more than one year of time may be saved on preparing an area of 144 drawpoints.
- Similar unitary costs of preparation are expected using drift boring development and pre-cast concrete instead of conventional preparation method.
- Both drift boring and pre-cast concrete modules, are not new inventions, they have been used extensively in other applications during more than 20 years, so the project may be classified as low risk.

The solutions analysed have started with crosscuts previously developed with conventional drill and blast practice. In the future the analysis will consider the possibility of making them with TBM machines.

Acknowledgements

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