State of Art of MOIL for Introduction of Modern Technology for Underground Mining Operations in Narrow and Weak Manganese Deposits of Central India

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Abstract

MOIL Limited is the largest producer of manganese ore and its value added products in India. Exploiting manganese from late 18th century, since then, the company has passed through many phases of technological developments by innovation and state of art for higher production, productivity and safety. MOIL operates 10 mines, except 3, rest of the mines is worked through underground. The Balaghat Mine is the largest and deepest underground manganese mine in Asia. The manganese deposits in central India are unique in respect of their formation. The ore body is basically sedimentary deposit with various types of geological disturbances and very poor rock mass quality with varying dip. The exploitation of narrow ore bodies with weak rock masses of manganese deposits in central India is a difficult and challenging task. Since 1994, all the underground mines of MOIL were using horizontal cut and fill method of stoping with various supporting systems, like pack pillars and timber square with manual rock/waste filling system. In order to improve the safety and productivity, the Company has introduced cable bolting techniques by modification of drilling rig by state of art and subsequently successfully introduced hydraulic sand stowing in all underground mines. This has changed total scenario of underground operations and helped to introduce mobile mining equipments such as SDL, LHD and Single Boomer – Jumbo Drill for underground operations in phased manner. The paper presents the successful story and state of art of MOIL that has helped for incremental improvements in safety, production and productivity of MOIL

Keywords: Cable Bolting, Hangwall, Jumbo Drill, Manganese Ore, SDL

1. Introduction

Manganese comprises about 0.1% of the earth's crust and is the 12th most abundant element. Some common rocks contain as much as 0.16% manganese on an average *(Source: IMI, Paris)*. Manganese ores in India are being exploited well over the past hundred years. These ore bodies are mainly of secondary origin and are associated with the older Achaean meta-sedimentary[1]. The deposits

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in India were originally classified as three fold *(Fermor,1909),* which were subsequently modified as fourfold (*GSI News 1973; Khrishnaswamy 1979).*

The manganese deposits in central India are unique in respect of their formation[5]. The ore body is basically sedimentary deposit subject to various types of geological disturbances. This area has the oldest meta-sedimentary named as Sausar series. Host rock mainly – Munsar mica-schist. Highly jointed ore zone associated with many geological discontinuities – like folds, faults etc. Generally 3 major joints planes running parallel to strike and 3 joint planes running across the strike in sausar series.

2. Support Requirement

The underground mines of MOIL are operated at shallow to moderate depths. Underground opening cannot be left permanently unsupported. The decision of 'support' versus 'no-support' depends on factors such as;

- The rock mass properties,
- The span width and the type of excavation,
- The unsupported openings range may be in span from 2 m up to 100 m,

It is clearly the rock mass properties that are of prime. For rock reinforcement in underground structures, an engineering analysis begins with evaluation of two fundamental factors[3];

- The strength of the different components of the rock structures and
- The forces that are loading it.

Table 1. Un-supported Span and Support Pressure – Balaghat Mine

Mean RMR	Max. Span (unsupported) - m	Support Pressure kg/cm²
29	2.07 - 2.73	2.25 - 2.83
44	3.58 - 5.56	1.24 - 1.79
35	2.43 - 3.58	1.79 - 2.47

During the experimentation of full column cement grouted 'Çable Bolting' at Balaghat Mine, the calculate unsupported span and support pressure is given in Table 1.

2.1 Pre Reinforcement – Cable Bolting

The concept of pre reinforcement consists of installing support prior to excavating the adjacent rock. The principal effect is to limit the displacement of the rock mass to small values. This minimizes the shear and dilation along existing geological structures and perseveres their in-situ cohesion and friction such that the rock mass becomes self supporting *(Little John, 1992).* Another advantage of pre-reinforcement techniques is that blasting can be done against and already reinforced surface, which would reduce the amount of blast damage. Additionally, the effect of sudden changes in the surrounding stress field resulting from mining can be better controlled by a pre reinforced rock mass. The effective pre reinforcement of the rock mass in excavations such as those for cut and fill mining, longer reinforcement elements are required[4]. Since it is difficult to install long rigid rock bolts, the technique of cable bolting using long cables has been developed. With this scenario, the company has experimented and established the 'Cable Bolting Techniques' for obtaining improved ground conditions in all the underground mines of MOIL

2.2 Empirical Design

Numerous methods for the design of roof bolts have been proposed over the years. The oldest simplest and probably still most widely used equation for bolt design is dead-weight suspension *(Obert and Duvall 1967):*

(U * t * We * R) where P = required bolt capacity;

P = (-------------------) SF U = unit weight of the rock;

(n +1) t = thickness of suspended rock;

n = number of bolts per row;

We = entry width;

R = row spacing;

SF = safety factor.

Design of cable bolting depends on the mass of rock to be supported and, it is essential to identify the probable mode of failure[6]. Then the weight of rock blocks likely to be separated from the competent formations can be estimated by any of the various conventional methods – beam theory for stratified rocks, and pressure arch theory for massive formations. Details are given Figure 1 & 2.

2.3 Rock Load Height (Capacity/Pattern)

The rock load height concept is a slightly more sophisticated version of the dead weight theory. Originally proposed by Terzaghi (1946), the theory predicts the load on the support based on the rock quality and the span. Unal (1984) defined the rock load height taking RMR indicated by Benawaski. The rock load height concept *(after Unal, 1984)* is mentioned hereunder;

(100 – RMR)

Ht = B (---------------) where, B is a width of opening/

(100) Roof span

The guidelines for cable selection were based on empirical methods provided by Barton, et al (1977)[7]. For large openings, the recommended cable length, L', in m is:

L' = 0.4 B/ ESR for roof and

L' = 0.35 H/ESR for walls

Here, B = opening width,

H = height of the opening (stope)

ESR = Excavation support ratio, ESR values are 1.6 for permanent opening, and 3 to 5 for temporary openings.

Potvin, Hudyma and Miller (1989) developed an empirical method for the design of cable bolts. The rock mass conditions are first assessed using NGI rock mass approach *(Barton and others, 1974)*, and adjustments are made to the Q values to obtain a modified stability number, N' *(Potvin and Miller, 1992)*[2].

2.4 Pressure on Square set in Stope

The timber square set support in the stope is shown in Figure 3. According to many investigators[3], the pressure on a gallery is in the form of parabolic dome as shown in Figure 3. As the theoretical formula is complicated, for practical purpose the approximate values have been taken.

To estimate load height of the dome the Protodyakonov formula is as follows:

h = l / f

h = height of the parabola load height comes to (0.4 to 0.53 m)

l = length of the cap on the wooden set (1.6 m)

f = Protodyakonov coefficient of hardness (weak schist 3) or 0.01 of the compressive strength of the rock (about 4)

From the above, it is found that 0.40 to 0.53 m top layer has to be supported additionally after erection of timber sq. set support.

3. Re-engineering in MOIL

For introduction of modern mining technology in narrow and weak ore body re-engineering for mobile underground equipment and mining methods is necessary as there are few underground mining equipment manufactures are available in the country. To introduce mobile underground equipment MOIL has carried out re-engineering of equipments and methods in phased manner.

3.1 Re-engineering for Equipment

The R&D Department of MOIL has developed the rig frame suitable for Cable Bolting drilling and installation procedure. Thereafter stoper has been developed for roof bolting. The imported machine for cable bolting drilling of Atlas Copco, Sweden and rig frame developed by MOIL is given below in Figure 4 and 5.

3.2 Re-engineering of Methods

Infrastructure of the underground mines of MOIL was not suitable for introduction of modern mobile underground mining equipments and hence MOIL has re-engineering the underground infrastructure for effective use of mobile underground equipments by state of art. The re-engineering of underground operations in MOIL mines are listed below;

For Support – Cable Bolting

Hydraulic Sand Stowing

Panel Working

Mechanical handling of ROM by SDL in stope (Crawler mounted)

Mechanical handling of waste by LHD in development headings (Tyre mounted)

Introduction of Single Boomer – Electro Hydrostatic drill machine (Crawler mounted)

Introduction of LHD (Tyre Mounted) with Jumbo Drill (Crawler mounted) for development headings

3.3 Introduction of Mechanized Stope Design

With success of 'Cable Bolting' cycle, the stope length from 30 m to 60 m for panel working of 3 stopes for mechanical handling of ROM by Side Discharge Loader (SDL) has been introduced and is given below in Figure 6.

Mechanical handling of ROM by SDL in the stope has improved the productivity (OMS/T) from 3.5 T to 9 T.

Increase Level Interval from 30 m to 45 m at Balaghat Mine:

It was decided to increase the level interval from existing 30 m to 45 m below 12th Level at Balaghat Mine. This enables larger quantity of minable reserves for underground stoping operation.

Introduction of modern mobile mining equipment in underground mines:

Recently introduced mobile mining equipment in underground mines of the Company:

- Single boomer electro hydraulic crawler drill machine, rate of penetration approximately 1 meter/minute. Used for faster cable bolting, Roof bolting, face drilling in underground mine to improve production, productivity and safety.
- Introduced SDL/LHD's in underground operations

4. Conclusion

The above technological adoptions in underground mines of the MOIL have been helped to improve safety and productivity. The phased mechanization in underground mines of MOIL is listed below;

- Face productivity has been improved from 2.4 T to 3.5 T in cable bolted stopes.
- Mechanical handling of ROM by SDL in stope has been successfully introduced and improved the face productivity up to 9 T.
- Single boomer crawler mounted electro- hydrostatic drill jumbo has been introduced at 13.5th Level along with LHD for drive development. Gallery dimensions have been increase. This has generated an avenue for trackless mining in underground.
- Level interval has been increased from 30m to 45m below 12th Level at Balaghat Mine
- Stope geometry has been changed and panel op-

eration has been successfully implemented.

- Valuable timber required for square set has been eliminated and it is helping to preserve the environment.

The above established technological set up in underground infrastructure and operations by state of art of MOIL have improved the production capacity from 0.6 million tonnes to 1.14 million tonnes from the year 1994 to 2015. Performance of MOIL Limited since the year 2001-02 to 2014-15 is given below in Table 2.

Table 2. Performance of MOIL

Details	2001-02	2014-15
Production – Manganese Ore (T in Lakh)	6.76	11.39
Output Per Manshift (OMS in T)	0.41	0.818
Total Income (Rs in Crore)	170.87	1139.86
Profit After Tax (Rs in Crores)	19.51	428.01

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