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COAL NEWS

COAL INDIA TO SEE INVESTMENT OF 2 LAKH CRORE IN FIVE YEARS

Coal India will invest ₹ lakh crore in modernisation and diversification, coal minister Pralhad Joshi said in an exclusive interview to Sarita Singh. The Minister said the government will launch the next tranche of commercial coal auction with at least 10 mines in January 2021. The government will not interfere in the bidding process, he said, and it will award the blocks to successful bidders in the first tranche of auctions as early as possible. Edited excerpts:

How do you view the response to the first raound of commercial coal auctions, which concluded recently. What will be the process ?

Of the 38 mines auctioned, 19 clearly got good bids and only four mines got single bids. So we have a good success rate despite Covid and liquidity crunch apprehensions. Before this, in all tranches put together, 116 blocks were put up for auction and around 35 were successfully auctioned. There is a provision as far as these single-bid mines in the current tranche are concerned that we can put them up again for auction taking the discovered price as the base price in month or so, after giving time to the companies to quote. Of the 38 mines, if 23 mines are done, it is almost 60% success rate.

Whatever happened in the earlier regime, I am assuring people that as far as the government of India is concerned, all the 19 blocks will be given to whoever has participated and won in the most transparent and won in the most transparent manner. We are not interfering in the process. Whoever has won, will get it.

Coal Imports have gone down drastically for now, but once demand picks up they will rise again. What is your plan ?

I have told Coal India to ramp up production because they are the dominant player. Even during the Covid lockdown, we had kept enough stock. Quality-wise, too, I am taking a meeting every quarter to check slippages. By that I want to instil confidence among the users of the coal for both quality and quantity - quantity for availability and quality so that consumers get whatever they pay for.

We are going to invest ₹ 2 lakh crore in Coal India in the next five years. Of this, ₹1.2 lakh crore will be spent towards coal infrastructure only. We are presenting it to the price minister but in principle it has been accepted. The investment will be for modernisation, purchase of new technology, clean coal technlogies, like coal gasification liquefaction, and new blocks.

TIGHTER ENVIRONMENT STANDARDS TO IMPACT COAL CONSUMPTION ACROSS ASIA: MOODY'S

As countries including India, China, Japan and Korea would look to meet their carbon emission standards they are set to cut down on consumption of coal Moody's research said. The research said that most countries would gradually aim at reducing their dependence on power generated from coal. We expect governments across Asia to tighten environmental standards, to meet their commitments to curb carbon emissions and to improve air quality, through review of those policies and measures, the report said. Countries including China, Japan and Korea have recently pledged to reach net zero emissions by 2050-60. This also comes at a time when Covid pandemic is set to push back the recovery of the global economy by two years to 2023.

"We expect a nascent economic rebound to take hold globally but recovery will remain fragile amid the coronavirus pandemic, thereby creating uncertainty around the pace of recovery of power demand growth and sustained levels going forward. Coal-fired power producers will likely bear the brunt of demand reductions in major countries including China, India, Japan, Korea and Indonesia. This is because renewable energy will play an increasingly important role in power supply given governments' clean energy policies and initiatives for green recovery," the report added.

COAL INDIA TO INVEST OVER RS 5,650 CRORE OVER 4 YEARS IN SOLAR TO CUT COSTS

Coal India Ltd will invest Rs. 5,650 crore to set up solar projects with a capacity of 3,000 MW, the company said. This is part of its effort to become a 'Net Zero Energy Company' by 2023-24, which means it would meet all its energy requirements through sustainable power. "While Rs.3,650 Crores is planned to be invested through CIL's Capex, till 2023-24, the rest would be met through joint venture models that the company intends to pursue for this initiative," CIL said in a statement.

The rest of the money would be sourced from other collaborations. MoU's with NTPC and Solar Energy Corporation of India (SECI) will account for 1,000 MW worth of projects each, while NLC Limited will make up the rest under the 'Coal Lignite Urja Vikas Private Limited'. The total capacity will comprise of 14 rooftop and ground-mounted solar power projects, scheduled to be completed by 2024. This move will also save 3,000 tonnes of carbon dioxide emission each year, the company added. This initiative will also help save 4.4% of the coal behemoth's annual power consumption expense, currently estimated at Rs. 3,400 crore for FY 2020.

Currently, CIL only has a solar capacity of 10 MW. It plans on gradually adding 220 MW in FY '22, 1,293 MW in FY '23, and peaking in FY '24 with capacity additions of 1,340 MW. "CIL's subsidiaries have already identified 1,156 acres of land between them where they will set up 220 MW solar projects by end FY' 22. For 2022-23 and 2023-24 CIL is eyeing to set up solar projects on pan India basis subject to power evacuation facility by central transmission utility," the PSU added in its statement. Through the inorganic route, CIL is also in discussion with NTPC to add 140 MW of solar power under the Centre's CPSE scheme. Including this, it will cumulatively result in just over 3,000 MW of operational renewable energy by FY '24 for Coal India.

MINING NEWS

MINING & CONSTRUCTION EQUIPMENT VOLUMES TO GROW BY 20% IN 2021 AMID STRONG DEMAND UPTICK: ICRA

Amid a strong demand recovery in mining and construction equipment industry since late June 2020, rating agency ICRA has estimated that the Industry's volumes to grow by 20% in 2021, and has revised the volume decline during 2020 to be at 12-14% from 15-20% predicted earlier. "The ratings agency in May 2020 had estimated a sharp 15-20% decline in industry volumes in FY 2021, but considering the demand revival since July and the continued market momentum in November, substantiated by dealer check-ins, the rating is revised to 12-14% of decline," said ICRA. The domestic mining & construction equipment (MCE) industry has posted a YoY growth of 20-22% in Q3 of 2020.

"Though growth is still lower by 14% compared to Q3 of 2018 levels, it is significant considering the deep demand contraction of around 40% in the first half of 2020," the statement said. As per ICRA's update, demand for the all-purpose backhoes recovered much faster than demand for other equipment like excavators. Supporting factors like strong project awards in the road sector, timely release of payments to contractors for all central government projects and a few state projects (in North India), and a strong rural demand (for agriculture and housing) aided recovery. "Sustainability of volumes remains a function of underlying economic activity and government finances…Weak state finances have impacted state capex which accounted for around 40% of the total country's outlay. This is a significant demand driver," said Pavethra Ponniah, vice president and sector head, Icra.

The key MCE demand drivers in the current market are central government projects, particularly roads and rural demand. Healthy awards and execution rates of road projects by the NHAI has boosted volumes of backhoes and excavators, more recently. However, new state projects have not taken off as most states are struggling with fiscal bandwidth, the statement said. Despite the volume uptick since late June/July20, ICRA has maintained a negative outlook on the sector as demand sustainability is uncertain. "Although the MCE industry's medium-term demand outlook remains favourable, given the need for continuing investments in infrastructure investments, demand for CE is typically highly cyclical in nature experiencing deep troughs and sharp peaks," said Ponniah. The ability of the players to successfully navigate through these cycles is critical, Ponniah added.

CABINET TO MULL MINING LAWS REFORM SOON

A clutch of proposals to reform the rules governing non-coal minerals will likely come under the consideration of the Cabinet soon. According to a draft Cabinet note prepared by the mines ministry, introduction of mining licences that offers with certainty tenure, ranging from the exploration to production stages, and removal of the distinction between captive and non-captive mines will be among the salient features of the new regime. The changes will also pave the way for re-auction of some 500 odd leaases that are embroiled in legal disputes and legacy issues.

There is also a proposal to develop a comprehensive and broad-based mineral index for determination of levies and taxes on the lines of recently launched National Coal Index. The objective of these changes is to attract more investments in the sector, including from foreign players.

"As regards the policy announcements under the Atmahirbhar Bharat Abhiyan, a comprehensive Cabinet note containing all proposals is already under submission to higher authority and on approval, would be put up for the cabinet," the mines ministry said in the note, review by FE.

Coal secretary Anil Kumar Jain, who also holds the charge of the mines secretary, said in Kolkata the roll-out of the reforms in the mining sector would take 6-8 weeks.

The first set of coal mines under the commercial mining policy has been auctioned off recently - most winning bidders offered handsome amounts as revenue share to the government, in some cases 40-40% Jain said, “We expect commercialisation of mines to bring competitiveness and a level-playing field between PSUs and private players.” In the next 5 to 6 years, the mining sector is said to increase direct employment by 7 lakh and indirect employment by over 20 lakh, Jain said.

The proposal to introduce seamless exploration-cum-mining-cum-production regime of virgin areas had been among the long pending wish lists of the mining industry.

NMDC HIKES IRON ORE PRICE FOR THE SECOND TIME IN NOVEMBER TO RS 4000 PER TONNE

NMDC Ltd has hiked prices of lump ore for the second time this month by Rs 400 per tonne and that of fines by around Rs 300 per tonne. “Kindly note that the prices of Iron Ore w.e.f. 17-11-2020 has been fixed as Lump Ore at Rs. 4,000/- per ton and Fines at Rs. 3,610 per ton,” the company said in a BSE Filing. The company also announced a hike on 4th of November where Lump ore was priced at Rs 3,600 per tonne and Fines were priced at Rs 3,310 per tonne. This is an increase of 4% in lumps and a decrease of 4.7% in fines compared with October prices. The series of price hikes indicate a shortage in the iron ore supply in the market, said a secondary steel player requesting anonymity.

India’s top steelmakers also complained their production for the quarter ended September was affected due to a shortage in availability of iron ore and several steel industry bodies have petitioned the commerce ministry to address the issue. “Everyone will be affected. This will also lead to an increase in the steel prices going ahead. While we don’t procure directly from NMDC, other players in Odisha following NMDC have increased prices,” said JSPL's managing director, V.R. Sharma. “We are affected due to the high cost of iron ore. Currently we are facing issues in terms of quantity as well as quality. We have also sent representations to the government on this,” said managing director of Kalyani Steel, R.K. Goel to ET. Kalyani Steels Ltd is one of largest secondary steel producers making mild steel, rolled steel products, carbon and alloy steel ingots and billets. “Price of iron ore has almost doubled. Iron ore pellets were around Rs 5400-5500 per tonne in May and right now it is around Rs 11,000 per tonne. While primary players are increasing steel prices, secondary players are bleeding,” said Vivek Adukia, Chairman, Steel Re-Rolling Mills Association of India. NMDC Ltd has reported a 2% year-on-year fall in October production at 2.43 million tonnes on the back of Covid-related challenges and a heavy monsoon, the company said in a statement.

However, on a month-on-month basis, the company’s October production has gone up by 33% compared to its September production of 1.83 mt. Addressing this issue NMDC said that it is trying its best to increase production to fight the shortage. “Further, NMDC is committed to surpass the production of previous financial year with increased production from Bailadila Mines in Chhattisgarh and likely resumption of operations in Donimalai Mines in Karnataka in the ongoing financial year,” said Sumit Deb.

EU STEEL MARKET’S DEMAND RECOVERY TO BOOST TATA STEEL EUROPE'S EARNINGS IN H2 OF FY21

Tata Steel, Europe has suddenly become very crucial, as the old continent shows distinct signs of stirring back to life despite isolated lockdowns. Top steelmakers in Europe have raised prices of carbon steel – something that would have a material impact on their performances. So much so that Tata Steel Europe may post positive earnings in Q3 and Q4, say analysts. “Europe is witnessing price hikes in carbon steel…which if it sustains for longer will lead to earnings upgrades for companies including Tata Steel,” said global brokerage firm, Morgan Stanley in its recent report.

ArcelorMittal has raised its EU HRC spot prices by euro 600 per tonne from around euro 540 per tonne. If accepted, this would take the European spreads to a record level of around $400 per tonne vs the historical average of $244 per tonne, other steelmakers will follow suit. “Most of the European peers like ArcelorMittal, SSAB and Voestalpine have indicated a probable pick up in demand in the Dec 2020 quarter on a sequential basis with potential for better spreads,” said Morgan Stanley’s report. Tata Steel did not comment. Along with a strong demand revival, a structural shortage of steel and lower solid fuel prices are also helping boost profit performance. “While capacities idled in Q1FY21 are gradually restarting, we expect supply constraints to sustain in Q3FY21…lending support to prices,” said Amit Dixit, research analyst, Edelweiss Institutional Equities.

Tata Steel Europe could surprise the street in Q3 and Q4. Spreads have been increasing, and they have been booking contracts since June, and these price increases will boost their Ebitda, added Dixit. Morgan Stanley has said that a sustained period of wider spreads would benefit European operations and limit cash losses. Tata Steel reported a consolidated net profit after three quarters at Rs 1,665.07 crore for the September quarter, and Tata Steel Europe reported a loss of Rs 462.07 crore during the same quarter. “We expect the company’s European operations to post a positive Ebitda in Q3,” said Amit Murarka, research analyst, Motilal Oswal Financial Services.

Tata Steel recently announced holding talks with Sweden-based steelmaker, SSAB, for the potential sale of Tata Steel’s Netherlands business, including the Ijmuiden Steelworks. While the deal is still at an early stage, analysts believe that with positive demand revival in Europe, the company will get a good deal on the sale. “The recovery in demand in the EU might result in the company getting a good price on the deal, but the deal is still at a very early stage of completing the due diligence process,” added Murarka. The recovery will come in as a breather for Tata Steel’s struggling operations at Port Talbot in the UK. While the company has planned to sell its profit-making Netherlands business, it is looking for some support from the UK government for its Port Talbot plant.

“This is positive for Tata Steel India too. With Europe seeing recovery and prices moving up which will be sustained until the end of Q4, there won’t be any debt from the parent to the UK operations for FY 21 at least,” said an analyst tracking the company, requesting anonymity. Given China’s faster-than-expected recovery in demand and prices, EU prices will likely sustain until the end of FY21, said the person cited above.

JSW STEEL TO ACQUIRE 26.45% STAKE IN JSW VALLABH TINPLATE FOR RS 35 CRORE

JSW Steel has entered into a legally binding share purchase agreement to acquire the remaining 26.45% stake of JSW Vallabh Tinplate for a total sum of Rs 35 crore from the existing third party shareholders as it will add strategic value, the company said. “JSW Steel Limited (“Company”) has entered into a legally binding share purchase agreement to acquire JSW Vallabh Tinplate Private Limited in one or more tranches, 1,32,37,227 equity shares of INR 10/- each,” the company said in a BSE Filing. Upon closing of the transaction JSW Vallabh Tinplate will become a wholly-owned subsidiary of the company, with the company's direct and indirect shareholding in JSW Vallabh Tinplate increasing from 73.55% to 100%, the company said. “The prospects for tinplate are encouraging and it will be of strategic importance for JSW Steel Ltd to become an important player in this segment,” the company said in its statement.

The company clarified the acquisition does not fall within related party transaction(s) and the promoter/ promoter group/ group companies do not have any interest in the entity being acquired. JSW VTPL manufactures tinplate and has a 1,00,000 MT per annum tinplate manufacturing facility in Beopror Village, Rajpura, Patiala District in the State of Punjab in India.The company has clocked a turnover of Rs 534.74 crore during FY 2019-20. In the year 2014, JSW Steel marked its entry into tinplate business, by acquiring 50% stake in Punjab-based Vallabh Tinplate Pvt Ltd (VTPL) for about Rs 46 crore. VTPL was owned by Vardhman Industries Ltd, However, In the year 2019, JSW Steel completed the acquisition of Vardhman Industries Ltd (VIL) by infusing Rs 63.50 crore into the debt-ridden company.

JSW OWNED SHIVA CEMENT TO INVEST RS 1,500 CRORE ON CLINKER FACILITY IN ODISHA

Shiva Cement, a subsidiary of Parth Jindal-led JSW Cement, will be investing Rs 1, 500 crore in a 1.36 million tonne clinker unit project to be established in Sundergarh district of Odisha through a combination of long-term debt and equity, the company said. “Once commissioned, this clinker unit will service JSW Cement’s manufacturing facilities across the East region and is expected to create around 500 direct & indirect job opportunities,” said Parth Jindal, JSW Cement's managing director, during the media interaction.

Shiva Cement has already received some of the regulatory and statutory approvals and is on track to obtain other necessary clearances, Jindal said. The company expects to commission the clinker unit by the end of next fiscal. The project includes setting up of a 1 million tonne per annum (1MTPA) grinding unit, 8 MW waste heat recovery power plant, 4 MTPA crushing plants at its dolomite and limestone mines. The company plans a 10 Km long overland belt conveyor to transport limestone from the mines to the manufacturing plant and own railway siding with 12 Km long railway track upto Sagra station to ensure seamless transportation of finished goods to the market.

The Rs 1500 crore project will be serviced via debt to the extent of Rs 1.150 crore and JSW will invest ?150 crore through redeemable preference shares and the remaining through a rights issue. JSW Cement has manufacturing units at Vijayanagar in Karnataka, Nandyal in Andhra Pradesh, Salboni in West Bengal, Jajpur in Odisha and Dolvi in Maharashtra. “This was always the plan, Clinker was coming all the way from Andhra Pradesh and the cost was very high along with some supply chain disruption taking place at any time. This is a very strategic investment for us,” Jindal said. Shiva Cement’s clinker project contracts have been awarded to Thyssenkrupp Industries

India and Larsen & Toubro. Thyssenkrupp has been contracted to design and supply a new state of the art 4,000 tonnes per day capacity Clinkerization unit and L&T has been awarded the contract for Civil, Mechanical & Refractory erection work of the new clinker unit at Shiva Cement.

For JSW Cement, the new clinker unit being established by Shiva Cement is part of its strategic roadmap to achieve 25 MTPA capacity by 2025, with a special focus on scaling up its presence in the Eastern region of India. "All business initiatives and investments are driven to achieve the targeted financial, production and sales growth position and list the company publicly in the next few years," Jindal said. The current expansion will also aid in a raw material integration with JSW Steel's planned acquisition of the 3.5 million tonne (MT) Bhushan Power and Steel Ltd (BPSL) is also located in Odisha. "JSW Steel is set to acquire BPSL, given that they are present in the same location, there will be further raw material integration and security for this current unit," Parth Jindal said. Shiva Cement's plan to establish a new clinker unit further reaffirms the group's commitment to investments in the State. The new clinker unit at Shiva Cement in Odisha will provide a strategic advantage, Jindal said.

MINES SAFETY NEWS

DRAFT RULES UNDER HE OCCUPATIONAL SAFETY, HEALTH AND WORKING CONDITIONS CODE, 2020

Gazette Notification No. 598, issued on November 19, 2020 .The following draft rules, which the Central Government proposed to make in exercise of powers conferred by Sections 133 and 134 of the Occupational Safety, Health and Working Conditions Code, 2020 (37 of 2020) read with section 24 of General Clauses Act, 1897(10 of 1897) and in supersession of the-

1. The Dock Workers (Safety, Health and Welfare) Rules, 1990;
2. The Building and Other Construction Workers (Regulation of Employment and Condition of Services) Rules, 1998;
3. The Model Factories Rules;
4. The Mines Rules, 1955;
5. The Mines Rescue Rules, 1985;
6. The Mines Vocational Training Rules, 1966;
7. The Pithead Bath Rules, 1959;
8. The Mines Crèche Rules,1966;
9. The Contract Labour (Regulation and Abolition) Central Rules, 1971;
10. The Inter-State Migrant Workmen (Regulation of Employment and Conditions of Service) Central Rules,1979.
11. The Working Journalists (Conditions of Service) and Miscellaneous Provisions Rules, 1957;
12. The Cine-Workers and Cinema Theatre Workers (Regulation of Employment) Rules, 1984;
13. The Sales Promotion Employees (Conditions of Service) Rules, 1976. except as respects things done or omitted to be done before such supersession, are hereby notified as required by subsection.

(1) of said Section 133 and sub-section (1) of sub section 134, for information of all persons likely to be affected thereby and notice is hereby given that the said draft notification will be taken into consideration after the expiry of a period of 45 days from the date on which the copies of the Official Gazette in which this notification is published are made available to the public;

Objections and suggestions, if any, may be addressed to Shri Shivakant Kumar, Under Secretary to the Government of India, Ministry of Labour and Employment, Room No: 17, Shram Shakti Bhawan, Rafi Marg, New Delhi or by email (fasli@dgfasli.nic.in and shivkant.kr@gov.in) the objections and suggestions should be sent in a proforma containing columns (i) specifying the name and address of the persons and organizations and column (ii) specifying the rule or sub-rule which is proposed to be modified and column (iii) specifying the revised rule or sub rule proposed to be submitted and the reasons therefore; Objections and suggestions, which may be received from any person or organization with respect to the said draft notification before expiry of a period of 45 days, specified above, will be considered by the Central Government.

OB SLIDE IN WCL MINE, 3 DRILL MACHINES BURIED

Padmapur opencast coal mine under WCL Chandrapur area on Wednesday afternoon. Though no fatality was reported, three large drill machines, including two new ones, were buried under tonnes of soil.

Sources said while work was underway in the first shift at Padmapur opencast mine, a large chunk of overburden started sliding down. The workers in the mine were startled by the sudden slide and rushed out to safety. The drill operators also abandoned their machines and fled to safety.

Sources told three drill machines were buried under the OB slide completely. The caving of the OB dump continued for several hours.

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Stability Assessment of Highwall Slope of an Open Pit Coal Mine – A Case Study

S. K. Reddy* K. R. Chandar*

ABSTRACT

An opencast coal mine is located at Peddapalli District of Telangana State. The mine is situated on the southern bank of river Godavari. There are six coal seams under exploitation in the mine viz. – I, II, IIIA, III, IV and V seams. The mine is working with an annual targeted coal production of 4.09 million tonnes. The present working depth of the mine is 193 m with a stripping ratio of 5.57 m3/tonne. With the removal of overburden of about 300 million m3 in the mine, resulted in the formation of highwall slopes towards south side.The highwall slopes are developed in Barakar and Talcher formations. In this area,a major fault, numerous minor faults\slips, joints and shear zones are noticed and they are more or less parallel to fault. Presently, tensile cracks and vertical subsidence observed at top surface of the highwall slopes due to mining activity in this area. An assessment of the south side highwall slopes need to be carried out in order to evaluate slope stability conditions with a view to maximise the production and concern towards conservation of the mineral with safe working conditions. Geotechnical studies covering geologic mapping, lidar survey, laboratory study of the material and numerical analysis using GALENA software is carried out for stability assessment of the disturbed zone in the highwall slopes. Based on above studies, recommendations for bench parameters and final pit slope stability related to disturbed area of the south side highwall slopes of the mine is discussed in this paper.

Keywords— slope stability, open pit mining, geotechnical studies and numerical analysis

INTRODUCTION

An opencast coal mine is located at Peddapalli District of Telangana State. The mine block covers an area of about 4 Sq.km and situated on the southern bank of river Godavari. The coal deposit in the mine has the incrop almost parallel to the river bank and on the dip side. There are six coal seams under exploitation viz. – I, II, IIIA, III, IV and V seams with minimum and maximum depths of 15 m and 220 m respectively. The strike of the coal measures is NW–SE with a gentle North- Easterly dips. The gradient of the seams varies from 1 in 5 to 1 in 10. The mine is working with an annual targeted coal production of 4.09 million tonnes with shovel and dumper combination technology (Fig. 1). The present working depth of the mine is 193m with a stripping ratio of 5.57 m^3/tonne. With the removal of overburden of about 300 million m^3 resulted in the formation of south side highwall benches. Presently, tensile cracks and vertical subsidence were observed at top surface in the highwall slopes due to mining activity in this area.

An assessment of the south side highwall slopes was carried out in order to evaluate bench slope stability conditions with a view to maximize the production and concern towards conservation of the mineral with safe working conditions. Geotechnical studies covering geologic mapping, lidar survey, laboratory study of the material and numerical analysis using GALENA software is carried out for stability assessment of the disturbed zone in the highwall slopes. Based on above studies, recommendations for bench parameters and final pit slope stability related to disturbed area of the south side highwall slopes of the mine is made.

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FIELD INVESTIGATIONS

A. Geological Mapping along Highwall Slope

Geological mapping is carried out in the quarry where disturbed area is present (Fig. 2). It is observed that top benches were developed on Talcher formation and the bottom benches were carved on Barakar formation (Table-1).

While mapping the highwall benches, the exposed fault plane was traced. From the geological mapping, the measured dip angle of the fault is taken as 65°. Along the fault plane, clay occurred as predominant infilling material and infilling material got eroded where water seepage is noticed (Fig. 3). In the vicinity of fault, numerous minor faults\slips and joints were noticed and they are more or less parallel to fault. Two shear zones were also mapped with 2 m width and striking in N40°E direction traversing across the benches.

Fig. 1: A view of the mine workings

Fig. 2: South side highwall benches in the mine

Table. 1: Geological succession at mine area

	Group	Formation	Descriptionon of material	Maximum thickness (m)
Recent	LOWER GONDWANA		Soil cover and alluvium	28.96
PERMIAN		Barren measures	Coarse to pebbly felspathic sandstones with clays	25.91
		Barakar	Upper Member Dominantly sandstones with eight correlatable coal seams	166.33
			Lower Member Predominantly coarse grained white sandstone	79.40
		Talchir	Fine to medium grained pale greenish sandstones and khaki green shales	

Fig. 3: Shows fault plane condition in the disturbed area

Almost, the entire mine block is covered with thick alluvial cover of black cotton soil, being the flood bank of the River Godavari. The thickness of the soil cover varies from 5.79 m to 28.96 m in the south central part close to the south western boundary of the block. In general the formations from top to bottom are soil, siltstone, sandstone and coal seams.

Fig. 4: Tensile cracks and vertical subsidence at surface level of highwall slope

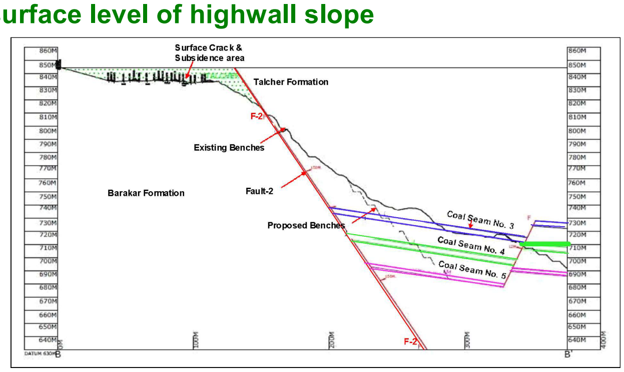

Fig. 5: Disturbed area section towards south side highwall benches

Fig. 6: Lidar laser scanning survey towards south side highwall benches

Table. 2: Geo-mechanical properties of different lithology of slope material

Lithology	Cohesion (kPa)	Friction angle (degree)	Density (kN/m^3)
Black cotton soil	28	18	17.5
Silty clay	25	25	17.0
Sand	05	33	16.8
Sandstone	230	28	22.0
Coal seam	190	24	14.4

The cracks and vertical displacement observed in this area having alluvium cover of 25 m which is part of Talcher formations (Fig. 4). Immediately below the disturbed surface, only 3 seam, 4 seam, Index seam and 5 seams are left for extraction and all the top seams were mined out.

HIGHWALL SLOPE STABILITY ASSESSMENT

The slope stability analysis of the disturbed section of south side highwall of the quarry is carried out by limit equilibrium method with using GALENA software. Limit equilibrium analysis considers the slope performance only at the equilibrium condition between the resisting and disturbing forces for sliding (GALENA version 7.0, 2016). To represent the slope performance other than the equilibrium condition, it is necessary to have an index and the widely used index used to be factor of safety. Factor of safety is calculated as the ratio of shear strength to the available shear stress required for equilibrium, integrated through the whole slide. It is assumed to be constant throughout the potentially sliding mass. For slope stability analysis of highwall with back filling, the cut- off factor of safety 1.2 is considered (Hoek, E. and Bray, J.W., 1991).

For slope stability analysis of considered highwall section is as shown in Fig. 5 and profile is surveyed with lidar equipment (Fig. 6). The relevant strength properties used for slope stability analyses are given in Table-2.

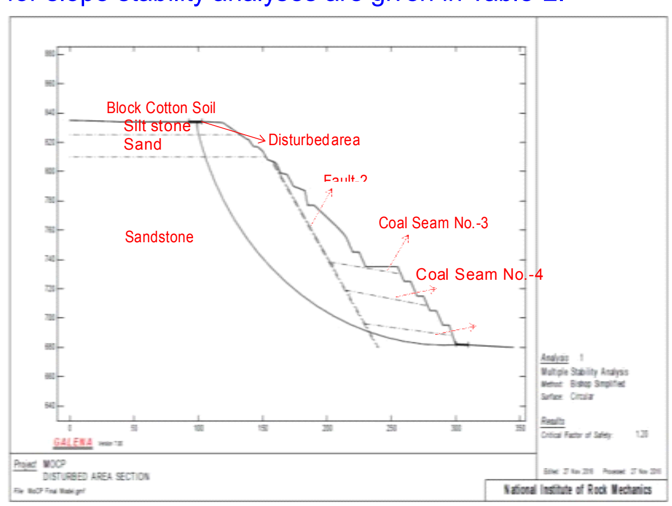

Fig. 7: Disturbed area highwall slope stability analysis

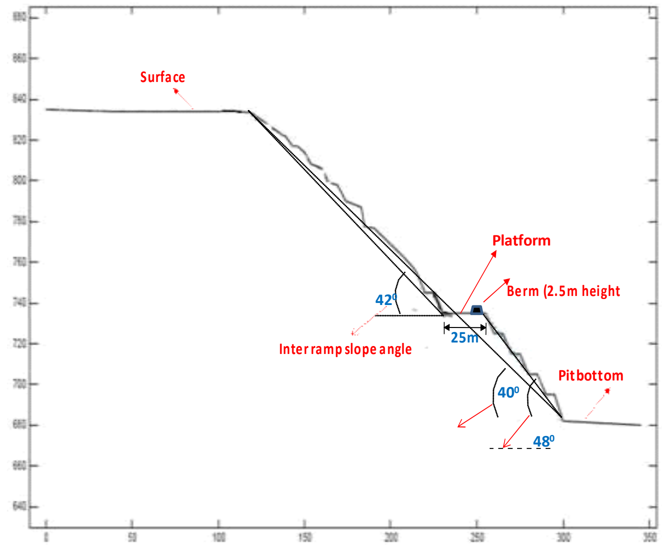

Fig. 8: Final configuration of highwall benches

RESULTS AND DISCUSSIONS

The stability analysis of south side highwall benches from 835 m RL to 680 m RL with a platform of 25 m at 735 m RL found a factor of safety of 1.20 (Fig. 7). The platform needs to be providing a berm with broken materials along the crest. The berm serves the function of forming a 'ditch' between the berm and the toe of the slope to catch falling rocks. The platform berm for disturbed area of south side highwall should be 2.5 m height by 6 m width.

The highwall benches should be maintained 10m height by 5m width with a slope angle of 650. The recommended top and bottom inter ramp angle is 42° and 48° with a platform of 25 m at 735 m RL, and final overall slope angle is 400 for highwall slope. The recommended final slope for disturbed area of south side highwall benches is as shown in Figure 8. The part of the pit with final slope geometry should be backfilled immediately or there should not be any active mining near the final slopes. The final slopes should be formed at pit cessation stage.

These recommendations are valid with well-developed drainage system and controlled blasting. If any observance is made for the occurrence of adverse hydrological condition or the remedial measures are not effective then this slope angle has to be corrected accordingly. The slope monitoring should be done for active/ ultimate mine slope to detect any instability well in advance.

The possible reasons of the cracks and vertical subsidence are a fault was present in the disturbed zone. The steeper slope between 835 m RL and 735 m RL, weak and weathered lithology, improper drainage, and regular production blast in close proximity of fault would most likely have initiated cracks and vertical subsidence along fault. The chances of undercutting/ day lighting of the fault plane along steep dip of bench slope would be high. The day lighting fault plane under undrained condition cause slope failure in weak lithology.

The mapping of weak zones, faults and bedding planes should be a regular process in the mining area. The generated data will be used as an input parameter to reanalyze the stability to get the realistic picture of the mine slopes in different geo-mining conditions. It will help to detect any unfavourable conditions at different stages of mining at the earliest possible.

CONCLUSIONS

On the basis of the geotechnical studies, the possible reasons of the cracks and vertical subsidence in highwall slope is because of steeper slope, weak and weathered lithology, improper drainage, and regular production blast in close proximity of fault. The chances of undercutting/ day lighting of the fault plane along steep dip of bench slope would be high. The day lighting fault plane under undrained condition cause slope failure in weak lithology. The recommended top and bottom inter ramp angle is 42° and 48° with a platform of 25 m at 735 m RL, and final overall slope angle is 400 for highwall slope. The highwall benches should be maintained 10 m height by 5 m width with a slope angle of 65°. The highwall slope design optimized with a view to maximize the production and concern towards conservation of the mineral with safe working conditions.

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Instrumentation and Recent Practices for Safe Blasting in Opencast Mines – Field Experimental Studies

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ABSTRACT

Blasting near sensitive areas has always been a cause of concern and utmost care has to be taken to keep the charge per delay below the stipulated level. Part of the scientific studies conducted on ground vibrations induced by blasting, and to estimate safe maximum charge per delay to protect the nearby structures are presented. This paper also presents instrumentation with accelerometers, and scientific studies conducted on ground vibrations due to blasting with various types of explosive and accessories (Cartridge, Site Mixed Emulsions, electronic detonators etc) at Dunguri limestone mine, Jindal Power Opencast Coal Mine- Tamnar, and Baphlimali Bauxite Mines under M/S Utkal Alumina International Limited to design safe blasting practices to contain the ground vibration levels below the damage criteria to protect the structures surrounding the blasting site. A number of field visits were made to collect the geotechnical data, and monitoring ground vibrations induced by blasting for above excavations. A number of blasts were monitored to study various blast parameters related to blasting Overburden and pit benches and to understand the effect of blast on the surrounding structures, and rock mass conditions at the above three excavations.

Keywords— Mining excavations, ground vibrations, PPV, frequency, safe blasting design, opencast mines, sensors

INTRODUCTION

When an explosive charge detonates, intense dynamic waves are set around the blast hole, due to sudden acceleration of the rock mass. The energy liberated by the explosive is transmitted to the rock mass as strain energy. The transmission of the energy takes place in the form of the waves (Mehdi and Mehdi, 2013). The energy carried by these waves crushes the rock, which is the immediate vicinity of the hole, to a fine powder. Blast induced ground vibrations, which are propagated in rock, can be divided into Compression waves, Shear waves and Rayleigh waves. The motion of the ground particle takes in three perpendicular directions viz. vertical, longitudinal and transverse directions. For the compression wave, the particle moves along the direction of propagation (longitudinal), while the shear wave moves across this direction (transverse). The Rayleigh waves have elliptical particle movements in the vertical plane (vertical). The particles rotate backward in this plane.

The propagation velocity for the different wave types is dependent of the elasticity and density of the medium. Typical velocities for shear waves in rock vary from 2000-4000 m/s correspondingly for compression waves 3000-6000 m/s. For inhomogeneous and stratified rocks the propagation of wave energy is complicated. During unfavourable conditions resonance and focusing effects may be created by the interference of incoming and reflecting waves. Under such conditions the vibrations may increase and not decrease when the distance from the blast source get larger. The three important wave characteristics, which are significant for blast damage, are amplitude, frequency and duration. The amplitude, which is given as acceleration, particle velocity or displacement, depends on detonating charge, length of the charge, confinement, damping conditions in the ground, the building response and the distance between the object and blasting. Concerning ground conditions and building response nothing can be done. Earlier peak particle velocity was the sole criterion for the ground vibration standards. However, after the role of frequency in the damage to the structures became known, it is now common to prescribe maximum permissible peak particle velocity along with corresponding frequency.

Detailed scientific investigations on drilling and blasting including design of safe blasts vis- à-vis ground vibrations in various mines were conducted by the first author and details illustrated (Jayanthu, 1989(a), 1989(b), 2011, 2013, 2016 and 2016).

PREDICTION OF GROUND VIBRATIONS

A number of investigators have studied ground vibrations from blasting and have developed theoretical analysis to

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explain the experimental data (Mehdi and Mehdi, 2013, Jayanthu, 1989(a), 1989(b), 2011, 2013, 2016 and 2016). First author conducted investigations in various coal and metal mines of India for design of safe blasting operations.

The energy released is considered to be proportional to the square root of charge. Earlier studies on wave propagation showed that the amplitude of particle displacement can be given by

$$A = K\left(\frac{Q^{0.5}}{D}\right) \qquad (1)$$

Where K is site constant; D is the distance and Q is the charge per delay.

Assuming the cylindrical explosive geometry for long cylindrical charges, Researchers working on blast-induced ground vibrations concluded that any linear dimension should be scaled with the square root of the charge weight. Blasts should be scaled to the equivalent distance, which is the actual distance divided by the square root of the charge. The corresponding relation known as USBM predictor equation takes up following form:

$$A = K\left(\frac{D}{Q^{0.5}}\right)^{\beta} \qquad (2)$$

Where K and are site-specific constants, which depend on local geology and ground characteristics and other terms have their usual meanings. The USBM predictor equation is used in India for calculating maximum safe charge per delay for different distances according the standards fixed by DGMS. The value of K and aredetermined by regression analysis of the data generated by trial blasts in terms of A, D and Q.

DAMAGE CRITERIA

The damage criteria was proposed by many organizations including USBM, DGMS, Indian Standards etc based on the Permissible PPV in mm/s and Frequency of the ground vibrations for various types of structures (16-19). The criteria based on the Permissible PPV in mm/s and Frequency of the ground vibrations for various types of structures as per DGMS (1997) as presented below in Table 1 and 2 are generally followed to estimate safe charge per delay to limit the ground vibrations within safe limit in Indian geomining conditions.

Table 1: Damage Criteria Vis-À-Vis Buildings / Structures Not Belonging to the Owner

Type of Structure	Dominant Excitation Frequency		
	<8 Hz	8 to 25 Hz	> 25 Hz
a) Domestic Houses	5	10	15
b) Industrial Building	10	20	25
c) Sensitive Structure	2	5	10

Table 2: Damage Criteria Vis-À-Vis Buildings / Structures Belonging to the Owner

Type of Structure	Dominant Excitation Frequency		
	<8 Hz	8 to 25 Hz	> 25 Hz
a) Domestic Houses	10	15	25
b) Industrial Building	15	25	50

The parameters, which exhibit control on the amplitude, frequency and duration of the ground vibration, are divided in to Noncontrollable Parameters, and Controllable Parameters. The non-controllable parameters are those, over which the Blasting Engineer does not have any control. The local geology, rock characteristics and distances of the structures from blast site are non-controllable parameters. However, the control on the ground vibrations can be established with the help of controllable parameters such as Charge Weight , Delay Interval, Type of Explosive, Direction of blast progression, Burden, spacing and specific charge, Coupling, Confinement, Spatial distribution of charges etc.

INSTRUMENTATION

Minimate Blaster is used for blast monitoring at various sites in and around the mine (Fig 1). Table 3 shows details of the instrument used for the study. The Minimate Blaster is a reliable blast monitoring in a simple and economical package with advantages such as Small, rugged package for portability and easy setup, Simple menu driven operation, Easy one button, download and reporting with concerned software, Continuous monitoring etc.

Further studies with application of transdisciplinary research including Wireless Sensor Network (WSN) and Internet of Things (IoT) is also being tried under the guidance of first author for collection of more relevant data, analysis and communication of data for better implementation of the results at mine sites. Following are some more advantages of the above instrumentation:

i. Integral monitoring log records time and duration of monitoring jobs.
ii. Auto Record™ mode allows for continuous recording as long as activity cycles about the trigger level.
iii. Fully compliant with the International Society of Explosives Engineers (ISEE) - Performance Specifications for Blasting Seismographs - requirements with the ISEE Linear Microphone and an ISEE Geophone (2250Hz).
iv. Fully compliant to the DIN 456691 Standard with optional DIN Geophone (1315Hz).

Table 3: Specifications of the Instrument Used For the Study

Key Features	Easy to use Auto Record stop mode
Channels	Microphone and Triaxial Geophone
Available Memory	30 events
Record mode	Manual and Continuous
Available sample rate	1024 to 4096 S/s per channel
Unit Dimensions	81 X 91 X160 mm
Unit weight	1.4 kg
User Interface	8 domed tactile keys
Product rank	Low cost

GEOMINING DETAILS

Scientific study was conducted on ground vibrations due to blasting at Dunguri limestone mine, ACC ltd, JPL – Tamnar Coal Mine, and UAIL Bauxite mine for estimation of explosive charge per delay for keeping the ground vibrations within the safe limits of Peak particle velocity and frequency. Details of the studies were presented in various reports of concerned mines (2-7).

Fig. 1: Instrumentation for monitoring of ground vibrations due to blasting

ANALYSIS OF OBSERVATIONS

A. Case Study-1

The vibro-graph was installed at a predetermined distance in the range of 150 to 750 m from blast site to the monitoring station to monitor the ground vibrations generated from blast at Dunguri Lime stone mine (Fig 2). The Fly rock, fragmentation and muck pile tightness was assessed qualitatively using visual inspection. The Peak particle velocity (PPV) was measured for experimental blasts with respect to the distance from the blast site to the monitoring station with varying Charge per delay for various experimental blasts. Dominant Frequency , and Sound Pressure levels (SPL) were in the range of 2-34.3 Hz, and 100-140+, respectively (Table 4).

Ground vibration monitoring stations with various experimental blasts in the above mine were located during the investigations at a distance of 150 to 750 m from the blast site. Experimental blasts were conducted with explosive charge per delay in the range of 30 to 55 kg, and total number of holes per blast was in the range of 15 to 130. At 750 m distance from the blast site, maximum PPV observed was about 0.191 mm/s, while maximum PPV recorded for a distance of 150 m was 8.6 mm/sec. Maximum PPV observed at a distance of 200 m to 500 m was within the range of 2.52 to 1.33 mm/sec. Observations shows that explosive charge of 50 kg per delay would induce PPV less than 5 mm/sec beyond 200 m distance from the blast site with the present blasting practice in the mine. To predict the safe charge per delay for reducing the damage potential for various distances from the blast site, regression analysis was done. Fig 3, and 4 shows the event report of typical blast and result of regression analysis for estimation of safe charge per delay to contain the ground vibrations within safe limits. In majority of the observations, the maximum air over pressure recorded was within 140 dBA, which is within the safe limits. The dominant frequency of ground vibration in the range of 2 to 34.3 Hz for distances from 150 m to 750 m in the experimental trials. Since the structures with normal civil construction may have a natural frequency of about 20 Hz, it is suggested to meticulously design the blasts with explosive charges considering both PPV and frequency content.

Table 4: Details of Monitoring Distance, PPV, and Frequency of Ground Vibrations in Dunguri Mine, Acc

Distance (m)	No of holes	PPV (mm/s)	Frequency (Hz)	SPL (dbl)
500	64	L-1.33, T-0.953, V-1.59, PPV-1.62	21.5	114
150	67	L-1.65,T-2.98,V-3.24, PPV-4.16	19.8	125
300	99	L-2.54,T-2.22,V-1.91, PPV-3.52	2	100
200	15	L-2.29,T-1.14,V-1.59,PPV-2.52	2.25	100
400	80	L-1.27,T-1.46,V-1.71,PPV-2.05	11.3	134
500	40	L-0.69,T-1.33,V-0.06,PPV-1.33	24	126
600	96	L-0.76,T-0.69,V-0.63,PPV-0.873	25.3	116
750	55	L-0.127,T-.127,V-0.063,PPV-0.191	18.3	110
150	130	L-4.95,T-6.60,V-8.13,PPV-8.60	2.25	140+
500	58	L-0.572,T-2.98,V-1.08,PPV-3.10	34.3	130
150	63	L-4.45,T-5.46,V-0.953,PPV-6.10	17.8	140+

Fig. 2: A view of blasting in trial blast at Dunguri mine, ACC (Case study-1)

Predictor equation in terms of the scaled distance (x) and PPV (Peak particle velocity) developed to represent the data for utilization in estimation of safe explosive charge per delay to keep the vibration level within the safe limits is as follows:

$$PPV = 489.21(Scaled\ disatnce)^{-1.4} \qquad (3)$$

Since the PPV levels were within safe limits of damage level criteria (< 5 mm/sec) for any type of structures other than sensitive structures, the blasting pattern may be followed with the respective explosive charge per delay as shown in Table 5 for containing the PPV of ground vibration within damage limit for various distances from the blast site.

Table 5: Estimation of Charge Per Delay (Kg) For Containing PPV Within 5mm/Sec

Distance	Charge per delay (Kg) for containing PPV within 5mm/sec
100	14
150	32
200	57
250	90
300	129
350	176
400	229
450	290
500	358

A. Case Study-2

Many blasts were monitored for estimation of suitable charge per delay for keeping the ground vibrations within the safe limits of Peak particle velocity and frequency. Blasts were monitored by the team of Blasting Experts and assisted by Blasting In charge of Jindal Power Open cast Coal Mine along with the present investigators. The vibrograph was installed at a predetermined distances in the range of 100 to 350 m from blast site to the monitoring station to monitor the ground vibrations generated from blasting. The flyrock, fragmentation and muckpile tightness was assessed qualitatively using visual inspection. The Peak particle velocity (PPV) was measured for various blasts with respect to the distance from the blast site to the monitoring station including the Charge per delay for various blasts.

Microphone	Linear Weighting
PSPL	10.00 pa.(L) at 1.624 sec
ZC Freq	9.1 Hz
Channel Test	Passed (Freq = 20.0 Hz Amp = 308 mv)

	Tran	Vert	Long	
PPV	1.33	0.953	1.59	mm/s
ZC Freq	32	39	30	Hz
Time (Rel. to Trig)	0.223	0.173	0.205	sec
Peak Acceleration	0.0331	0.0265	0.0398	g
Peak Displacement	0.00589	0.00508	0.0123	mm
Sensorcheck	Passed	Passed	Passed	
Frequency	8.0	7.7	8.0	Hz
Overswing Ratio	3.8	3.9	3.6	

Peak Vector Sum 1.62 mm/s at 0.205 sec

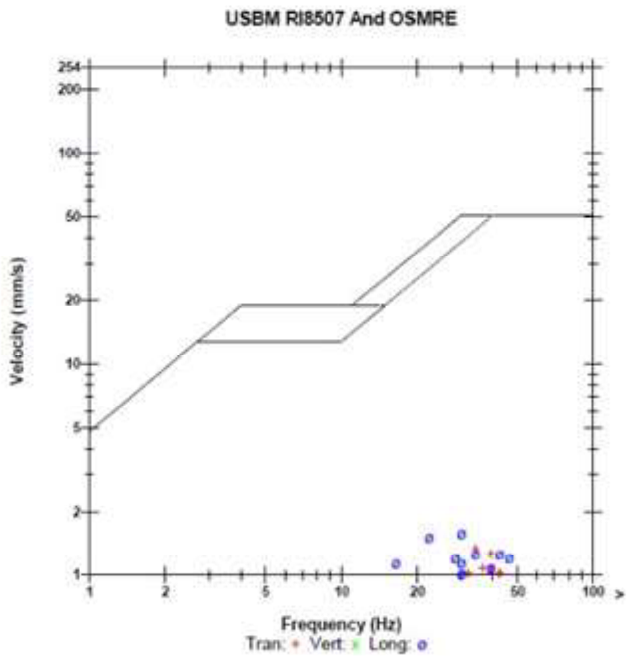

Fig. 3: Event Report of a typical Blast at Dunguri mine, ACC

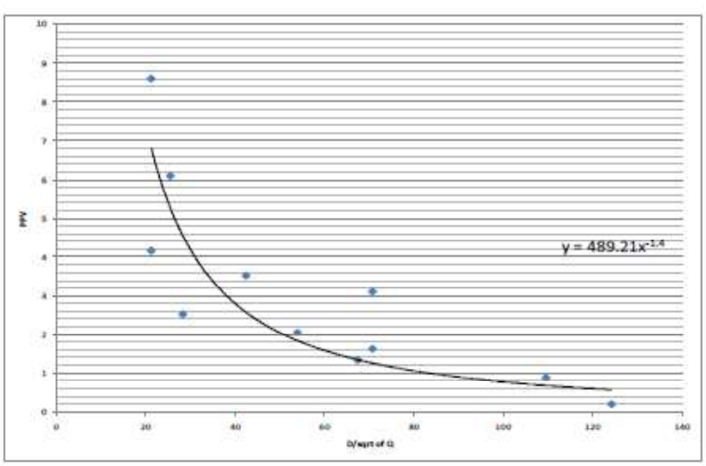

Fig. 4: Regression analysis for estimation of safe charge per delay

Details of observations including the wave pattern in a typical blast is presented in Figure 5 with the damage criteria of OSMRE/USBM indicating that the ground vibrations vis-à-vis frequency content of vibration is within the safe limit for the structures corresponding to the distance of about 150 m from the blast site. Blast Vibration study report of Jindal Power Open cast Coal Mines for a typical blast is presented in Table- 6. The ground vibration data for various blasts including Peak particle velocity (PPV), the distance from the blasting site to the monitoring station; the Charge per delay for various blasts was analyzed for understanding the effect of ground vibrations induced by blasting at Jindal Power Open Cast Coal Mine. The following predictor equation in terms of the scaled distance (x) and PPV (Peak Particle Velocity) is found to represent the data, and proposed for utilization in estimation of safe explosive charge per delay to keep the vibration level within the safe limits.

$$PPV = 290.12(Scaled\ disatnce)^{-1.296} \quad (4)$$

Accordingly, the safe charge per delay recommended to keep the vibration level below 5 mm /sec is presented in Table 7 for the above geomining conditions of Jindal Power Opencast Coal Mine- Tamnar.

Table 6: Blast Vibration study report –Case study-2

1	Date of Blast	07/07/08
2	Location	VIII Seam OB
3	Strata	Medium hard Sand Stone
4	No of Holes	47
5	Depth of Holes (Mtr)	4.5 to 6.0
6	Burden x Spacing (Mtr)	4.0 x 6.0
7	Diameter of Holes (Mtr)	159 mm
	Explosives Used	
8	Powergel B- 1 (SME) in kg	1500
9	Primex (100gm pellets) in Kgs	4.70
10	Total Explosives in Kgs	1504.70
11	Accessories Used	Exel (250/25MS, 42MS,65MS)
12		Electric Detonato
13	Maximum charge/ Delay (Kgs)	70
14	Volume Blasted (Cu. Mtr)	6158.0
15	Powder Factor (Cu.Mtr/Kgs)	4.10
	Post Blast Observations	
16	Blast fragmentation	Good
17	Fly Rocks	Within 20Mtr.
18	Throw	Normal
19	Muck File	Good

Distance (m.)	200	300
PPV (mm/Sec)	3.75	2.35
Frequency (Hz)	23	18

Table 7: The safe charge per delay to keep the vibration level below 5 mm/sec at various distances from the blast site

Distance of blast site from the Kosumpali village (m)	Safe Charge/Delay (kg)
100	18.9
200	75.9
300	170.8
400	303.7
500	474.5

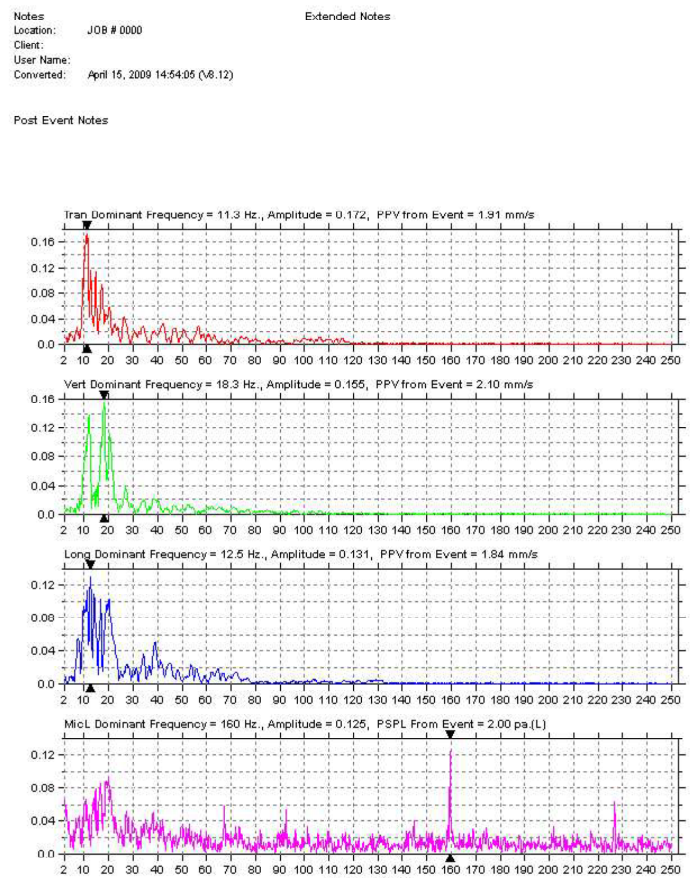

Fig. 5: Wave pattern in a typical blast vibration data-Case study-2

C. Case Study-3

Details of monitoring distance, PPV, and frequency of ground vibrations etc for a typical experimental blast are shown in Table 8. Emulsion matrix is observed to be a non explosive material having density of 1.40 g/cm3. NONEL system was used for initiation with accessories TWINDET-17/125 ms, TLD – 25 ms etc. Maximum charge/delay was in the range of 35 – 50 kg in the trial blasts. EMULBOOST manufactured by M/s IDL of 125 g cartridge weight was used as booster charge. The density of SME emulsion matrix is reduced by chemical gassing and below 1.30 g/cm3 detonation was observed. The density change on rate of gassing of matrix was also measured in the field conditions. Table 9 shows the density of matrix at different time after gassing during experimental trial. Detailed measurement of density of the emulsion mixture supplied by M/s Keltech Energies Ltd at the study site without gassing was 1.4 g/cc which are found to be nonexplosive. The density was 1.3 g/cc with gassing reduced to a minimum of 1.04 g/cc even after 4 hours of gassing.

The blast result was also assessed in terms of ground vibrations, its frequency, air over Pressure produced and Fly rock. The vibrograph was installed at a predetermined distances in the range of 110 to 175 m from blast site to the monitoring station to monitor the ground vibrations generated from blast. The Fly rock, fragmentation and muck pile tightness was assessed qualitatively using visual inspection. The Peak particle velocity (PPV) was measured for experimental blasts with respect to the distance from the blast site to the monitoring station with varying Charge per delay for various experimental blasts. The maximum air over pressure recorded was within 80 dB (L), which is within the safe limits. The blasting operation produced PPV less than 15 mm/sec, which is within safe limit for the industrial structures belonging to the owner in the frequency range of <8 Hz and 8-25 Hz for distances up to 110 m to 175 m. The ground vibration data including Peak particle velocity (PPV), the distance from the blast site to the monitoring station; the explosive Charge per delay for various blasts was analyzed for understanding the effect of ground vibrations induced by blasting at Baphlimali Open Cast bauxite Mine. The following predictor equation in terms of the scaled distance (x) and PPV (Peak particle velocity) is found to represent the data, and proposed for utilization in estimation of safe explosive charge per delay to keep the vibration level within the safe limits.

$$PPV = 19.681(Scaled\ disatnce)^{-0.427} \quad (5)$$

Table 8: Details of Trial Blasts – Case Study-3

S. No.	Particulars	FACE 1	FACE 2
1	Date of Blast	9/14/2013	9/14/2013
2	Location of Blast	2nd Bench/RL 1025	1st Bench/RL 1030
3	Type of Strata	HARD	HARD
4	ORE/OB	BAUXITE	OVER BURDEN
5	Hole Dia in mm	160	160
6	Drill hole Pattern	STAGGERED	STAGGERED
	a. Depth of the hole in m	8	6
	b. Burden in m	4	3.5
	c. Spacing in m	5	4.5
7	Total no of holes blasted	57	152
8	No of rows	4	4
9	Max Charge per hole in Kg	80	55
10	Max Charge per Delay in Kg	80	110
11	Fly Rock distance in m	15	16
12	Misfire if any	NO	NO
13	smoke if any	NO	NO
14	PPV mm/sec	5.55	12.5
15	Frequency in Hz	6.1	13.5
16	Distance from Observation Station to Blasting site in m	150	125
17	Total quantity of SME used in Kg	4500	7810
18	Total quantity of Emul Boost used in kg	14.250	35.750
19	Total quantity of Explosive used in kg	4514.250	7845.750
20	Percentage of Booster used	0.4	0.4
21	Type of detonators used	Nonel Initiation	
22	Stemming Material used	DRILL CUT	DRILL CUT
23	Fragmentation	Good	Good
24	Throw	As desired	As desired

CONCLUSIONS

On the basis of the scientific experimental study conducted with various instrumentation for understanding of behaviour of ground vibrations induced by blasting with various types of explosive and accessories (Cartridge, Site Mixed Emulsions, electronic detonators etc) of benches in three mines, following are the conclusions and recommendations for protection of surface structures and safe design of blasting in respective opencast mines:

Table 9: Density of bulk explosive with time upon gassing

Time (Min.)	Safe Charge/Delay (kg) Matrix with AN prill in field (g/cm^3)
0	1.40
5	1.21
10	1.14
15	1.21
20	1.09
25	1.08
30	1.12
60	1.06
70	1.05
80	1.04
90	1.04

1. In Dunguri open cast limestone mine, ACC, it is recommended to use less than 358 kg as explosive charge per delay to contain the ground vibration level below 5 mm/sec beyond the distance of 500 m. Blasting operation with blasting parameters; 4.0 – 5.0 m spacing, and 2.5 – 3.5 m burden for bench heights of 10 m was observed to be safe with Aquadyne explosive of 50 kg of charge per delay beyond 200 m distance from the blast site. The dominant frequency of ground vibration in the range of 2 to 34.3 Hz for distances from 150 m to 750 m in the experimental trials.
2. The safe charge per delay for the distance of 100 m, 200 m, 300 m, 400 m, and 500 m is 18.9 Kg, 75.9 Kg, 170.8 Kg, 303.7 Kg, and 474.5 Kg, respectively was recommended to keep the vibration level below 5 mm/sec for the above geomining conditions of Jindal Power Opencast Coal Mine- Tamnar.
3. At UAIL Mines, blasting operation with bench heights of 5.5 – 8.0 m was observed to be safe and productive with powder factor of 2.41 to 4.22 ton/kg of explosive with 520 kg of SME charge per delay, and 80 kg of SME charge per hole with 3.5- 4.5 m spacing, and 2.5 – 3.5 m burden. Emulsion matrix is a non-explosive material having density of 1.40 g/cm3. The density of emulsion matrix is reduced by chemical gassing and for density below 1.30 g/cm3 detonation was observed. The density was g/cc with gassing, and reduced to a minimum of 1.04 g/cc even after 4 hours of gassing. Ground vibration levels and air overpressures were within the safe limits for a distance beyond 110 m from the blast site with good fragmentation, muck profile, and acceptable fly rock.

On the whole, it is recommended to use respective explosive charge per delay to contain the vibration levels as per the damage criteria for various distances from the blast site in the above three mines. To improve the economics of blasting operations, air deck blasting may be followed with detailed studies on costs of drilling, explosives, blasting, mucking, transportation, crushing etc. for the opencast mine. Further studies with application of trans-disciplinary research including Wireless Sensor Network (WSN) and Internet of Things (IoT) is also recommended for collection of more relevant data, analysis and communication of data for better implementation of the results at mine sites.

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Extinguishment of Exhaustive Fires in Exposed Coal Benches with Chemi- Fog

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ABSTRACT

The study evaluates the state and extent of exhaustive fires in exposed coal benches developed over underground galleries and premeditated the utmost viable technology for combating the fires and preventing its re-occurrence. The authors have used a high accuracy thermo-vision Camera and evaluated the state and extent of the fires in exposed galleries, crushed coal at the floor and overlying strata comprises different formations like shale and sandstone at Shankarpur Open Cast mines of Kenda Area Eastern Coalfields Limited (ECL). To deal with a fire at a specific site, several endothermic fire- retardant chemicals of different combinations and concentrations - according to the magnitude of the fires were tested. The most appropriate combination and concentration for effective cooling, retarding the surface oxidations reactions and minimizing the possibilities of re-occurrences of heating were applied at the site-specific. The application methodologies were designed in such a way that chemical fog/chemical admixed water may easily reach at desired places i.e., overlying strata, the cavity of the two stone pieces and the unapproachable area where heating may apprehend - through the nozzle of wide spray pattern with fine droplets and controlled discharge pattern. To begin with, dealing with the fires; blazing fires (>10000C) at exposed gallery mouth was dealt with flame/fire retardant chemicals (MgCl2+CaCl2 in the ratio1:3) mixed in water (0.04%w/v). As a result, the temperature brought down to }"70-900C immediately. Fires of lower intensity up to 70-350oc in coal benches and loose coal mass were dealt with DAP of concentration 0.02% (w/v) by simple jetting; temperature brings down 550c even after several hours. After dealing with the blazing fires, water thickened with chemicals were sprayed over hot materials and proved very useful in avoiding the re-occurrences of heating.

Keywords— Spontaneous Heating, Exhaustive Fire, Chemical fog, Firefighting

INTRODUCTION

A scientific study has been assigned by the management of Eastern Coal Field Coalfields Limited (ECL) to prognosticate the fire conditions were, therefore, advise the suitable measures to deal with extensive fire in exposed gallery mouth of R-VIII seam at Shankarpur OCP. The objectives being safe extraction of coal pillars catching fire on exposures and thereby save the precious coal reserve.

There are seven coal seams of varying thickness, and the area exhibits gentle undulating topography sloping towards the south-east. The concerned coal seam R-VIII at Shankarpur OCP was developed before nationalization by the underground method in two sections. The thickness of the R-VIII seam within the proposed zone varies from 10.50m to 11.50m, and the average gallery height of the abandoned old workings for both the sections of R-VIII seam is 3.50m.
A huge quantity of superior grade coal is locked in developed pillars, and underground galleries/ voids are filled with water. After dewatering, the exposed gallery mouth in both the sections catches fire within short durations. In thermal mapping, almost all exposed galleries at Shankarpur OCP were engulfed inactive fires and temperatures ranged from 1000C and above at many places (Tripathi, 2005).

IDENTIFICATION OF FIRE

Fire at Shankarpur OCP was mainly due to wet and reactive coal exposed to air for long duration followed by air circulation through fractured/blasted strata. Indeed, just after dewatering, wet coal starts drying and creates large surface area for oxidation and ultimately spontaneous heating leading to start fire. These fires are disgracing valuable source of energy and pose occupational and environmental problems.

ASSESSMENT OF FIRE RISK POTENTIALS

Assessments of the fire risk potentials are most crucial in combating the fires; it dependent upon endogenous coal characteristics and exogeneous mining parameters-

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$$\text{Fire Risk Index} = \sum_{i=1}^{n} \begin{pmatrix} \text{Coal characteristics;} \\ \text{Geomining conditions;} \\ \text{Mining environment} \end{pmatrix}$$

Coal characteristics have been determined in the laboratory whereas mining and environmental parameters are obtained from site-specific of the mines. Fire Risk Potentials is a non-explicit function of several mutually inter-dependent variables therefore, uncertainties are always associated in determining the risk (Tripathi, 2005).

A. Evaluation of Fire Risk Potentials at Shankarpur OCP
Refer to Table 1.

ASSESSMENT OF THE STATE AND EXTENT OF FIRE-INFRA RED THERMOGRAPHY

Thermal mapping of exposed galleries, overlying strata and loose coal at the floor has been carried out. Photographs of blazing fire in exposed galleries and its respective thermal images showing temperature > 10000C and 659 0C respectively are shown Fig. 1.

Table 1: Fire risk evaluation Shankarpur OCP, Kenda Area ECL.

S No	Parameters	Set Elements	Fire Risk Rating (Low/Moderate/ High)	Risk Value
		Coal characteristic		
	Category of coal (Chemical nature)	Sub Bituminous	Moderate	0.5
	Friability	Poorly Friable	Low	0.3
	Moisture content	>2% and < 8%	High	0.6
	Volatile matters	High	High	0.7
	CPT& IPT Value	120-160^{0}C	Moderate	0.5
	Sulphur content	Traces (<0.5%)	Low	0.2
	Calorific value	G-6	Moderate	0.4
		Mining parameters		
	Thickness of coal seam	>10m	High	0.7
	Method of working	Open cast mining on previously underground developed galleries in two slices	High	0.9
	Status of U/G galleries	(i) Waterlogged (iii) Dewatering prior to extraction	High	0.7
	Duration of idle coal face /Exposure of galleries after dewatering and or blasting	? > One month	High	0.7
	Overall slope of bench/ Coal seam Gradient	1: 10; 1:20	Low	0.3
	Source of Hot spot / Previous history of fire in the mines	Fiery mines	High	0.9
	Humidity	Wet/Evaporation of moisture speedup oxidation after dewatering	Hight	0.9
		Geological parameters		
	Overlying strata	Shell /stand stone	Medium	0.4
	Geological disturbance	Fault near boundary line	Low	0.2
	Height of cover / OB	<0m	High	0.5
	Rock bumps/dyke	Absent	Low	0.0
	Gassiness	Degree-I	low	0.2
	Wind speed	Low <2kmph	Low	0.2
		Overall fire risk		High

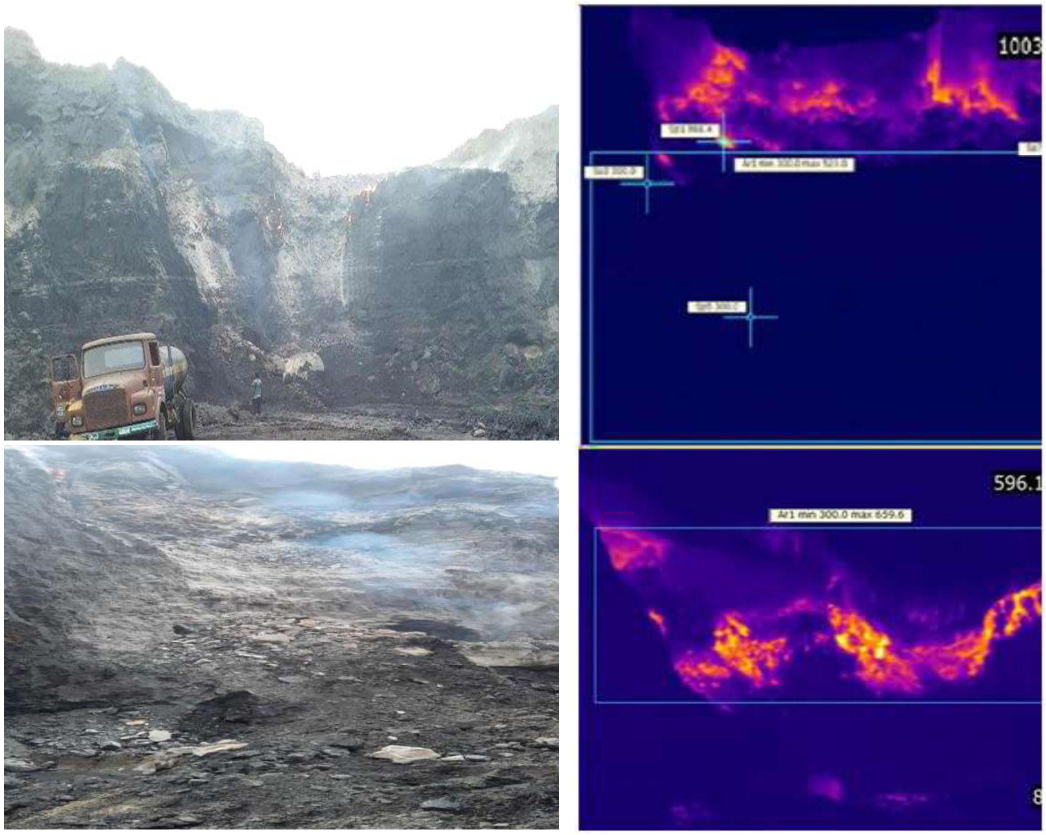

Fig. 1: Blazing fire in exposed galleries and its respective thermal images showing temperature > 1003.5^0C and 596.1 ^{0}C respective

DEALING OF EXHAUSTIC FIRE IN EXPOSED GALLERIES

The thermal survey by thermo vision camera state and extent of the fire in exposed distance. Application technology to deal with the fires includes-

1. Fires of high intensity / blazing fires in exposed galleries and crushed coal were dealt galleries mouth and loose coal at the floor has been determined. The temperature in exposed with endothermic, fire fire fighting chemicals $MgCl^2$ retardant and and $CaCl^2$. Both C and above; and overall temperature ranges from 650 C - 10680 C at different locations. The combination and concentration of the firefighting chemicals were decided based on the magnitude of the fire at a particular site. The methodology to deal with fire using chemical fog includes a high-pressure pump (7 kg/cm^2) mounted over a water tanker (capacity 5000lt) lying at a safe chemicals were mixed in a water tanker of capacity 5000lt in the ratio 1:1 and made the solution of concentration 0.04%w/v. Then chemical mixed water was sprayed in the form of fog/mist over the flaming fires in exposed galleries and loose coal mass where temperatures were measured > 10030C as shown in Fig -2. As a result, temperature dropdown to H" 900C in few minutes; and even after 6 hrs there was no major change in temperature.
2. Fire 0f lower intensity in crushed coal at the floor and at the gallery mouth were dealt with Di-ammonium phosphate {DAP: $(NH_4)_2HPO_4$} - a cost-effective and efficient, endothermic, fire retardant and wetting agent. Di-ammonium phosphate was mixed in a water tanker (5000lt) and made a solution of a concentration of 0.04%W/v. The solution was sprayed to deal with the lower intensity fire and cool the strata rapidly shown in Fig-3.

CONCLUSIONS

Good mining practice is the primary remedy; therefore, good mine practices must be strictly adhered to; including comprehensive thermal monitoring to ascertain the fire. The guiding principle to control the fires are as follows-

1. Coal benches must be regularly monitored for any change in temperature. Temperature ranges above 60, seeks immediate attention.
2. The time lag between dewatering and extraction should be shorten.

Fig. 2: Dealing of high intensity and low intensity fires with different chemicals and compositions.

3. The fire must be dealt in totality. Therefore, continuous fire-fighting operations are suggested till fire extinguished.
4. The firefighting team should be established, consist of managerial and supervisory officials, including operators for carrying out different firefighting activities efficiently and safely.

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Geological Aspects Associated with Banded Hematite Jasper (BHJ)-Iron Ore (Hematite) Transformation at Meghahatuburu Iron Ore Deposit, West Singhbhum, Jharkhand: An Implication for Quality Control of Iron Ores

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ABSTRACT

The volcano-sedimentary banded iron formations (BIFs) of Meghahatuburu iron ore deposit (MIOD) of the West Singhbhum district, Jharkhand, Eastern India are mainly hosted by banded hematite jasper (BHJ) and tuffaceous shale. Generally, BHJ is considered as a protore or a parent rock for the origin of various types of iron ores at MIOD. The field investigations and mineralogical studies corroborated with geochemical footprint of studied BIFs confirm that supergene and hypogene ore enrichment processes significantly contributed for the transformation of protore-BHJ into different types/grades of hematitic iron ores. However, supergene process seems to be dominating over hypogene hydrothermal process. The studied BHJ was firstly affected by hypogene process through magmatic or hydrothermal fluids followed by the secondary supergene ore enrichment process by meteoric water solution. The hypogene process had converted BHJ into high-grade iron ores such as martite-rich hard massive ores and specular hematite (>68 wt% total iron) while secondary supergene process had resulted into evolution of variable grades of iron ores including micro-platy hematite and blue dust. Hence, the present study mainly focuses on geological aspects associated with transformation of BHJ into different types of iron ores (hematite) on the basis of filed observations and laboratory studies that could be used in understanding the mineralogical variations in the iron ores at MIOD vis-a-vis its implication for quality control of iron ores for cost effective steel production.

Keywords— BHJ; Hypogene process; Supergene process; Martite; Specular hematite

GEOLOGICAL OVERVIEW OF MEGHAHATUBURU IRON ORE DEPOSIT (MIOD)

The MIOD, being a part of Noamundi iron ore basin (NIOB), occurs along the western limb of the horse-shoe shaped synclinorium (Fig. 1). The BIFs in the area strikes towards NE-SW to NNE–SSW direction and extends along a trend for about 7-8 km with a width of about 4-5 km. The thickness varies from 100- 120 meters. The banded hematite jasper BHJ- hosted iron ores dip towards west with an average dip amount of about 65°.

A. Host Rock Characteristics

The iron ore deposits at MIOD are hosted with various lithologies such as BHJ, tuffaceous shale and mafic volcanic rock (dykes) in order of their abundance (Figs. 2A to 2D). BHJ, however, is the main host rock of the studied BIFs which consists of alternate bands of hematite and jasper (Fig. 2B). They generally exhibit mega to micro-scale banding of different geometric types in various dimensions. The thickness of jasper bands ranges from 2-40 mm while that of iron bands ranges from 1-30 mm as observed during field studies. In addition, micro-folding and micro- faults are commonly observed in the BHJ sequences (Fig. 2B). The tuffaceous shale is the second most abundant host litho unit at MIOD which is considered to be originated from volcanic sources. They occur as intrusive bodies or dyke within iron formation with different colors such as white, yellow, purple, olive green and pinkish red with soft and sticky nature (Fig. 2C). Sometimes, they also occur as stratiform or intercalated bodies within the iron formations. Mafic volcanic rocks occur are dark colored, medium to coarse grained mainly as dykes or intrusive bodies (Fig. 2D). They mainly indicate continuation of volcanic rock formation or Dolerite Dyke which represents the youngest ltho-stratigraphic unit in the Singhbhum-Orissa iron ore region. They are well exposed near Base Camp area, Kiriburu.

B. Iron Ore Types and Ore Mineralogy

The studied deposit contains various types of hematitic iron ores such as lateritic ores (LO), goethitic ores (GO), hard laminated ores (HLO), soft laminated ores (SLO)

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and blue dust (BD) occurring in order from higher to lower elevations with increasing grade (Figs. 2A, 3 and 4). Blue dust is a deep blue colored, fine powdery, hematitic iron ore containing more than 64 wt% Fe and is considered as the best grade of iron ores. The ore microscopic studies show that martite- hematite is the major mineral phase while quartz and kaolinite are the major gangue constituents (Fig. 4C). Photomicrographs of BHJ exhibit alternate layers of hematite and jasper of variable thickness along with fracture filled secondary hematite. They also contain specularite (elongated, tabular hematite) with inclusion of secondary crystalline quartz (Fig. 4D). Hard Laminated and Massive Ores consist mostly of secondary microplaty hematite, goethite, martite (pseudomorph after magnetite formed due to oxidation of magnetite along fractures or grain boundary) followed by gangue minerals such as clay (gibbsite, kaolinite) and quartz (Fig. 4C). Soft laminated ores are analogous to HLO. Lateritic and goethitic ores are mainly made up of goethite and limonite followed by hematite with fine grained ferruginous matrix and cavity-filled secondary quartz and clay (Fig. 4B).

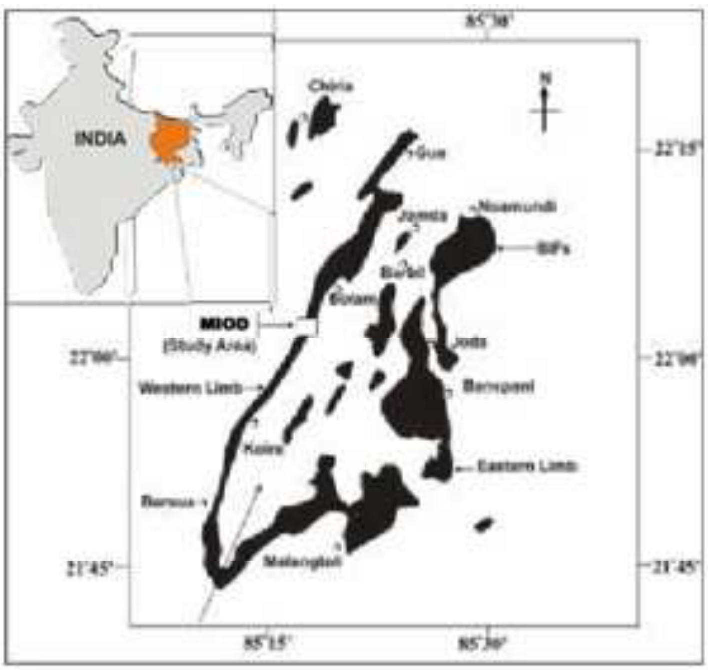

Fig. 1: Location of Meghahatuburu iron ore deposit (MIOD) at the western limb of horse-shoe shaped synclinorium, west singhbhum district, Jharkhand, eastern India (modified after: Chakraborty and Mazumder, 2002).

Also, specular hematite closely associated with secondary quartz veins occurs within BHJ and associated iron ores at MIOD which confirms hypogene hydrothermal origin (Fig. 4A). Its occurrence is sporadic in nature with low volume but is of high-grade containing about 68% total iron with very low contents of silica and alumina. The earliest or primary quartz occurs as layers or stratiform bodies within BHJ while secondary hydrothermal quartz occurs as veins or discordant bodies. Microplaty hematite with shiny surface is also observed at some places occurring at shallow depth (~40 m) which reflects deep weathering or supergene alteration (Fig. 3A). Acicular or microplaty hematite is essentially found in weathered BIFs (Lascelles, 2002). At places, geodes associated with crystalline quartz are seen occurring within the rock cavities.

In addition, the iron ores of the studied area also associated with various textural features such as replacement, colloform, deformational and vein-filling textures. The study of various textural patterns plays a vital role in understanding the mutual relationships or interlocking patterns between ore minerals and their associated gangue constituents and therefore helps to choose suitable beneficiation technique for quality up-gradation. These textural features overall indicate that the quartz, clay and other deleterious elements in the iron ores dominantly occur as disseminated pattern or as enclosed body within ferruginous matrix. Replacement texture is the most common ore texture which can be documented in almost all varieties of iron ores at MIOD and mostly observed in HMO and laminated ores where magnetite is replaced by martite (oxidized magnetite; Fig. 4C). Colloform textures are mainly observed in low-grade iron ores such as lateritic and goethitic ores consisting of concentric layers of goethite along with cavity-filled quartz and clay minerals (Fig. 4B).

GEOLOGICAL ASPECTS FOR BHJ-IRON ORE (HEMATITE) TRANSFORMATION AT MIOD

A. Mechanism for the Evolution of Meghahatuburu BIFs

Based on field, microscopic and geochemical studies on iron ores and associated host rocks, the evolution of studied

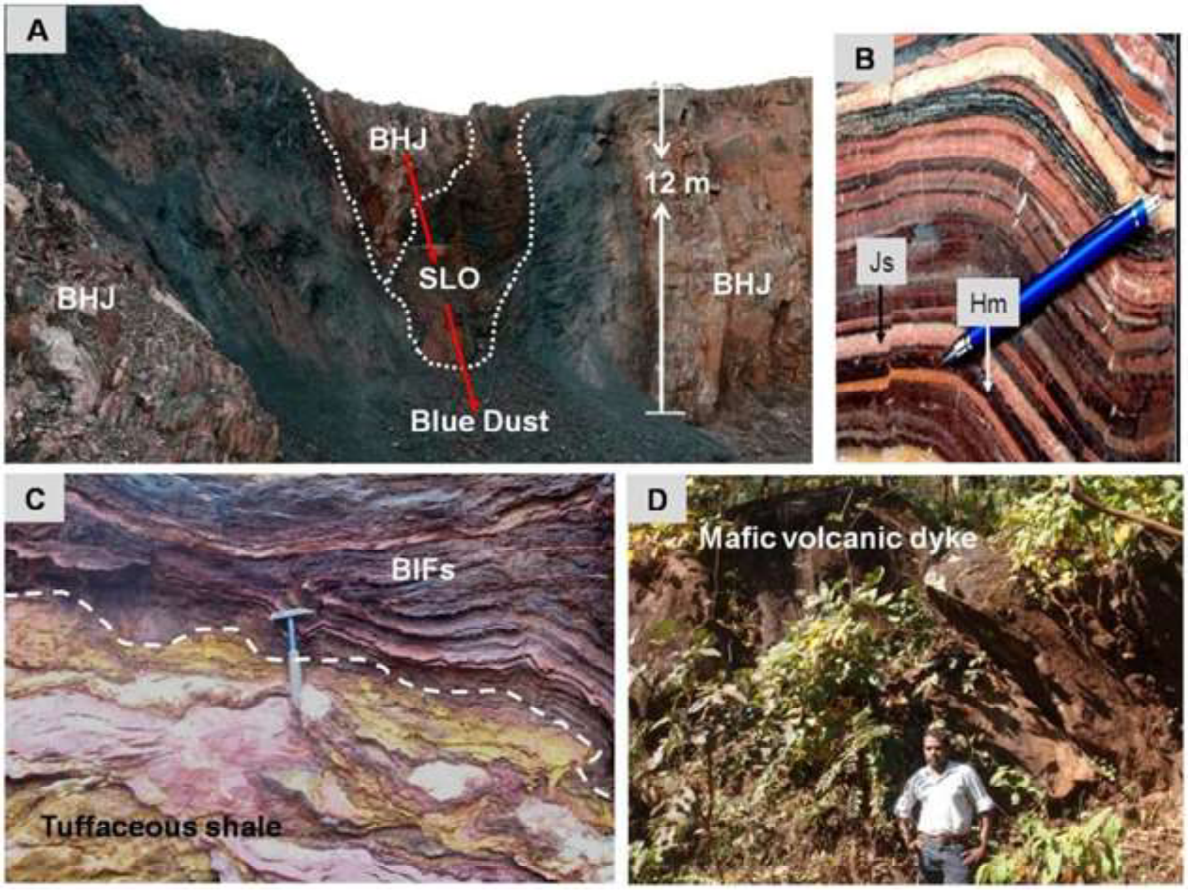

Fig. 2: Field photographs showing A) transformation of protore-BHJ into SLO and SLO to blue dust; B) close-up view of BHJ consisting of alternate bands of jasper (Js) and hematite (Hm); C) tuffaceous shale with variable colors in close association with BIFs; and D) mafic volcanic rock.

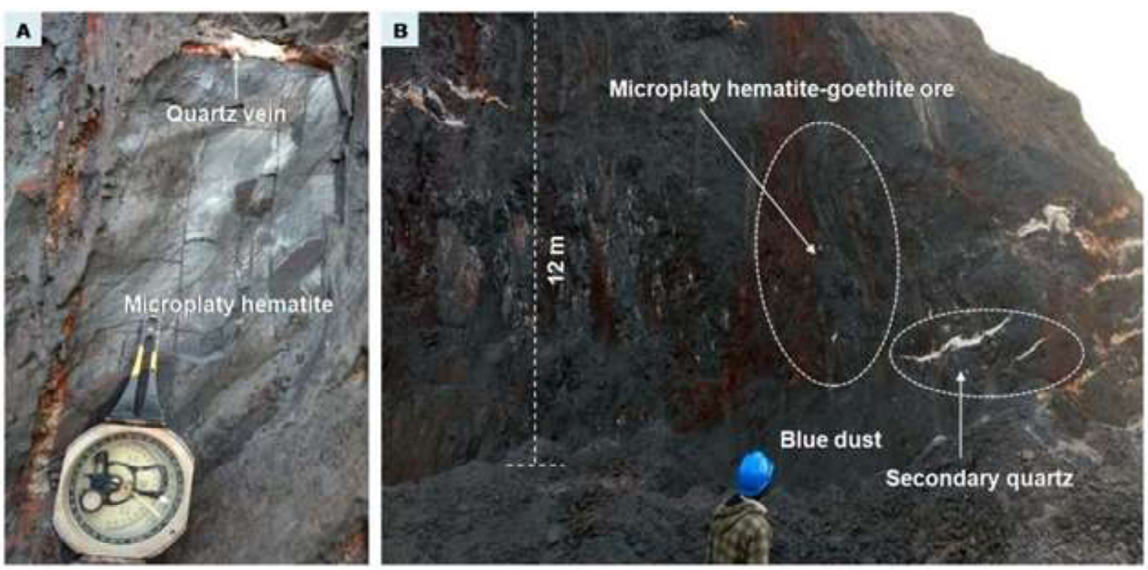

Fig. 3: Field photographs showing A) microplaty hematite associated with quartz vein occurring at about 856m elevation; and B) Association of microplaty-goethite along with high-grade blue dust iron ores reflecting leaching process and supergene alteration of BIFs.

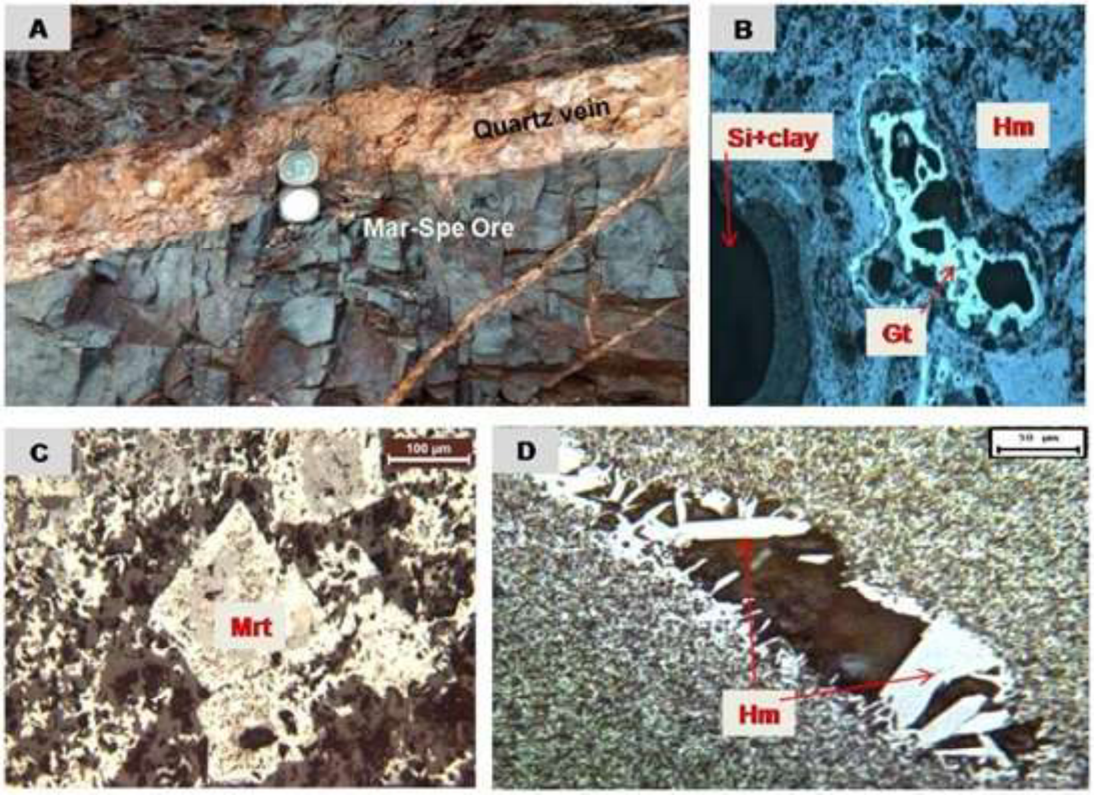

Fig. 4: showing: A) field photograph of martite-specularite (mar-spe) in BHJ; B) photomicrograph of goethitic ore showing colloform banding; C) Photomicrographs HMO consisting of martite (Mrt) and goethite along with relict magnetite representing replacement texture; D) specular hematite (Hm) associated with hard laminated ore.

BIFs and associated iron ores can be divided into following ore forming stages in order of occurrence:

Depositional Stage: It is the first stage of BIFs deposition which involves supply of BIFs precursor from hydrothermal sources (oceanic hydrothermal vents or mid-oceanic ridges) and subsequent migration and deposition of the fluids as BHQ (Banded hematite quartzite)/BHJ along with tuffaceous shale as intercalated bodies under less oxygenated depositional environment on granitic basement, i.e., Singhbhum Granite (Fig. 5A).

Hypogene Hydrothermal Stage: Followed by depositional stage, this is the one of the important stage for enrichment of BHJ into high-grade hematite ores which resulted into formation of martite, specularite and replacement of silica bands or quartz-1 (occurs as layers) from BHJ (Fig. 5B). This enrichment process is surmised to be caused due to heat anomaly and hypogene fluids of Dhanjori volcanic and mafic volcanic dykes or Newer Dolerite by around 2300 Ma and 1600 Ma respectively (Saha et al., 1988 and Mukhopadhyay, 2001).

Deformational Stage: This stage includes folding and thrusting of BIFs making avenues for downward migration of meteoric water solution through fractures, faults, joints and cracks. The downward circulation of meteoric water through these structural elements further enhanced the leaching process for the removal of deleterious elements such silica and alkalis from BHJ leading to formation of high-grade iron ores.

Secondary Supergene Stage: This is the most dominant ore forming process at MIOD which resulted in the enrichment of BHJ through secondary supergene processes under meteoric water solution forming different types/grades of hematite ores such as LO, GO, HLO, SLO, microplaty hematite and blue dust (Figs. 2A and 6). Also, it is characterized by the formation quartz-2 (occurs as veins or discordant bodies).

B. Enrichment of Meghahatuburu BIFs Vis-à- vis

Grade Optimization

The enrichment process of BIFs was observed across the world such as the Quadrilatero Ferrifero and the Ibicoara BIFs, Brazil (Cruz et al., 2018) and the Southern Cameroon BIFs (Sylvestre et al., 2018).

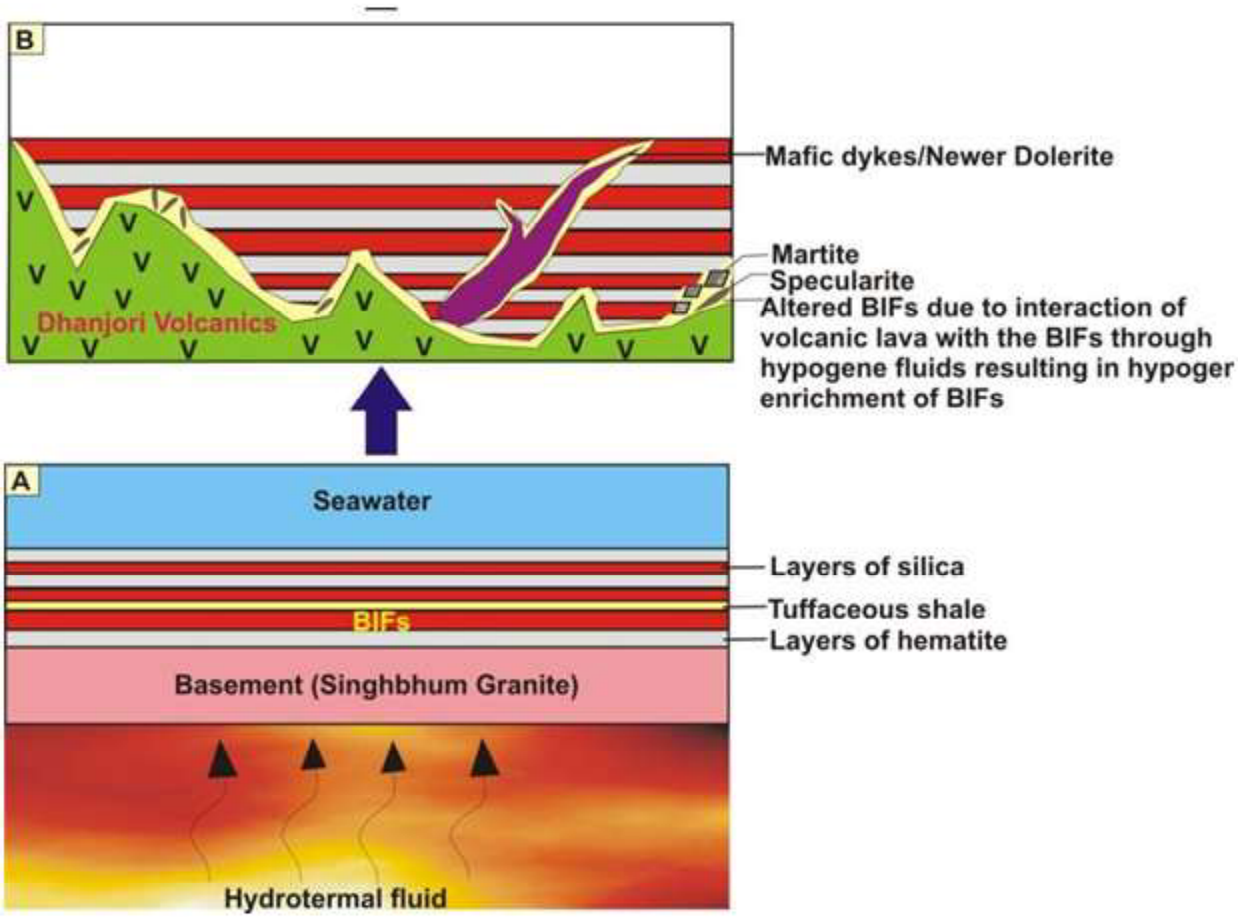

Fig. 5: Schematic diagram showing possible mechanism for: A) deposition of BIFs in the form of BHQ/BHJ along with tuffaceous shale as inter-bedded units; and B) intrusion of Dhanjori lava and subsequent mafic volcanic dykes into BIFs resulting in hypogen alteration of BIFs leading to formation of martite-speculartie ore and removal of silica from BHJ.

Similarly, the field, mineralogical and geochemical studies confirm that both supergene and hypogene ore enrichment process significantly affect the transformation of protore-BHJ into various types/grades of hematitic iron ores at MIOD. Supergene process through meteoric solution, however, appears to be dominating factor over hypogene hydrothermal ore enrichment process. These processes of ore enrichment were mostly aided with three-fold parameters, that is, lithological, structural and palaeoclimatic controls such as porosity, permeability, beddings, folds, faults, joints and fractures (Prasad et al., 2017).

The hypogene ore enrichment processes have been recognized as important in the formation of high-grade hematite deposits, particularly in Brazil, Australia and Canada (Basson and Koegelenberg, 2016). Angerer et al. (2014) reported that the high-grade iron ore deposits in the Hamersley Province, Western Australia confirms the presence of basinal brines and meteoric fluids, while the deposits in the Yilgarn Craton, suggest the influence of magmatic and meteoric fluids for the enrichment of BIFs through hypogene process. Similar role of hypogene process is also surmised at MIOD which leads to the formation of high-grade iron ores such as martite-rich hard massive ores and specular hematite as revealed through field observations and mineralogical studies (Figs. 4A and 4D).

The source of hydrothermal fluids for hypogene alteration at MIOD, however, is hitherto unknown. The only possible source of hydrothermal fluids for the hypogene enrichment could be the mafic volcanic dykes/Newer Dolerite intruded into BIFs or the heat anomalies due to the overlying Dhanjori volcanics. Similar role of volcanic dykes associated with hypogene hematite deposits has been advocated across the world (Conliffe, 2014). Besides, compaction and dewatering of underlying shale formation and subsequent pumping of fluids through bedding planes, joints or fractures during iron ore orogeny (2900 Ma.) might also be inferred as an alternative source of hydrothermal fluids at MIOD for hyogene enrichment of BIFs resulting into formation of high-grade iron ores.

The supergene enrichment process, on the other hand, is considered as the most important and dominating process for BHJ-iron ore transformation at MIOD. It was mainly caused due to circulation of meteoric water solution and removal of silica and other soluble elements (mainly Na2O and K2O) from BIFs/BHJ through continuous leaching process. The geochemical studies of the studied deposit confirm that the high-grade ores are enriched in iron and depleted in SiO2, CaO and alkalis. This has resulted in high-grade hematite ores such as blue dust which is evidenced by the presence of lateritic-goethitic cap rock, silicification and box-work structures.

Recently, fluid inclusion studies in quartz veins associated with iron ore deposits indicate that fluids with medium to high salinity (25–28 wt% NaCl eq.) and temperature (275–375 °C) are responsible for leaching of silica leading to enrichment of BIFs forming high-grade iron ores (Gomes et al., 2018). During supergene enrichment process, dissolution of silica takes place while Fe2+ goes into solution, leading to increase in porosity forming high-grade iron ores such as blue dust or flaky friable ores (Roy and Venkatesh, 2009b).

CONCLUSIONS

In view of the above discussion, it is evident that BHJ is the main petro-graphic unit at MIOD from which various types of hematite ores have been originated with variable grades.

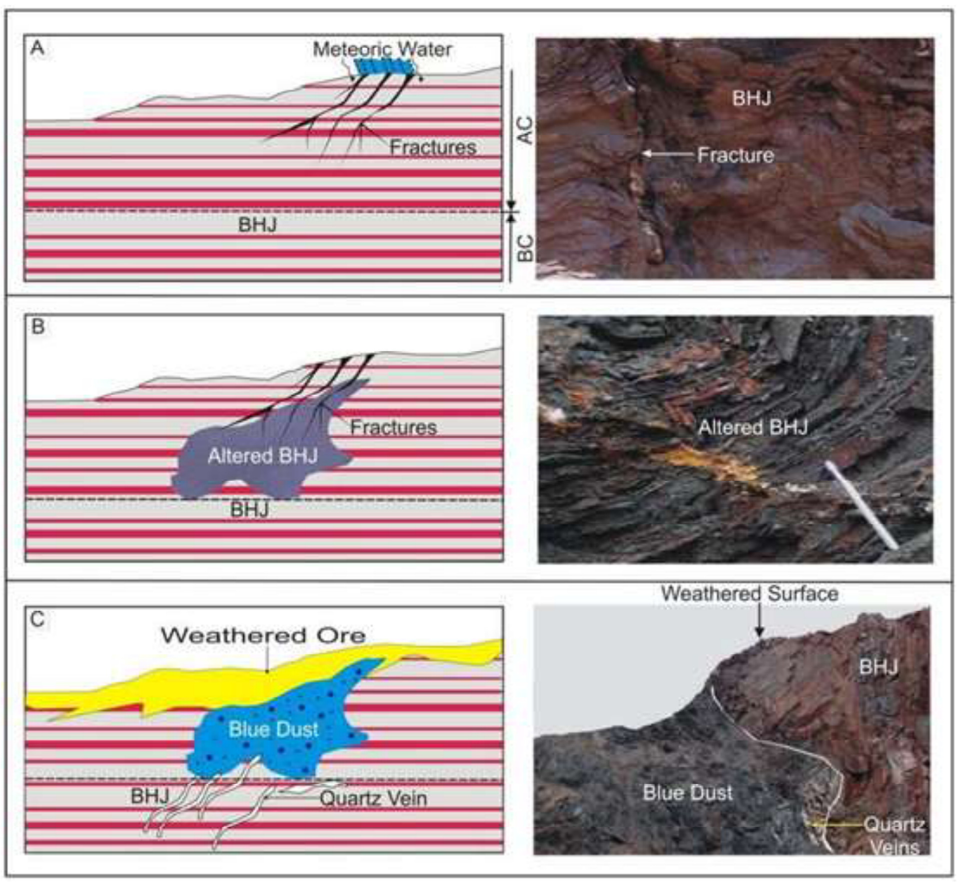

Fig. 6: Schematic diagrams along with field photographs showing supergene enrichment of BIFs showing:
A) fractures making avenue for removal of silica by the downward migration of meteoric water solution from BHJ (AC: acidic condition; BC: basic condition);
B) alteration of BHJ forming soft laminated ores retaining banded nature of BHJ; and
C) formation of blue dust as pocket. The field photographs showing close association of blue dust ores with BHJ, confirms.

Hypogene and supergene ore enrichment processes are mainly responsible for the transformation BHJ into iron ores (hematite) including high-grade ores such as blue dust through removal of deleterious elements (SiO2, CaO & Alkalis) from BHJ. Hence, the study of different geological aspects of enrichment processes of BHJ helps to understand the mineralogical variations in the iron ores that could be further used in making strategies for quality up-gradation of iron ore raw materials for cost effective steel production.

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An Overview on Instruments Used for Monitoring of Slope Movement

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ABSTRACT

Fatal slope failures range from small, hand-sized rocks weighing only a few kilograms to massive highwall failures containing a million cubic meters or more of material. From conventional to computerized monitoring methods, using images from digital and video cameras; have been discussed in this paper for application to mine slope surveillance. These and other techniques will eventually provide new tools to augment current methods for monitoring ground control hazards in mine slopes.

Keywords—monitoring, slope, movement, failure

INTRODUCTION

When a rock or soil mass is disturbed, either by the actions of people or by natural events, it undergoes a redistribution of stresses, resulting in a change in shape. This realignment is reflected in displacements, deflections, loads, pressures, stresses, and strains, which can be detected and measured with the help of various devices. Many rock slopes move to varying degrees during the course of their operational lives. Such movement indicates that the slope is in a quasi- stable state, but this condition may continue for years, or even centuries, without failure occurring. However, in other cases, initial minor slope movement may be a precursor for accelerating movement followed by collapse of the slope. Because of the unpredictability of slope behaviour, movement monitoring programs can be of value in managing slope hazards, and they provide information that is useful for the design of remedial work.

Monitoring is the surveillance of engineering structures either visually or with the aid of instruments (Brown 1993). The objectives of a rock slope monitoring program are (Call 1982):

1. To maintain a safe operation for the protection of personnel and equipment.
2. To provide advance notice of instability, thus allowing for the modification of the excavation plan to minimize the impact of the instability.
3. To provide geotechnical information in order to analyze the slope failure mechanism, design appropriate remedial measures, and/or conduct a redesign of the rock slope.

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It is considered that monitoring programs are most appropriate for actively mined slopes such as open pit mines and quarries which have a limited operational life and where a carefully managed, on-going survey operation can be set up. The survey will be able to identify accelerating movement of the slope and take measures to minimize the risk by moving operations away from the active failure site.

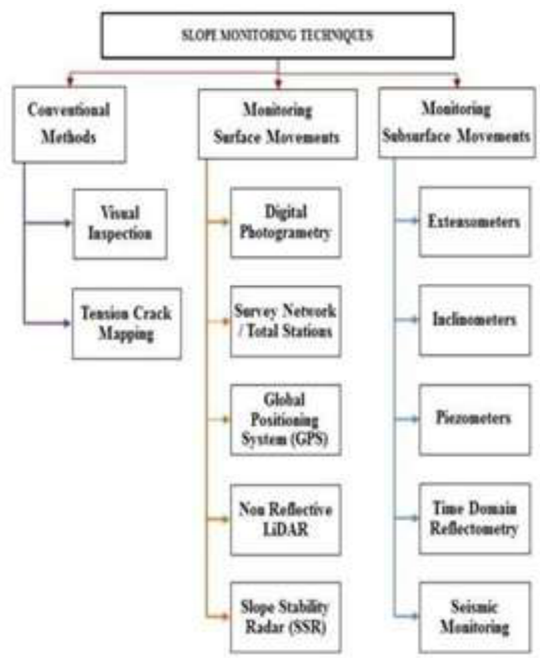


Fig. 1: Schematic representation of slope monitoring techniques (Vinoth et al. 2016)

TYPES OF SLOPE MOVEMENT

In setting up a movement monitoring program it is useful to have an understanding of the type of movement that is occurring. This information can be used to select appropriate instrumentation for the site, and assist in interpretation of the results. Furthermore, the type of movement is related to the failure mechanism and this information can be used to ascertain that an appropriate type of stability analysis is used. The following is a discussion on common types of slope movement, and their implications for slope stability(Wyllie and Mah, 2005).

A. Initial response

When a slope is first excavated or exposed, there is a period of initial response as a result of elastic rebound, relaxation and/or dilation of the rock mass due to changes in stress induced by the excavation (Zavodni, 2000). This initial response will occur most commonly in open pit mines where the excavation rate is relatively rapid. In comparison, the expose of slopes by the retreat of glaciation and the gradual steepening of slopes due to river erosion at the toe will occur over time periods that may be orders of magnitude longer. However, the cumulative strain of such slopes can be considerable.

Elastic rebound strain takes place without the development of a definite sliding surface, and is likely the result of dilation and shear of existing discontinuities. It is basically the reaction of the rock mass to unloading and is a function of stress and rock mass moduli. The rates of movement during initial response periods generally decrease with time and eventually show no movement. Another characteristic of initial response type of movement is that it can occur within a large volume of rock.

B. Regressive and progressive movement

An 'operational slope failure' may develop in an opencast mine, which can be described as a condition where the rate of displacement exceeds the rate at which the slide material can be safely mined (Call, 1982). A means of identifying either plastic strain of the rock mass or operational failure is to distinguish between regressive and progressive time– displacement curves (Fig. 2(a)). A regressive failure (curve A) is one that shows short-term decelerating displacement cycles if disturbing

events external to the slope, such as blasting or water pressure, are removed. Conversely, a progressive failure (curve B) is one that displaces at an increasing rate, with the increase in rate often being algebraic to the point of collapse, unless stabilization measures are implemented. Fig. 2(b) shows geological conditions that are commonly associated with these types of time–displacement curves. Where the slope contains discontinuities that dip out of the face, but at a shallow angle that is flatter than the friction angle of these surfaces (Type I), then it is usual that some external stimuli such as blasting or water pressures will be required to initiate movement. The onset of movement indicates that the factor of safety of the slope has dropped just below 1.0, but with a reduction of the external stimuli, the factor of safety will increase and the rate of movement will begin to reduce. In the case of water pressures causing movement, the opening of tension cracks and dilation of the rock mass may temporarily result in the water pressures diminishing, but as pressures gradually build up, another cycle of movement may start. Another condition associated with regressive movement is stick-slip behavior, which is related to the difference between static and dynamic coefficients of friction on rock surfaces (Jaeger and Cook, 1976).

Operations can be continued below slopes experiencing regressive movement, but it is necessary that the mining be conducted for short periods with frequent pullbacks, with care being taken to identify the transition to a progressive failure (Zavodni, 2000). As shown in Fig. 2(b), geological conditions that may be associated with progressive failure are discontinuities that dip out of the face at a steeper angle than the friction angle (Type II). Also, a slide surface on which the shear strength gradually diminishes with displacement may experience progressive failure. As shown by curve C in Fig. 2(b), a regressive failure may transition into a progressive failure and rapidly lead to collapse. Causes of this change in behavior can include; where mining daylights a sliding surface, breakup of the rock at the toe of the slope, an increase in water pressure, or continued mining causing the slope to accelerate beyond recovery. It is important to recognize the onset of progressive failure, which will require a diligent monitoring plan and careful analysis of the results.

C. Long-term creep

In contrast to the rapid excavation, and the consequent large scale, relatively fast movements that take place in open pit mines, mountain slopes may creep over periods of hundreds of years. Long-term creep may occur where there is no defined failure surface, such as a toppling failure (Type III, Fig. 2(a)), or where the change in slope geometry is very slow, for example, due to stress relief following glacial retreat or erosion at the toe by a river. Other causes of such long-term movement are historical earthquakes that each cause displacement, and climatic changes that result in periods of high precipitation and increased water pressures in the slope.

The various types of movements can be recorded with the help of the corresponding type of instruments as mentioned in Table 1.

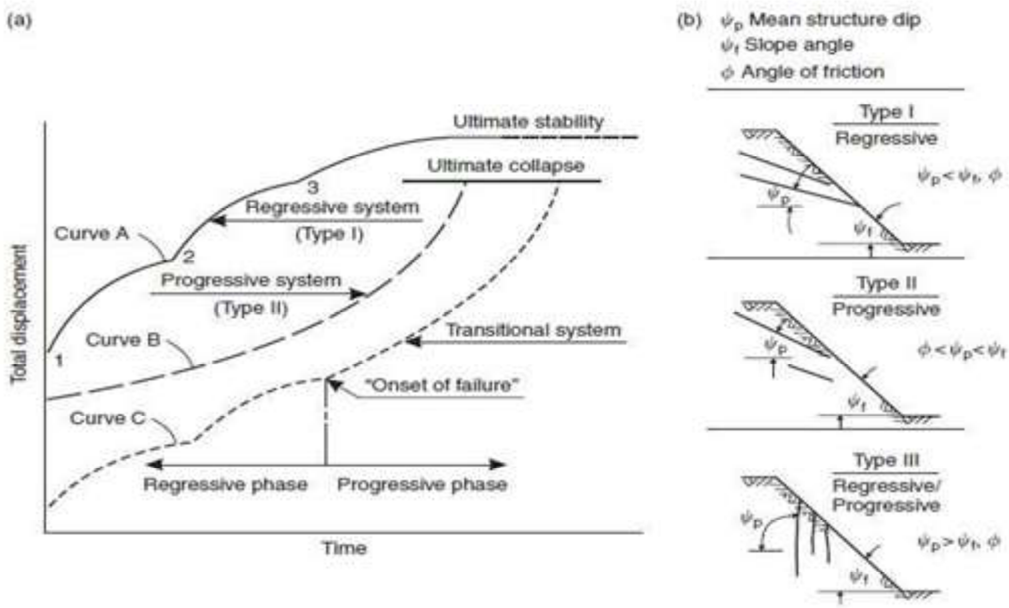


Fig. 2: Types of slope movement: (a) typical repressive and progressive displacement curves (b) structural geological conditions corresponding to types of slope movement (Broadbent and Zavodni, 1982)

Table 1: Type of instruments used to measure type of movements

Instrument type	Instrument	Measured index
Geometric measures	Ground reference point, survey monument Settlement plate, platform or cell, Liquid level gages Vertical inclinometer Horizontal inclinometer Tilt meter Crack meter Extensometer, Differential Global Positioning System (dgps), Digital camera with reference targets Automated total station Time domain reflectrometry (TDR) LIDAR (Light Detection and Ranging) Insar (Interferometric synthetic aperture radar)	Settlement and movement Settlement Inclination Rotation Width Movement Change in position Distance Vertical movement Surface map
Water related measures	Observation well Peizometer Raingauge	Water level Water pressure Rainfall
Mechanical measures	Strain gauge Load cell Accelerometer Acoustic emission monitoring Fiber optic sensor Micro-seismic	Strain/stress Force Dynamic forces Particles sliding Strain or pressure Energy
Temperature Measures	Thermister, thermocouple and TDR, Fiber optic sensor	Temperature

Major displacement may or may not cause difficulties for mining, depending on a number of key factors. These factors include (Sullivan 1993):

- the nature of the material involved in the instability
- the type of instability
- the rate of movement
- the type of mining system employed
- the relationship of the instability to the mining operation

The above factors provide an economic basis for continuation of mining, support, excavation, etc. The protection of personnel and equipment is, however, another key consideration.

METHODS AND INSTRUMENTS FOR MONITORING OF SLOPES

Monitoring instruments usually consist of three basic components:

- a transducer or sensor to measure the property of interest
- a transmitting system, e.g. rods, electrical cables or telemetry devices to transmit the information to the readout location
- a readout unit, such as a dial gauge, to give a digital or graphical display of the measured quantity

A. Visual inspection

It has the benefit that all people working in the pit can and should be involved to their degree of capability. Thus, equipment operators should be required to report rockfalls, field supervisors should be involved in the slope inspection process and geotechnical staff should be involved in a regular detailed inspection process.

B. Digital Photogrammetry

The use of digital photogrammetry is the most common and a simple remote sensing technique to identify rock movements. The objective of digital photogrammetry is to identify wide displacement behavior of a target inferred by the comparison of photographed images (Fig. 3) using digital camera (Ohnishi et al., 2006). Using such digital photographs, it is also possible to estimate the geometric properties of the objects, the progress, extent and cause of slope deformation

(Ohnishi et al., 2006 and Firpo et al., 2011). Recent developments in the method have provisions for the generation of 3D models from the terrestrial photographs (Sturzenegger et al., 2009). The method has the ability to survey the inaccessible areas and high rock faces in rapid time providing remote characterization tool for rock slope practitioners, thereby making a permanent record of the status of the slope for future reference.

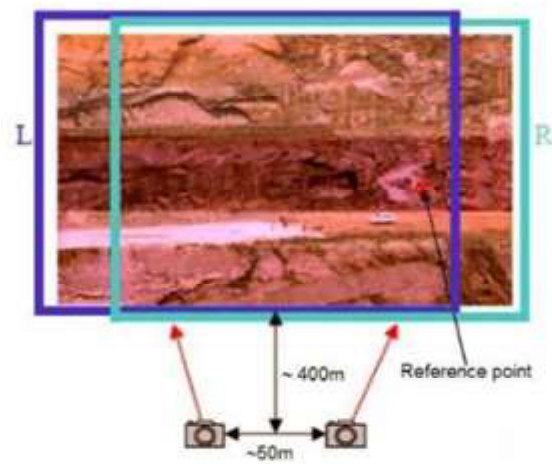


Fig. 3: Digital Photogrammetry (Vinoth et al., 2016)

C. Terrestrial laser scanner(TLS)

In contrast to traditional 3D data acquisition approaches (i.e. tacheometry and photogrammetry), terrestrial laser scanner is capable to rapidly acquire data without any requirement of direct contact to the object and extensive processing procedure. Similar to reflector less tacheometry, TLS measures three main components: i) Range (r); ii) Horizontal direction (□); and iii) Vertical angle (θ). To ensure TLS data are significant for further processing, most of the TLSs' on-board software automatically convert raw TLSs data (i.e. spherical coordinate system) into Cartesian coordinate system.

B. Survey Networks/Total Station (Robots)

A survey network consists of a series of prisms which are installed on the slope i.e. monitoring points at regular spacing. Their perspective positions are monitored using total stations from stable platforms at regular intervals. The relative movements of the target prism at the monitoring points help to identify the deformation and critical failures zones in advance; utilizing the movement of prisms (Fig. 4).

Fig. 4: Network of prisms and Automatic Total Station (Vinoth et al., 2016)

Surveying robots are increasingly being used for the monitoring of structures and terrains, because they relieve personnel from repetitive around-the-clock measurements (Rueger et al., 1994). With the availability of long range, high accuracy total stations in the recent years, the monitoring of slope using prisms have almost become a real time solution.

Robotic total stations provided with global navigation satellite system (GNSS) receivers are increasingly being used for automated, accurate, efficient and cost effective survey for monitoring slope in large open pit mines (Brown et al., 2007). The other major advantage of the method is that the total station can be fixed at point for continuous monitoring of the slope at the preset interval timings or it can be shifted from one point to other point manually for monitoring the fixed prisms movement. The relocation of the monitoring prisms could cause monitoring interruption with continued mining and extension of the slope face (Sjoberg, 1999).

E. Global Positioning System (GPS)

The Global Positioning System (GPS) is the U.S. based radio navigation, timing and positioning system which tracks the electromagnetic signals that the navigation satellites transmit day and night. The GPS is used to measure the movements with continuous or episodic monitoring of slopes, landslides and subsidence (Stewart et al., 1999, Gili et al., 2000, Malet et al., 2002, Forward et al., 2001 and Abellan et al., 2014). By the comparison of initial and final position of the GPS stations, level of deformation and the slope movements can be estimated. The availability of Differential GPS (DGPS)

provides real time information on the stability status of the slope and also the deformation rate both day and night. The method has great advantage when it comes to open sky surface mines with the installation of series of receivers along monitoring regions. But, the use of GPS is limited by the environmental characteristics, such as the vegetation and mountains and in rapid deformation scenarios (Malet et al., 2002). Now a days, GPS equipment are used in combination with photogrammetry, total stations network and remote sensing; as the control points for monitoring the slope stability of the mines (Gili et al., 2000).

F. Non - Reflective LiDAR Scanning

LiDAR stands for 'Light Detection And Ranging' and utilizes a beam of laser lights, targeted towards the area of monitoring which returns the digital representation of the critical area of the slope and their relative movements using the travel time of the reflected radiations (Abellan et al., 2014). Laser scanners are active self-contained measurement technology that generates its own light for measurement process (Osasan et al., 2010). Though, the application of laser scanners are well proved in monitoring landslides, the method has found lesser application in monitoring open pit slopes. The recent LiDAR scanners can be mounted in both the static and mobile surveying platforms which can provide digital elevation models (DEM) in rapid time and the survey of mine slope can be made up to 15 times faster than the conventional survey (Optech Incorporated, 2014The only restriction to its applicability is weather conditions and terrain humidity.

G. Slope Stability Radar (SSR)

The slope monitoring radar is a state-of- the-art technology which has completely transformed geotechnical risk assessment in surface mines (Osasan et al., 2010). Slope monitoring radar has emerged in the last 10 years as a leading edge tool for safety-critical monitoring of pit wall movements in surface mining (Farina et al., 2014). The beam of radar emitted from the antenna mounted on a fixed or movable platform scans the slope faces in both vertical and horizontal directions (Fig.5). Also, it is possible to estimate the magnitude of failure with broad areal coverage in all weather conditions. In the recent years, 3D visualization of the deformed surface isalso possible using the radar monitoring (Harries et al., 2007).

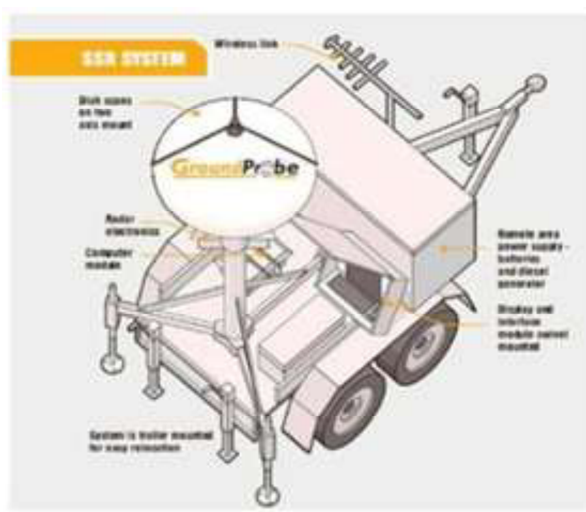


Fig. 5: Slope Stability Radar System (Vinoth et al., 2016)

Synthetic Aperture Radar (SAR) in open pit mines provides capability for detection of both large rapid slope failures to small slope deformation movements over the years [23]. The advantage of SSR system is that it can detect and alert movements of the strata with sub-millimeter precision, providing ample time for evacuating the resource from critical zones (Farina et al., 2014).

H. Extensometer

The fixed borehole extensometer measures only axial displacement between a fixed number of reference points on the same measurement axis. The basic components of a fixed borehole extensometer are an anchor, a linkage, and a reference head. A typical rod extensometer is shown in Fig. 6.

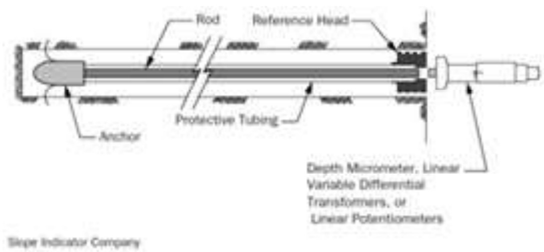


Fig. 6: Single-point rod extensometer

When more than two reference points are used, the instruments are referred to as multiple-position or multipoint extensometers (fig. 7). Multipoint extensometer data can reveal the relative movement between anchor points and the distribution of displacement, in addition to the magnitude, rate, and

acceleration of displacement (Slope Indicator Company, 1994).

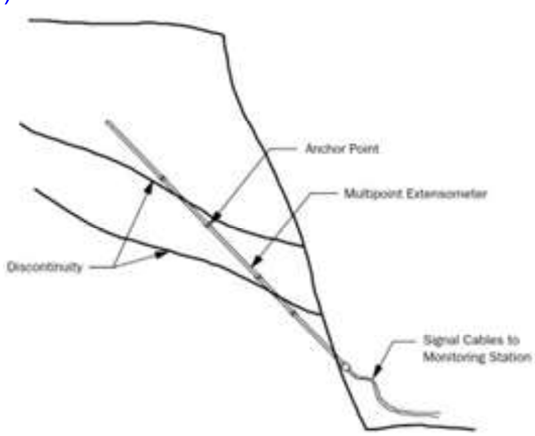


Fig. 7: Multipoint extensometer for monitoring magnitude and rate of movement along two discontinuities

The single most important precept of extensometer data interpretation is the accurate detection and recognition of acceleration. A typical time-displacement graph for a multi-position extensometer is shown in Fig. 8. Also shown on the bottom of Fig. 8 is a plot of acceleration versus time for the time- displacement data over the full length of the extensometer. Acceleration in this context is measured as the rate of change of strain (in micrometers per meter per hour) per unit of time (hour). Long lengths of wire can lead to errors due to sag or to thermal expansion. The major disadvantage of the wire-line extensometers is that the tension cable may cut when there is an unexpected large deformation or collapse causing complete reinstallation of the system.

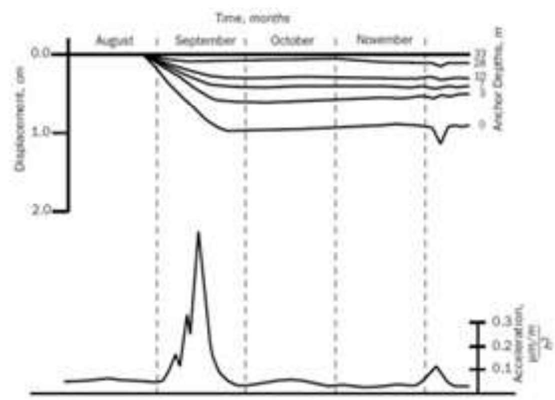
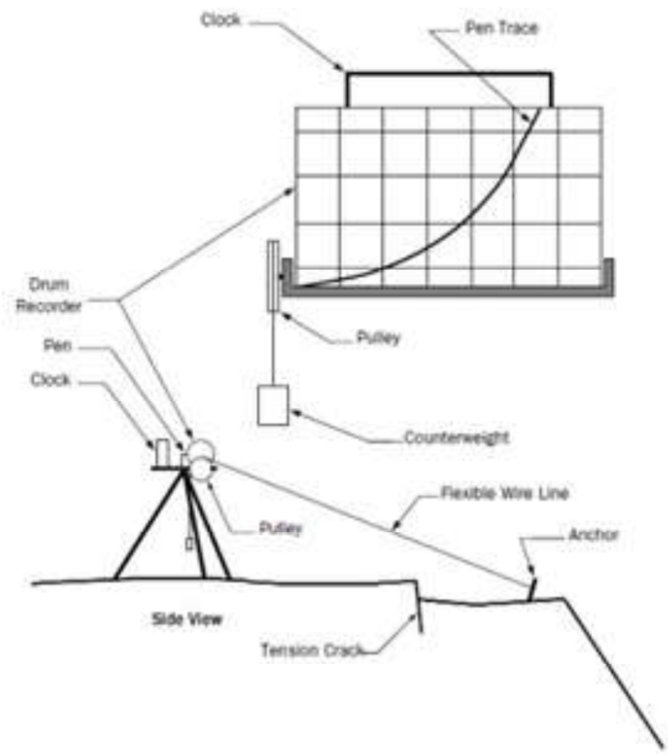


Fig. 8: Displacement versus time for a multi- position extensometer, as well as rate of change of displacement (acceleration) over the entire length of the anchor

A more recent development, the automated slope monitoring system, adds the ability to record real-time data automatically and then transmit the data to a central computer system for analysis. The automated system shown in schematic form in fig. 9 is composed of two main components: the slope monitor unit, which is located in the field, and the central computer and radio, which are located in the mine office. Alarms may also be transmitted if certain conditions occur, such as broken wire, excessive movement or velocity, or communication failures. Several factors are automatically corrected for in this system; i.e., there is a temperature sensor at the station to correct for wire expansion and contraction. The wire length and gauge are input into the software, and corrections are transmitted back to the system. The user can set the movement velocity tolerance to transmit data, and an alarm will sound if the movement exceeds a particular specified velocity.



Source: Adapted from Call (1982).

Fig. 9: Portable wire line extensometer with continuous recorder

I. Inclinometers

An inclinometer measures the change in inclination (or tilt) of a borehole and thus allows the distribution of lateral movements to be determined versus depth below the collar of the borehole as a function of time (Wilson and Mikkelsen 1978). Therefore, the application of inclinometers to slope stability studies is important for the following reasons:

- to locate shear zone(s)
- to determine whether the shear along the zone(s) is planar or rotational
- to measure the movement along the shear zone(s) and determine whether the movement is constant, accelerating, or decelerating

The sensors are normally positioned within the casing to span the zone where movement is anticipated. The string of sensors is usually attached to a data acquisition system that is programmed to trigger an alarm if certain boundary conditions are exceeded. The in- place inclinometer is expensive; hence, its use is generally limited to only the most critical applications (Boisen and Monroe 1993). A typical in-place inclinometer system is illustrated in fig. 10.

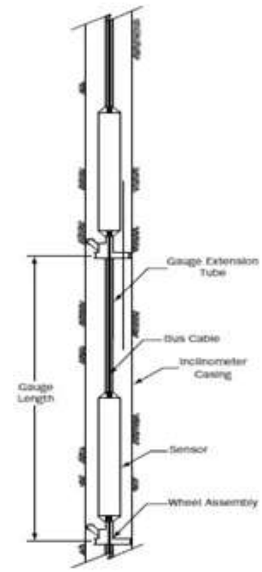


Fig. 10: An in-place inclinometer system

The inclinometer profile for the planar slope failure (fig. 11(a)) shows forward displacement of the inclinometer casing at the shear zone but no rotation between the shear zone and the upper slope surface. The inclinometer profile for rotational failure (fig. 11(b)) shows forward displacement at the shear zone as well; however, it also shows tilting backward from the shear zone to the upper slope face.

The slope inclinometers are used to determine the magnitude, depth, direction, rate and the type of slope movements. The depth of installation of inclinometers play a crucial role in monitoring rock movements, as shallow depth installation will result in low displacement measurements.

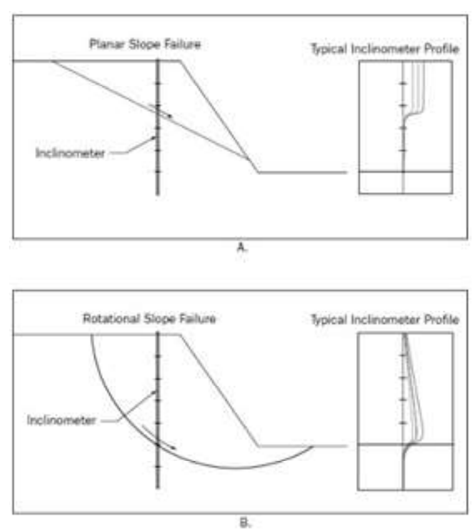


Fig. 11: Typical plots of inclinometer depth versus deformation: (A) rotational failure; (B) plane shear failure

The difference between extensometer and inclinometer is that extensometers measure deformation parallel to the borehole (along single axis) while accelerometers measure the deformations normal to the borehole (Osasan et al., 2010).

J. Piezometers

Piezometers (fig. 11) are the traditional methods for monitoring the slope instabilities experiencing ground water problems. The piezometers are used to measure the pore pressure within the rock mass which. This pore pressure to the reduction in the stability of slopes by decreasing the shear strength, development of seepage forces and intrusion of water in tension cracks which ultimately leads to slope failure.

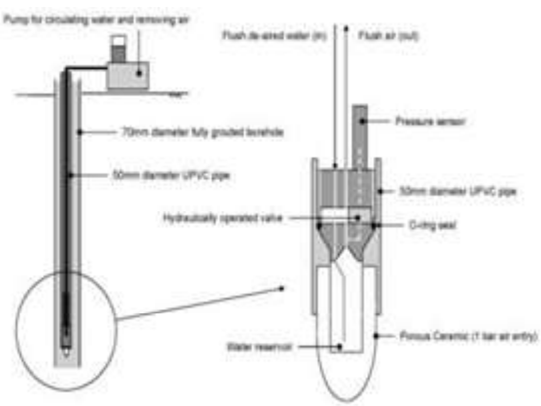


Fig. 12: Hydraulic Piezometer

K. Time Domain Reflectometery (TDR)

It has been utilized to monitor slope movements in a variety of geotechnical settings including highway cuts, rail beds and open-pit mines (Farrington, 2006). TDR monitors the subsurface deformation of slopes using an electrical pulse which is sent down through a conductor and examining the reflected signal to delineate discontinuities in the conducting material (Cai et al., 2001). A typical layout of TDR is given in Fig.12. Using TDR, the relative magnitude, rate of displacement and the location of zone of deformation can be determined immediately and accurately (Osasan et al., 2010). The method is more advantageous when it comes to monitoring slopes of expected movement but it fails to predict the failures as it can only monitor the rate of movement. The other disadvantage is the safety of implementing the method in unstable areas which may require considerable human effort.

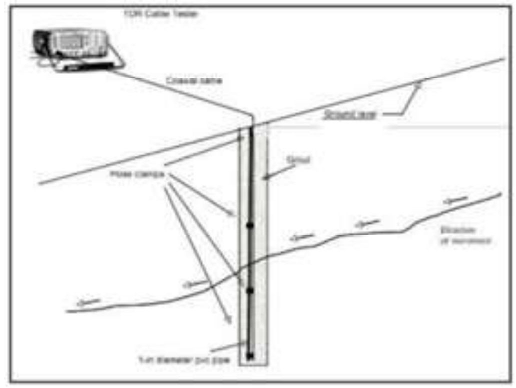


Fig. 13: Principle and Components of TDR

L. Microseismic Monitoring

The microseismic method is used in opencast mining environment for slope failure, prediction and associated scenarios. The microseismic events generated during the small rock movements are recorded by a series of data loggers and are transmitted to the processing system (Vinoth et al., 2014) (Fig.8). Then the events are processed for identification of zone of weakness, the stress conditions, deformation mechanics and their rate within rock mass. Also, such data can be used to understand the possible excavation damage zone, the initiation of new fractures or reactivation of existing discontinuities within the monitoring zone. The method has various advantages over other slope monitoring methods in terms of its high accuracy level (~0.001m), providing the deformation information in real time. The method in combination with geotechnical investigations and numerical simulations could be of vital importance to predict the geomechanical deformation within the rock mass and to understand the behavior of rock mass and stress paths due to mining activities.

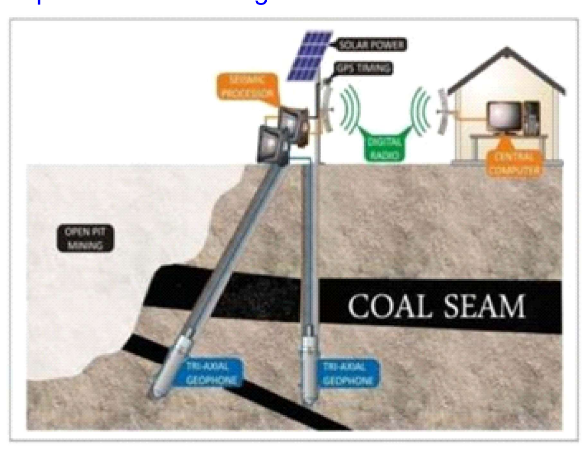


Fig. 14: Microseismic monitoring in opencast mine

CONCLUSION

Majority of the monitoring systems fail to communicate the information on the deformation scenarios and stress factors associated with mining. Conventional methods are time consuming with limited accuracy. Inclinometer, TDR, extensometer and LiDAR are unwarranted for real time information to early prediction of failures. In the recent years, slope stability radar and microseismic monitoring have garnered considerable attention for early forecast of slope failures and in estimating deformations with considerable accuracy. Radar technology is suited for predicting large scale movements, microseismic monitoring is capable of monitoring deformation on long term basis for identification of potential failure surface within the rock. Both the methods have the potential to estimate the response of rock mass to excavations and can predict the failure well in advance.

With the recent advancements, in terms of range and accuracy, it can be said that the future of deep opencast mines may incorporate these as the essential part of mine design for routine monitoring on long term basis. Integration of multiple instruments into a single portable unit could make monitoring more feasible and economic.

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