PRABHAT KUMAR
S. KIRAN
and
P. B. CHOUDHURY

Pillar and roadway stability assessment of development working of a metal mine with rock mechanics instrumentation – a case study

The paper deals with pillar and roadway stability assessment of development working of Ukwa underground metal mine of Manganese Ore India Ltd (MOIL). The assessment was conducted with rock mechanics instrumentation. Nine strain bars and six tape extensometers were installed to measure the strain and convergence in the roadways and strain in the pillars having size smaller than designed. The monitoring was continued for more than eight months.

The factor of safety (FS) was calculated for some randomly selected pillars and suggestions were made for their long-term stability if FS is less than 1.5.

This paper describes in detail the above instrumentation scheme, analysis of data and FS evaluation.

Introduction

Objective

The Manganese Ore India Ltd. (MOIL) entrusted a scientific study to erstwhile Central Mining Research Institute, Regional Center, Nagpur to assess the long-term stability of haulage and other permanent roadways at Ukwa mine. Accordingly, the study was started in July, 2004. Tape extensometers and strain bars were installed at different chainages and locations to monitor the convergence in the roadways and strain in the pillars respectively between 1850' and 1950' level within the chainage 8300 to chainage 10,000. The pillars having smaller size than the designed size of 10m×10m were selected for strain measurement. The present paper deals with the instrumentation, data analysis and recommendation made in the said study.

Geology

The manganese ore body of Ukwa mine extends along NE – SW direction for 6 km alongwith associated rocks of Munsar and Sitasaongi formation. Structurally, the Ukwa deposit is undisturbed i.e. without major folding and faulting. The general strike of the deposit is N30° to 65° E to 65° W and dips northwest between 15° to 35° with ore of dip angle like coal seams. The host rocks of Munsar and Sitasaongi formation show foliation due to deformation which is parallel to the bedding plane. The minor rolling of the ore body along with its associated rocks indicates a folding of very mild intensity along the strike of the formation.

Messrs. Prabhat Kumar, S. Kiran and P. B. Choudhury Central Institute of Mining and Fuel Research, Regional Centre, Nagpur. E-mail: pk_cmri@yahoo.com. E-mail: cmrirc@dataone.in

Instrumentation schemes

A total of nine locations were selected between 1850' and 1950' level between Ch.8300 to 10,000 for instrumentation. A number of nine strain bars and six tape extensometers were installed at different chainage and locations. The locations of installed instruments are given in Table 1.

The instrumented location covered a long strike length of the ore body and various rock mass types. Tape extensometers were installed to assess the convergence in the main roadways in various sub-levels and strain bars were installed at the side by pillars to obtain the strain both vertically and horizontally depending on the crack/joint directions.

Further, all types of pillars like sill, crown, barrier and development pillars were monitored for strain measurement.

Monitoring and data analysis

Monitoring was conducted periodically for more than eight months to understand the behaviour of pillar and roadway stability. The strain measured at nine different chainages and levels are quite low and are therefore insignificant. Plot of strain in respect of one strain bar at Ch.9500 at 3rd sub-level is shown in Fig.1.

The convergence is measured by tape extensometer at six different chainages and locations. It can be observed that maximum convergence has not exceeded 2.64 mm. Convergence as observed from one of these tape extensometers at Ch.8500 is shown in Fig.2.

Safety factor estimation

The instrumentation was carried out in some of the selected locations to have a broad overview. Though the observed variation in strain and convergence were not alarming, further analyses were made to have an overview on the safety of the standing pillars with following methodology.

Table 1: Location wise installed instruments at Ukwa mine

	Location	Number and direction of strain bar	Type of instrument
1	Ch.9500, 3rd sub-level inclined pillar	One, vertical	Strain bar 369, tape extensometer
2	Ch.8750, 1950' level crown pillar	One, vertical	Strain bar 368, tape extensometer
3	Ch.8300, 3rd sub-level crown pillar	One, vertical	Strain bar 379, tape extensometer
4	Ch.9540, 5th sub-level north	One, horizontal	Strain bar 372
5	Ch.8600, 3rd sub-level inclined pillar	One, vertical	Strain bar 375, tape extensometer
6	Ch.8600, 3rd sub-level sill pillar	One, vertical	Strain bar 376, tape extensometer
7	Ch.10,000, 4th sub-level south	One, vertical	Strain bar 374, tape extensometer
8	Ch.10,000, 4th sub-level south	One, horizontal	Strain bar 366
9	Ch.8750, 1950' level crown pillar	One, vertical	Strain bar 367

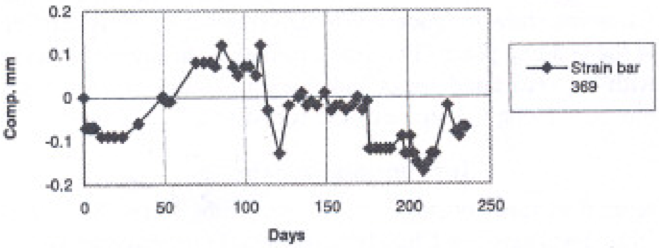

Fig.1 Strain bars 369 installed vertical at Ch.9500 at 3rd sub-level

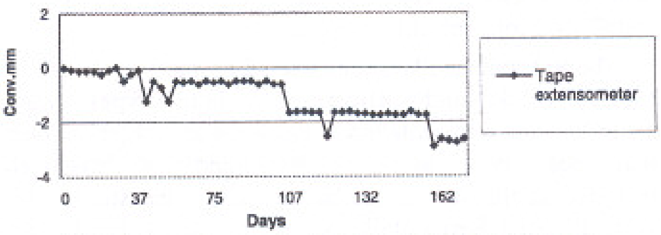

Fig.2 Tape extensometer installed at Ch.8500 sill pillar

Unlike coal mines, no general equation for pillar strength available is for metal mines because of the varied nature and structural features of different ore bodies. As such, a pillar strength formula has been derived here from the first principle of rock mechanics. This formula involves the effect of size on compressive strength in the form of a rock mass strength parameter (Sheorey,1997) and the effect of width/height (W/H) ratio as proposed by Biniawski (1984). It should however be understood that the rock mass strength included in the equation is for a very large volume of rock and therefore underestimation in the strength of the mine pillar. Therefore, a safety factor of 1.5 has been recommended for stability instead of the usual value of 2.0.

1. The actual length (W1, m) and width (W2, m) and normal height (h, m) of having smaller dimension than designed one were measured.
2. Pillar load (P) was calculated from the pillar dimensions, average roadway width (B, m), dip of the ore body (á, °) using the following equation:

$$P = \frac{(W1+B)(W2+B)}{W1.W2}\left(\cos^2\alpha + k\sin^2\alpha\right) \quad \text{... (1)}$$

where,

$$k = s_h/s_v \quad \text{... (1a)}$$

$$s_h = \frac{\nu}{1-\nu}\gamma H + \frac{\beta EG}{1-\gamma}(H+1000) \quad \text{... (1b)}$$

$$s_v = \gamma H \quad \text{... (1c)}$$

γ = Unit weight of rock per m depth = 0.027 MPa per m

H = Depth from surface, m

β = Coefficient of linear expansion = 8×10^{-6}

E = Modulus of elasticity of hangwall, MPa = 4500 MPa

G = Thermal expansion of rock = 0.024°c/m of depth

n = Poisson's ratio of hangwall rock = 0.25

3. The pillar strength (S) was calculated using the following equation:

$$S = \sigma_{cm}\left[0.64 + 0.36\left\{\left(\frac{2W!.W2}{W1+W2}\right)\Big/h\right\}\right]$$

where, σ_{cm} = rock mass strength of the ore body = $\sigma_c . e^{[RMR-100]/20}$

σ_c = uniaxial compressive strength of ore body = 61 MPa

4. Factor of safety (FS) = S/P

The calculations of safety factor for the selected pillars are shown in Table 2.

It can be seen from Table 2 that the FS is less than 1.5 in some cases. As the pillars are to stand for long period FS less than 1.5 may be detrimental. Hence conditions of such pillars should be strengthened by adequate support and closely and regularly monitored to avoid unsafe conditions. In case the pillars are yet to be developed, the pillar size can be increased or the roadway height should be properly maintained to improve the estimated FS to 1.5 or more. The exercise can be repeated by the mine authority for all the standing pillars and

TABLE 2: DETERMINATION OF FS FOR SOME SELECTED PILLARS

Pillar no.	W1	W2	h	S	H	G	s_h	s_v	k	P	FS
1	9.42	5.42	2.26	8.693	85	0.024	2.01492	2.295	0.8780	5.659	1.54
2	10.42	8.02	2.17	10.734	85	0.024	2.01492	2.295	0.8780	6.661	1.61
3	12.27	11.42	2.17	13.031	85	0.024	2.01492	2.295	0.8780	7.951	1.64
4	11.57	5.53	2.37	8.896	85	0.024	2.01492	2.295	0.8780	5.913	1.50
5	11.42	6.52	2.37	9.518	85	0.024	2.01492	2.295	0.8780	6.298	1.51
6	13.02	11.72	2.72	11.380	85	0.024	2.01492	2.295	0.8780	8.188	1.39
7	7.12	5.42	2.26	8.114	85	0.024	2.01492	2.295	0.8780	5.360	1.51
8	7.92	5.42	3.27	6.752	85	0.024	2.01492	2.295	0.8780	5.476	1.23
9	10.67	8.92	2.92	9.203	70	0.024	1.86264	1.89	0.9855	7.158	1.29
10	10.82	8.32	2.57	9.802	55	0.024	1.71036	1.485	1.1518	7.301	1.34
11	15	11	2.35	12.940	55	0.024	1.71036	1.485	1.1518	8.943	1.45

σ_c = 61 MP_a, RMR = 50, σ_{cm} = 5.01 MP_a, ν = 0.25, γ = 0.027MP_a/m, $\beta = 8\times10^{-6}$, E = 4500 MP_a, B = 2.1 m, $\alpha = 30°$

suitable stabilization measurers can be adopted as suggested for those which are having FS less than 1.5.

Conclusions

The following conclusions are drawn from this study:

1. The observed data indicated very insignificant strain in the pillars and maximum convergence was 2.64 mm in the roadway, which is also low.
2. The factor of safety (FS) was determined for some random pillars in view of long-term stability. Though the FS was more than 1.2 in all the cases, but a close monitoring and some stabilisation measures are recommended where the FS is less than 1.5 as those pillars are to stand for a long period of time. Further, the pillars near the stoped out area need to be monitored closely (and strengthened if required) as the condition in the stoped area could not be assessed due to sealing. To reduce the weathering and deterioration effect of the phyllite present at the top and bottom of the pillars and subsequent instability due to this, 50-100 mm thick shotcreting with netlon (optional) at the pillar top and bottom covering the phyllite formation was suggested.

Acknowledgements

The authors are thankful to Director, CIMFR for permission to publish the paper. Thanks are due to the MOIL authority for sponsoring this study. The authors also thankfully acknowledge the support and facilities provided by Ukwa officials during the course of study. The authors are also thankful to Dr. P.R. Sheorey for his contribution during the course of study. Lastly, the authors pay homage to our former Scientist-in-Charge Late Dr. A. K. Charkarborty for his valuable guidance during the preparation of this paper.

References

1. Biniawski, Z. T. (1984): Rock mechanics Design in Mining & Tunnelling, Balkema, Rotterdam.
2. Sheorey, P. R. (1997): Empirical Rock Failure Criteria, Balkema.
3. Kumar, Prabhat, Kiran, S., Choudhury, P. B., Jhanwar, J. C., Jha, B. K., Saharan, M. R., Chakarborty, A. K. and Bandopadhyay, C. (2005): Rock mechanics instrumentation for stability assessment of development workings at Ukwa Mine. CMRI Project Report No. GC/MT/N/4/2004-05.