THE INDIAN MINING & ENGINEERING JOURNAL

(Incorporating Mineral Markets: The Founder Publisher & Editor: J.F. De. Souza, Mumbai)
www.theimejournal.com

VOLUME 60: No.12 **DECEMBER 2021** ISSN 0019-5944

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Published Monthly by IME Publications.
Annual Subscription : Rs.650/- (Incl. Postage), Unit Price: Rs.50/-
FOREIGN: £ 75 OR US $ 150 (By Air Mail)
*Payment by Cheque/Draft. Cheques drawn outside Bhubaneswar must include Rs.50/- (Overseas £1 or US$2) as bank charges and should be drawn in favour of "**The IM& E JOURNAL"** payable at Bhubaneswar*

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PRABHAT KUMAR
DIRECTOR-GENERAL

MESSAGE

It gives me great pleasure and pride to learn that The Indian Mining and Engineering Journal is celebrating the 60th year of its publication in 2021. On this auspicious occasion a Special Volume (e-Journal) is going to be published which will be a source of knowledge to the mining fraternity.

Mining sector is critical to India's economic and social well being. Mining and quarrying sector contributes around 2.06% of the Gross Domestic Product (GDP). The mining sector under index of Industrial Production (IIP) witnessed a growth of 1.7 percent year on year basis. Indian economy is on the aspirational path of becoming a $5 trillion GDP economy by 2024-25. Mining Industry is going to have a sizable contribution to the envisaged GDP and wealth creation. India being a developing economy, is dependent on the growth of energy sector in order to achieve the desired economic growth. Recently we have seen the up surge in demand of coal and non-coal minerals. The mining industry and other stakeholders have to keep themselves updated technically as well as in resource management to maintain the pace and growth of the nation.

I have observed that The Indian Mining and Engineering Journal has played a significant role amongst the mining professionals by sharing the scientific knowledge and the practical experience supported with field data in the form of papers. I believe that it's effort pave the way for increase in the production capacity of the country with utmost priority on the safe practices and techniques. Continuing efforts of the Indian Mining and Engineering Journal since 60 years is laudable endeavors.

I wish, The Indian Mining and Engineering Journal its editorial team and all the contributors a great success in their endeavors in the times to come.

Prabhat Kumar

K. Madhusudhana

President
Mining Engineers' Association of India
Hyderabad

MESSAGE

It gives me great pleasure to learn that The Indian Mining & Engineering Journal is organising a National Seminar on **"SUSTAINABLE DEVELOPMENT OF MINERALS & COAL RESOURCES ",** Annual Awards and Diamond Jubilee Celebration Function on 17-18 December 2021 at AKS University, Satna.

I am indeed delighted to deliver my greetings for the Diamond Jubilee Celebration of Indian Mining & Engineering Journal.

The Indian Mining & Engineering Journal has worked for improvement of all the aspects of mining industry including technological innovations, Drilling & Blasting, Rock Excavation , Extraction, Beneficiation for safe and sustainable development with the help of dedicated and sincere efforts of its members for the past 60 years.

The Journal provides an opportunity to the mining professionals to showcase their talent and explore their creative potential. I am sure that the matter incorporated in the Journal will project the needs of tomorrow and help the policy makers to incorporate the innovative ideas for the progress of our country.

The Seminar is going to cover several aspects of mining activity regarding minerals and coal resources which is going to touch upon various mining rules/regulations at the National level for major minerals and minor minerals for sustainable development.

I trust that the one-day seminar will deliberate on the current issues being faced by the Indian Mining Industry. I am sure this seminar will be a mile stone in understanding the new rules and generating proposals to remove or reduce the hurdles existing in the rules that prevent ease of doing mining business.

Many Congratulations to Indian mining and Engineering Journal on completing 60 years of truly lifechanging education and research. The Journal continues to get better and I look forward to celebrating many more milestones with the best in the India.

We are thankful to all the members of organizing committee for their sincere efforts in making this Seminar a grand success.

All the best for the new stage of journey

Wishing you all the very best.

Date: 02.12.2021

K.Madhusudhana

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निदेशक
Dr. Pradeep K Singh, FASc, FNASc
Director

MESSAGE

It is a matter of great pleasure that **Indian Mining and Engineering Journal** is organizing National Seminar on **Sustainable Development of Minerals and Coal Resources (SDMiNER-2021)** and Annual Awards Function at AKS University, Satna during December 17-18, 2021 on the occasion of **Diamond Jubilee Celebration** of Indian Mining and Engineering Journal.

It is heartening to note that the seminar aims to provide a platform for dissemination of knowledge where researches, engineers, academicians, planners and policy makers would share and globalize their technologies and research work.

I am sure that with the participation of eminent people from across the country, the event for future technologies for mining industries will get a further boost and many new ideas for existing and upcoming industries will emerge.

I congratulate all those who are associated with this event and wish the event a grand success.

PK Singh

(Pradeep K Singh)

CSIR-CIMFR, Dhanbad
6th December, 2021

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The Indian Mining & Engineering Journal, Vol. 60, No.12 December 2021, pp.06-15
Printed in India, @ IME Publications, ISSN 0019-5944

Environmental Issues With Best Management Practices in Mining Sustainability

Professor (Dr.) Gurdeep Singh*

ABSTRACT

There is a widespread concern of environmental and social issues in mining sustainability. Management of these issues in a responsible manner is a big challenge for sustainability of mineral sector. This paper presents the major environmental issues such as climate change, acid rain, ground level ozone, disturbance to hydrologic regime, water conservation, acid mine drainage, heavy metals contamination, siltation of productive and agriculture lands, changes in land use patterns, ecological disturbance etc. coupled with the societal development issues. Application of best management practices (BMPs) in select cases has also been presented to demonstrate the responsible mining in management of environmental and social issues to provide mining sustainability.

Key Word: Environmental Issues in Mining, Best Management Practices (BMP), Sustainability, Societal Development, Mine Water Augmentation, Land Use Management.

INTRODUCTION

Minerals play an important role in the economic development of the country as minerals are the basic raw materials to promote the growth. The development and extent of judicious utilization of mineral resources adds to the index of growth of a nation and its people. The mineral industry in India is reckoned not only as an important contributor to the country's GDP and foreign trade, it is also one of the major industries that absorb a considerable amount of the country's working population. The Indian mining industry provides employment to about 1.1 million persons. India's mining industry is projected to touch over $50 billion (about Rs 3, 00,000 crore) accounting for about 2.5% of the GDP, a latest report said [1, 2]. This industry is spread almost all over the Indian Territory and has operations in some of the remotest areas of the country, where it can claim itself to be the sole leader of infrastructure development. The mining leases occupying about 0.7 million hectares which is 0.21 per cent of the total land mass of the country. This industry operates more than 2600 mines which consist of 574 coal mines, 2054 metalliferous mines and a score of other small mines [1, 3, 4]. India produces 87 minerals out of which 4 are fuel minerals, 10 metallic, and 47 non-metallic and 23 minor minerals. The Indian economy to a great extent depends on the value of the minerals produced, as these represent a major portion of the raw materials for the nation's industrial activities. The report on metals and mining pointed out that India has immense natural resources and is ranked among top 10 globally for production, second in barytes, chromite and talc/steatite/pyrophillite, third in coal & lignite, fourth in iron ore and kyanite /sillimanite, fifth in manganese ore, steel (crude) and zinc, sixth in bauxite, eighth in aluminium and tenth in magnesite of the world's resources [2].

Indiscriminate and unplanned mining causes irreversible damage and deterioration of natural resources. Mining activities affect surrounding i.e. air, water, soil, land, biological diversity etc. The environmental impacts of mining activities may have short-term as well as long-term implications. Guidelines for taking necessary precautions before, during and after mining operations are laid down to ensure sustainable development. The role of mining in sustainable development is one issue that decision makers and resource managers have wrestled with for decades. Mining is one of those activities that really connect issues relating to people, development, and the environment. The negative impact of mining on health, land, water, air, plants and animals, and other aspects of society can be reduced by careful planning and implementation of mining activities. It is essential to strike a balance between mineral developments on the one hand and the restoration of the environment on the other.

ENVIRONMENTAL ISSUES

The mining operations like land acquisition, drilling, blasting, dewatering, extraction, transportation, crushing and other associated activities are carried out in underground and opencast mines [5,6]. Mining operations

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damage the environment and ecology to an unacceptable degree, unless carefully planned and controlled. There is a need for balance between mining and environmental for overall sustainability.

Various impacts of mining on environment and their mitigation measures are presented:

IMPACT OF MINING ON AIR QUALITY

Air pollution in mines is mainly due to the fugitive emissions of particulate matter and gases including greenhouse gases such as CH4, CO2, and NOx etc. Most of the mining operations produce dust. The major operations producing dust are drilling, blasting, hauling, loading, transporting and crushing [7]. Basically, dust sources in mines can be categorized as primary sources that generate the dust and secondary sources, which disperse the dust and carry it from place to place called as fugitive dust.

Opencast mining is more severe an air pollution problem in comparison to underground mining. High levels of suspended particulate matter increase respiratory diseases such as chronic bronchitis and asthma cases while gaseous emissions contribute towards global warming besides causing health hazards to the exposed population. The uncontrolled dust not only creates serious health hazard but also affects the productivity through poor visibility, breakdown of equipment, increased maintenance cost and ultimately deteriorates the ambient air quality in and around the mining site. The dust can also pollute nearby surface waters and stunt crop growth by shading and clogging the pores of the plants. Besides polluting the environment, the generation of dust means the loss of fines, which act as road surface binders.

PROBLEM WITH GREENHOUSE GASES, ACID RAIN AND GROUND LEVEL OZONE

The key environmental challenges associated with mining are – greenhouse gases, acid rain and ground level ozone, issues which can be local, regional and global in their impacts.

The greenhouse effect is a natural phenomenon, which refers to the increase in the earth's surface temperature due to the presence of certain gases in the atmosphere. There is concern that this natural phenomenon is being altered by a greater build-up of gases caused by human activity. This is known as the enhanced greenhouse effect. The combustion of coal, like that of other fossil fuels, produces CO_2, a gas that is linked to global warming through the greenhouse effect. These emissions of greenhouse gases are a major global challenge of climate change.

At the 26th Conference of Parties (Glasgow CoP 26), Indian Prime Minister Narendra Modi declared a five-fold strategy termed as the "panchamrita" — to make carbon emission half by 2030 by reducing emission of greenhouse gases and to combat global warming as well as climate change. These five points include:

- India will get its non-fossil energy capacity to 500 gigawatts (GW) by 2030
- India will meet 50 per cent of its energy requirements from renewable energy by 2030
- India will reduce the total projected carbon emissions by one billion tones from now onwards till 2030
- By 2030, India will reduce the carbon intensity of its economy by less than 45 per cent
- So, by the year 2070, India will achieve the target of Net Zero

The combustion of coal produces gaseous emissions of Sulphur dioxide (SO_2) and nitrous oxides (NOx) that are responsible for the production of 'acid rain' and 'ground level ozone'[7,8]. Acid rain occurs when SO_2 and NOx gases react in the atmosphere with water, oxygen and other chemicals to form acidic compounds. Ground level ozone (O_3) is mainly responsible for smog that forms a brown haze over cities. Ground level ozone is formed when NOx gases react with other chemicals in the atmosphere and is enhanced by strong sunlight. Emissions of SO_2 and NOx are termed trans-boundary air pollution because the environmental impacts from the production of these gases are not restricted by geographical boundaries.

(II) IMPACT OF MINING ON WATER REGIME

- **Disturbance to hydrologic regime**

Mining and its associated activities not only uses a lot of water but also affects the hydrological regime of the district and often affects the water quality. Large and deep opencast mines usually have great impact on the hydrologic regime of the region .The major hydrological impact of a large and deep opencast mine, however, is on the ground water regime of the region. The water seeping into the mine and collected in the mine sump is partly used up in the mine and the excess amount is discharged into the surface drainage system. The water used up in the mine for spraying on haul roads, conveyors, at loading and unloading points, bunkers etc. are lost by evaporation. A deep mine is likely to have longer haul roads requiring more spraying water. The water used for green belts and plantation areas are also lost by evapo-transpiration. Many areas of the country are faced with the problem of over exploitation of ground water resources resulting in alarming lowering of water table[9,10]. Therefore, a lot of care has to be taken in estimating the water need and the mines of future are likely to be subjected to a lot of constraints on water use and discharge.

Acid Mine Drainage

Acidic water results in severe water pollution problems. Acid Mine Drainage (AMD) refers to distinctive types of waste bodies that originate from the weathering and leaching of sulphide minerals present in coal and associated strata. Environmental effects of AMD include contamination of drinking water and disrupted growth and reproduction of aquatic plants and animals. Effects of AMD related to water pollution include the killing of fish and loss of aquatic life and corrosion of mining equipments and structures, such as, barges, bridges and concrete materials.

AMD is the most persistent pollution problems in mines of North Eastern Coalfield. Generally, water quality characteristics of acidic mine water reflect high acidity and high hardness along with high iron and sulphate contents[11,12]. Various toxic trace/ heavy metals become soluble in acidic water and may be presenting significant to concentration levels depending upon their availability in the source material. Fortunately the considerable majority of coal mining areas are safe and only in a few localized areas problem of AMD exists[13]. AMD cripples the economy of mines due to compliance of stringent environmental standards and involves huge cost burden in its management.

(III) IMPACT OF MINING ON LAND

Irrespective of the type of mining used for extracting coal, mining invariably results in enormous land disturbance-e.g. large scale excavation, removal of top soil, dumping of solid wastes, cutting of roads, creation of derelict land etc. The mining industry, in general, is reluctant to rehandle overburden material for economic reasons but in a few cases it has been planned to rehandle the material to fill the voids created at the end of mining, and it is expected that the practice will become more widespread in future. Opencast mining has more potential impact on land than underground mining. With improved technology, opencast coal mining is being used extensively because of its cost effectiveness and productivity though it results in large-scale land disturbance. Although underground mining has considerably less impact than opencast mining on land, it causes enough damage through subsidence as observed in Jharia and Raniganj Coalfields[6,14]. The surface subsidence inflicts severe damages to engineering structures such as highways, buildings, bridges and drainage besides interfering with ground water regime.

(IV) IMPACT OF NOISE AND VIBRATIONS FROM MINING

A cumulative effect of all mining activities produces enormous noise and vibrations in the mining area, which constitutes a source of disturbance. The availability of large diameter, high capacity pneumatic drills, blasting of hundreds of tonnes of explosive etc. are identified as noise prone activities. Input crushing system with mobile crusher and large capacity materials handling plants are being installed to facilitate speedy handling of large quantities. All these activities are major sources of noise & vibrations in and around the mining complexes[2].

The obvious implication of noise is, of course, the potential for noise-induced hearing loss. In addition, noise produces other health effects, influences work performance and makes communications more difficult. Besides, the fauna in the forests and other areas surrounding the mines/ industrial complexes is also effected by noise and it has generally been believed that wildlife is more sensitive to noise and vibrations than the human beings.

(V) IMPACT OF COAL MINE FIRES

A number of coal mines in the country are affected by fires leading to steady destruction of precious energy resource. The reason for mine fires presumably involves the phenomenon of spontaneous heating through two interrelated processes viz., the oxygen coal interaction or oxidative process and the thermal process. If remains uncontrolled, the fire could spread further through interconnected pathways and fissures in the strata. It is estimated that about 10% of total national coal resources are in the fire-affected areas[2,8].

Mine fires give rise to several environmental problems besides safety hazards and economic losses. Apart from direct losses due to burning of coal, the other associated hazards encountered are: i) gas poisoning, ii) difficult geo-mining conditions, iii) sterilization of coal, iv) hindrance to production v) explosions, vi) damage to structure and adjacent properties, etc**.**

SOCIAL ISSUES

Coal mining, despite the very substantial benefits they bestow on society, stir strong emotions. A great ongoing social challenge for the mining industry is sustainable development and community acceptance of its role in society. The problem of mining-induced displacement and resettlement (MIDR) poses major risks to societal sustainability[15,16].

(i) *Landlessness:* MIDR raises the significant risk of landlessness by removing the foundations upon which productive systems, commercial activities, and livelihoods are articulated.

(ii) *Joblessness:* The ethnic people living in the designated areas depend generally for their livelihood on the land. Since, in mining areas the land is taken for mining and associated activities these people lose their livelihood.

(iii) *Homelessness:* Defined as the "loss of house-plots, dwellings and shelter." For many people homelessness may be only temporary, but in poorly executed displacements, it remains chronic.

(iv) *Risk of Marginalization:* The risk of marginalization threatens displaced individuals and entire communities as they slip into lower socio-economic status relative to their local areas.

(v) *Changes in population dynamics:* All the manpower required for mining and associated activities comes from outside as such trained manpower is usually not available in ethnic population.

(vi) *Cost of living:* Increased industrial and economic activities generate more money and increase the buying power of the people directly and indirectly associated with these activities. This leads to an increase in the cost of living.

(vii) *Health Risks:* The already marginal health status of displaces is worsened by the stress and trauma of moving. Recurring problems are reported with resettled populations gaining access to safe potable water and safe sanitation; increased diarrhoea, dysentery and epidemic infections often result.

(viii) *Disruption of Formal Educational Activities:* Risk occurs in the disruption of education and routine socialization. Displacement and relocation often cause a significant interruption in the functioning of schools and in child access to education during the year of transfer or for longer periods of time.

(ix) *Addictions:* Increased economic activities and affluence brings in more addictions in the society. In the tribal areas the ethnic people may also get affected by additional addictions.

Mining companies must accept the right of land-owners to negotiate access to their land, to determine whether or not exploration or mining takes place there. If access is given, they must be able to negotiate conditions, such as the preservation of sacred sites, access to traditional hunting grounds, proper resettlement and rehabilitation of those who have to be moved and the determination of compensation packages Account should be taken of alternative plans proposed by the affected people, who must be allowed to identify suitable resettlement sites. Where those being displaced have agriculture as their primary source of income and livelihood, every effort must be made to replace land with land [17]. If suitable land is not available, other strategies built around opportunities for employment or self-employment should be used. Relocated people must receive legal land titles for their resettlement plots, whether these are house plots or agricultural land.

Mining Sustainability: Many of the mining projects rendered unsustainable and even abandoned as environmental aspects were not given appropriate attention. Many of these are termed controversial with public protests coupled with judicial intervention and are listed below:

Major Controversial Mines

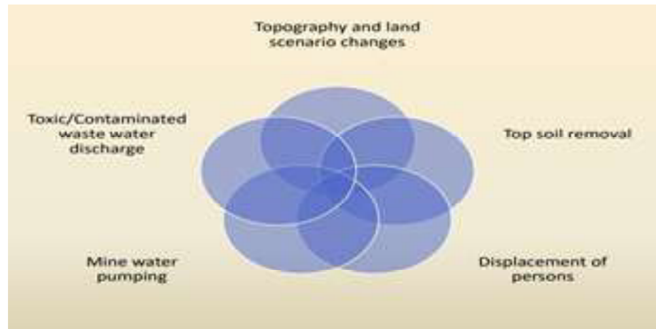
- Aravali Mining Banned: The Supreme Court on February 19, 2009, ordered closure of 157 of the 261 mines in the Aravalli hills in Rajasthan.
- Kudremukh Iron ore Mine, Karnataka
- East coast Bauxite Mine, Orissa
- North-Eastern Coalfields, Assam
- Gandhmardhan Bauxite Mines
- Lime Stone Mines in Doon Valley
- Iron Ore Mines in Singbhum
- Iron Ore Mines in GOA and Bellary- Hospet Region
- Panna Diamond Mine
- Jharia Coal Mines, Jharkhand

RECENT CONTROVERSIES IN MINING AREAS

- **Ban on Mining in Karnataka:** Hon'ble Supreme Court of India banned mining in Karnataka in July 2011 in the wake of the Karnataka Lokayukta report about irregularities in the mining sector. The Hon'ble Supreme Court allowed resumption of mining operations in Category 'A' and 'B' (108) mines with a cap on production of 30 MTPA in April 2013.
- **Ban on Iron Ore Mining in Goa:** Hon'ble Supreme Court of India had imposed a blanket ban on mining operations of Goa in October 2012 due to certain illegalities as reported by Justice Shah Commission. Hon'ble Supreme Court has lifted the ban in Goa on 21 April 2014 and imposed a cap on production up to 20 MTPA.
- **Ban on Mining in Odisha** In its recent order dated 16 May 2014, Hon'ble Supreme Court imposed a partial ban on iron ore mining in Odisha considering the findings of the Justice MB Shah Commission which establishes the prevalence of rampant illegal mining in Odisha. It stayed ban on mining in the 102 leases with no environmental clearances and 26 mining leases operating as second and subsequent renewals.

Environmental Scenario of Bellary-Sandur-Hospet Region : Overall environmental scenario with focus on carrying out mining activities in a sustainable way has been defined by the Supreme Court empowered Committee(CEC) which is being followed all over India in mining regions including Bellary-Sandur-Hospet, Goa, Odisha etc. Salient features of sustainability aspects are presented below in respect of Bellary-Sandur-Hospet:

ENVIRONMENTAL IMPACTS



Development of R & R Plans in the Region

- Consequent upon complaints of large scale illegal mining and environmental deterioration in three districts – Bellary, Chitradurga and Tumkur – of Karnataka, the Hon'ble Supreme Court of India had closed mining operations in 2011 in 166 mining leases.
- A Central Empowered Committee was constituted.
- On Recommendations of the Central Empowered Committee (CEC), the Hon'ble Supreme Court directed preparation and implementation of:
  - Reclamation & Rehabilitation plans (R & R Plans)
  - Supplementary Environment Safeguard Plans (SESP)

Classification of Mines as per CEC

Category	Nature of Encroachment	No. of leases	Recommendation
A' Category	Where the encroachment in mining activities outside the lease wasmarginal mining leases.	46	May resume Mining
'B' Category	Where the encroachment in mining pit outside thelease is up to 10% of the mining pit area orencroachment in overburden dumps outside the lease is upto 15% of the mining lease area, or both : mining leases	69	Resume Mining underspecific conditions
C' Category	Where the encroachment in mining pit outside thelease is above 10% ofthe mining pit area orencroachment in overburden dumps outside the lease is above 15% of the mining lease area or both	51	•Cancellation of Leases •E-auction of the existing stock •Implement R&R Plan

Feasible Production Capacity

Production capacity allowed as per IBM/MoEFCC/KSPCB's statutory approvals
Production capacity based on available mineral reserves
Production capacity based on available dumping space
Production capacity based on capacity of transport infrastructure based on standards prescribed by Indian Road Congress

Production Capacity Based on Available Mineral Reserves

- Existing mineral reserves and resources, based on reliable existing exploration data and as approved by Indian Bureau of Mines (IBM), are considered for computing the production level taking 20 years life of the reserves
- Objective
- ➢ To discourage excess production if the reserves do not support.
- ➢ Aimed at encouraging exploration

Production Capacity Based on Available Dumping Space

- The waste dumping is not allowed to be carried out outside the lease area.
- ➢ Dump capacity is computed based on area/volume identified for waste dumping as per IBM approved mine plan
- ➢ Ore production capacity is computed for 5 years' period based on actual stripping ratio for the last 5 years
- ➢ Dumping volume is computed based on scientific dump planning –terraced dumping, incorporation of drains, toe walls, check dams, etc – to ensure stable dumps
- Objective
- ➢ Ensure stable dumps and to encourage backfilling leading to improved mine land reclamation.

Production Capacity Based on Capacity of Transport Infrastructure

- Adverse impacts of 'mining' actually relate to traffic – related impacts
- Transport route for carrying the ore to its customers/ destination (including ports/railway sidings) is studied thoroughly.
- ➢ The road capacity is computed based on guidelines of Indian Road Congress (IRC).
- ➢ Quality of roads, terrain, type of traffic, other public traffic plying on the same road, are other factors considered while computing the mine capacity
- Objective
- ➢ To encourage transport options like aerial ropeways, downhill conveyors, rail transport etc.

- **Water Quality Management Plan**

Engineering Measures

- ➢ In order to maintain proper mining execution many measures have been taken up.

Following are constructed inside and outside mine lease area by lesses (ex: Donimalai Iron Ore Mine)

- ➢ Gully checks
- ➢ Garland Drains
- ➢ Check Dam

These check dams and settling tanks are de-silted every year before onset of monsoon.

- ➢ Waste consists of mainly limonitic laterite, phyllites/ shales, ferruginous clay, sill and dyke etc.
- ➢ The waste rock is not toxic and have no alarming heavy metal content
- ➢ Dump slopes/tops to be stabilized by planting tree saplings, grass and root bearing saplings.
- ➢ Prevent wash off of the material, constructing Toe-walls of suitable size at base of waste dumps.

D. EXAMPLE OF BEST MANAGEMENT PRACTICES

1. AUGMENTATION OF PUMPED OUT MINE WATER FOR SUSTAINABLE DEVELOPMENT OF COAL MINING REGIONS

The need to provide potable water supply in the densely and thickly populated highly industrialized, water scarce coal mining areas of India, cannot be over-emphasized. Mining populations in these regions have been facing acute shortage of water supply and in some places people have to walk a few kilometers to collect the water for their daily needs. Epidemics also occur due to water-borne diseases, due to the non-availability of a properly treated water supply.

Millions of gallons or mine water is being discharged daily from underground coal mines. This valuable water resource of generally acceptable quality, becomes contaminated with various domestic and industrial trade effluents and subsequently is just wasted while putting on an enormous energy cost burden on the underground mines[13,19]. This study highlights that this underground mine water can be augmented to meet various water supplies, particularly for drinking purposes. Treatment of this water resource at some places is also presented [8]. A simple scheme for augmentation of underground mine water for potable purpose is also suggested.

Water Demand in Coal Mining Areas: There has been an acute shortage of water in many places within the coal mining areas of India and one such example is Jharia and Raniganj Coalfields in eastern India. The quantity of water available for an individual for day to day use for various purposes along with the corresponding WHO recommended quantity is presented in Table 1.

Table 1: Quantity of Water Available for an Individual for day to day use

Sl. No.	Purpose	WHO's recommendation litre/person/day (A)	Quantity available litre/person/day (B)	Percent shortag e(%) (C)
1.	Drinking/Cooking	15	8.5	43.3
2.	Bathing/Personal Washing	60	12.0	80.0
3.	Utensils Washing	15	5.0	66.6
4.	Cloth Washing, Washing	20	7.5	62.5
5.	House Washing	10	5.0	50.0
6.	Flushing/Refuse disposal Washing	60	15.0	40.0
7.	Garden	10	-	100.0
8.	Wastage	20	7.0	65.0
	Total	210 Lits.	60.0 Lits.	71.42

$$C = \frac{A - B}{A} x100\%$$

Water Availability Status in Jharia Coalfield: The population of Dhanbad town and the Jharia Coalfield, which is at present at the level of about 15.0 lakh. The potable water demand for an estimated population of 15.0 lakh at 30 GPCD (135 LPCD) works out to 45 Mgd. Considering 10% for loss in distribution and 25% water demand for private industries, the total demand comes to 49.5 Mgd. The userwide break up of demand is as follows:

(a) BCCL employees - 19.5 Mgd
(b) Rehabilitation colonies (non BCCL) - 23.0 Mgd
(c) Dhanbad and Baghmara towns - 7.0 Mgd

The Mineral Area Development Authority (MADA) which is the 'sole source' of water supply to the non-BCCL population is supplying water to Dhanbad and Baghmara towns also. The industrial water demand of the Jharia Coalfield has been assessed as 34 Mgd.

On the completion of the Jharia Reconstruction Scheme, the underground mines shall be pumping 61 Mgd. The domestic water demand comes to 49.5 Mgd and the industrial water demand has been assessed as 34 Mgd. The total demand comes to 83.5 Mgd and the availability would bc only 61 Mgd, thus the whole of the underground pumped out mine water can be treated for potable purposes as this is of good quality except hardness (Gurdeep Singh, 1990). This will not only meet potable water demand considerably but also cut down the treatment costs under existing conditions. The rest of the water demand will be met from the River Damodar and its tributaries. Even though the underground mine water is fully taped it does not meet the total demand and cost has to be incurred for abstraction of water from surface water bodies to meet the rest of the demand. As the River Damodar and its tributaries are rain-fed the flow becomes very negligible in the summer. The water supply becomes a great problem during the summer. Thus, in such a condition mine water is the ideal source which can be augmented to meet the various water supplies particularly for domestic purposes which is in accordance with the National Water Policy. The National Water Policy emphasises the need to augment the water availability from such sources as well as to meet various demands of the local people.

Mine Water Quality Classification: A classification of underground mine waters, as arrived at on the basis of analysis of mine waters from various coal mines of eastern India, is given in Table **2.** General water quality characteristics under each category are summed up in Table 2. Most of the mine waters fall under category A2 which have high to medium concentrations of dissolved solids, hardness, sulphate with low to medium concentration of suspended solids. Biochemical parameters (BOD, COD) and toxic metals are present at insignificant levels. Waters of category AI, which are slightly alkaline in nature, differ from those of category A2 in that they are not hard and contain comparatively low concentration of dissolved solids and sulphate. Chloride concentrations of both the categories are not very different and are generally at an acceptable value. Mine waters of category A3 contain very high concentration of dissolved solids particularly sulphate and chloride with very high hardness content and their occurrence is rare and limited to some of the worst affected mine fire areas. All the mine waters revealed bacteriological contamination and special attention needs to be paid to disinfection.

Table 2: Quantity of Water available for an Individual for day to day use

Sl. No.	Purpose	WHO's recommendation litre/person/day (A)	Quantity available litre/person/day (B)	Percent shortage (%) (C)
1.	Drinking/Cooking	15	8.5	43.3
2.	Bathing/Personal Washing	60	12.0	80.0
3.	Utensiles Washing	15	5.0	66.6
4.	Cloth Washing, Washing	20	7.5	62.5
5.	House Washing	10	5.0	50.0
6.	Flushing/Refuse disposal Washing	60	15.0	40.0
7.	Garden	10	-	100.0
8.	Wastage	20	7.0	65.0
	Total	210 Lits.	60.0 Lits.	71.42

Classification of Mine Waters Based on Hardness: Water samples collected from the underground mines were hard to very hard which is revealed from Table 3. About 75% of the samples were found to be lying in the very hard category. This is the main cause of the underground mine waters non-acceptance among the public, particularly due to difficulty in cooking and consumption of lots of soap for washing and bathing purposes. The release of phosphates from the soaps and detergents consumption is also contributing towards the eutrophication of confined water bodies. Further hardness content in the mine waters also results in scale formation.

Pumped out Mine Water Treatment: Mine water in general is treated mainly by conventional methods using aeration followed by flocculation with rapid and slow mixing and sedimentation. The water enters the rapid gravity filters after which it is disinfected by chlorination and supplied to the consumers. In the case of mine water with significant hardness (>300 mg/l) softening by lime soda process or ion exchange process is additionally practiced. Addition of coagulant in excess to the mine water will hasten flocculation and increase bactericidal efficiency thus it is economical to use the minimum quality of coagulant and to depend on chlorination for bacterial safety of the water.

In the mining areas, there are a number of collieries- the

Table 3: Classification of Mine Waters

		Category of the Minewaters		
		A-1	A-2	A-3
Water Quality Parameters				
A.	pH	7.5-8.5	7.0-8.5	6.0-8.0
B.	Alkalinity (m/l $CaCO_3$)	200-7000	100-500	10-30
C.	Hardness (mg/l $CaCO_3$)	50-150	200-1500	1000-2000
D.	Total Dissolved Solids (mg/l)	300-700	500-1500	1500-2500
E.	Total Suspende dSolids (mg/l)	5-30	12-50	10-50
Bio-chemical Parameters				
A.	DO	5.5-8.0	5.0-8.0	5.0-8.0
B.	BOD	<1	<1-2	<1-2
C.	COD	8-30	15-50	15-60
Element or Ion Content				
A.	Calcium (mg/l)	10-50	50-200	100-150
B.	Magnesium (mg/l)	10-30	40-180	80-100
C.	Total Iron (mg/l)	0-2	0-5	0-5
D.	Sulphate (mg/l)	10-100	100-800	1000 and above
E.	Chloride (mg/l)	18-40	2245	80-400
F.	Bacteriological Contamination Coliform Organism (MPN/100 ml)	0-180	6-180	0-18

workings of which facilitate the pumping of millions of gallons of water which is being discharged putting on enormous costs on energy for pumping. Some of the collieries have their own treatment plants in the vicinity of the mine for the treatment of mine water and supplying it to the mining community. The schematic layout of such treatment plants is given in Figure 2. Many of these units have not been observed in proper operating conditions. In many of the cases the filler beds were found to be choked and the quality of water obtained after treatment was not of the required standard. In some cases the treated water had either excess or deficient of free residual chlorine which is objectionable for the aesthetic and public health point of view.

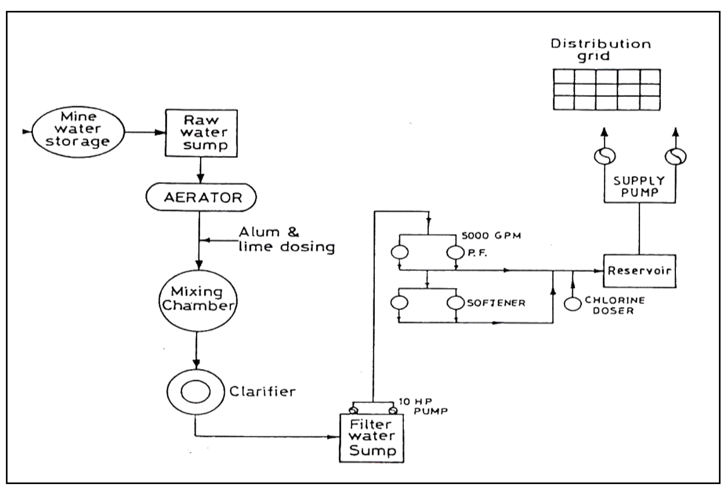


Figure 2: Schematic Layout of Water Treatment Plant in Practice at some of the Coal Mining Regions

CONCLUSION

Environmental issues as a consequence of mining are dealt with respect to air quality, greenhouse gases, acid rain, ground level ozone, noise and vibrations; disturbance in hydrologic regime, acid mine drainage, land damage, land use, subsidence, ecological restoration, social aspects, are reviewed in this paper. Sustainability as defined by the Supreme Court has been defined and is being in practice in almost most of the major mining regions. Best Management Practices (BMPs) have been provided with one specific example of augmentation of pumped out mine water for sustainable development of coal mining regions. Further, adoption of BMPs in mining established lots of profitability besides bringing in social, economic and environmental credibility with overall mining sustainability.

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The Indian Mining & Engineering Journal, Vol. 60, No.12 December 2021, pp.16-20
Printed in India, @ IME Publications, ISSN 0019-5944

Slope Stability Monitoring: Problems & Possibilities

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ABSTRACT

Slope stability monitoring is mandatory in coal mines. The main purpose of slope monitoring is ti predict the slope failure in advance and avoid the failures. There are various methods/instruments to monitor the slopes and various researchers have given various permissible displacements, but there is no well accepted approach of either monitoring or permissible deformations. So, in this paper an attempt is made to discuss need for slope monitoring, various method and instruments and need to develop an integrated slope monitoring plan.

INTRODUCTION

Slopes are designed for safe conditions based on physico mechanical properties of rocks. Now days reliable and accurate numerical modelling based softwares are available to determine the slopes with different geometry and optimize the same. The basic input to any numerical model is rock properties which are generally determined from borehole logs or by collecting samples from benches. Based on the variation in the rock mass, different sections are marked and analyzed for the stability of slopes. But still there would be a possibility for variation of rock mass which lead to reduced Factor of Safety casing slope failure. In such cases, slope stability monitoring can help in identifying the weak zones/probable failure zones so that necessary seps can be taken to avoid slope failures.

SLOPE MONITORING IN OPENCAST MINES

Because of the unpredictability of slope behavior, slope monitoring can be of value in managing and preventing slope hazards, and they provide information that is useful for the design of remedial work. As illustrated in Figure 1, a slope monitoring system can be divided into four sections namely, Visual monitoring, surface measurements, subsurface measurements and remote monitoring technologies. A very cogent factor in an effective slope monitoring system, as pointed out by Little (2006), is the creation of a comprehensive database system for the large volume of geotechnical information obtained from the mine. All data from exploration core logging, face mapping, rock testing, water and slope monitoring must be incorporated into the database system to ensure that no data is lost, and that the data is available for safe and productive slope design.

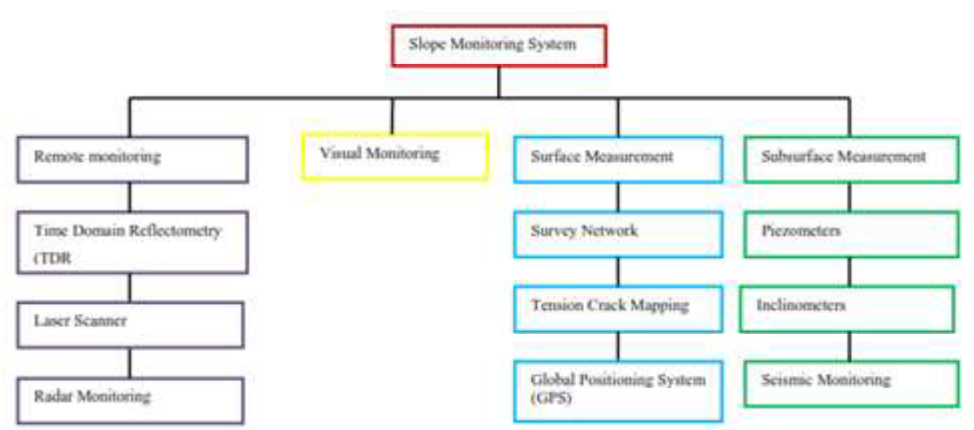

Figure 1: Slope Monitoring System (Little M.J., 2016)

Slope monitoring is generally carried out with conventional methods. In many cases, the data is acquired and analyzed offline and sometimes the data may be inaccurate and insufficient. In conventional methods of slope monitoring, different instruments used directly or indirectly are wireline extensometer, inclinometer, borehole extensometer, tiltmeter, crack meter, etc. In such type of monitoring using conventional instruments, the physical presence is required at the site and the readout units are physically connected to the base units and generally, such monitoring can be done only during the daylight. On the other hand, wireless-based

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instrumentation like Slope Stability Radar (SSR) and Light Detection and Ranging (LiDAR) can monitor slope moments effectively, but these are highly technology-based, will work in daylight only and are very expensive. Slope failure is a significant problem among the various issues in opencast mines. For an early prediction to avoid slope failures and to sense the slope movement, sensors are being used apart from conventional methods to monitor slope stability to get an early warning alert.

METHODS OF SLOPE MONITORING

In the early days, the slope monitoring included inspection of the tension crack along the slope face and mapping the readings of daily reports obtained from the manual inspection. These readings were analyzed regularly to observe the movement of the rock mass. Visual inspections are conducted by routine monitoring of slope, pit, access ways, high wall and low-walls in coal mines and crest (Osasan and Afeni, 2010). Such conventional geotechnical and survey instrumentation will continue to have their place in slope monitoring, and survey options also are used in slope monitoring, complementing the latest monitoring systems (Cawood & Stacey, 2006).
The **conventional slope monitoring systems** are divided into visual inspection, sub-surface, and surface/ remote monitoring methods.

Visual Inspection: Visual slope monitoring inspections are to be done by routine walkover at the pit, access ways, high walls and crest, which are close to potentially dangerous working areas by an Engineer. The Engineer compares the last visit observations with the latest one and records any deleterious slope stability changes that might have occurred (Girard et al., 1998).

Sub-Surface Monitoring Methods: In this method of slope monitoring, different instruments used directly or indirectly are wireline extensometer, inclinometer, borehole extensometer, settlement gauge, tiltmeter, groundwater table gauge, rain gauge, crack gauge, etc. These instruments measure geometrical and physical parameters such as distance changes between points, tilt angles, borehole profiles, stresses and groundwater pressures (Nunoo, et al., 2015).

Surface/Remote Monitoring Methods: Surface measurement methods to measure displacements at discrete points and over large slope areas. The recent and emerging technologies used to monitor the slope continuously are Total Stations (TS), Light Detection and Ranging (LIDAR), Slope Stability Radar (SSR), Global Positioning System (GPS), Time Domain Reflectometry (TDR) and Digital Photogrammetry.

Conventional slope monitoring systems are not capable of having the potentiality to identify the failure mechanisms involved and these old traditional methods (instruments) that exist for this purpose are more costly. These instruments have their drawbacks: more expensive, limited working for daylight hours, human resources required to operate, less accuracy and affected by atmospheric factors like rain, dust, etc. Besides, radar-based slope stability systems also monitor the slope failures, but they demand high costs. Other wired systems are too difficult to set up and manage. This method cannot collect information in time and it cannot meet the requirement of continuous monitoring.

Total Station: A total station (TS) is an electronic/optical instrument used for surveying. It is an electronic transit theodolite integrated with electronic distance measurement (EDM) to measure vertical and horizontal angles, the slope distance from the instrument to a particular point and an onboard computer to collect data and perform triangulation calculations. Electronic Distance Measurement (EDM) is the main component, ranging from 2.7 km to 4.3 km. Vertical and horizontal angles will be measured with this instrument. The measurement accuracy is between 5 mm to 10 mm for every km and the accuracy of angle measurement fluctuates from 2 to 6 seconds. The factors that will influence the accuracy of the total station include atmospheric factors like fog, dust and human mistakes, harm to prism or movement of the survey station and blunders created by instrument or reflector setup errors (Ding et al., 1998).

LiDAR: Light Detection and Ranging (LiDAR) technology using Terrestrial Laser Scanning (TLS) is finding application in mapping the topography of pit faces and slope monitoring. Laser scanning has similarities to radar scanning because of the difference in the signal's wavelength and repeatability of measurement, which is less accurate. However, the LiDAR instrument works with an accuracy up to a centimeter range of up to 2000 m. More extended range scanners (up to 6 km) are also available, but the accuracy drops somewhat. Several survey equipment manufacturers produce laser scanning systems. Because of the lower accuracy than radar, laser scanning is generally not used for slope monitoring (Read and Stacey, 2010).

Slope Stability Radar (SSR): Radar-based system is a state-of-the-art development for monitoring slope movement in opencast mines. It offers sub-millimeter precision and broad area coverage of wall movements through rain, dust, smoke and operates both day and night. The primary purpose of radar is detection and location of the range, altitude, direction, or speed of both moving and fixed targets. The most common types of radars used for monitoring of slope of opencast mines are Synthetic Aperture Radar (SAR), Slope Stability Radar (SSR), Movement and Surveying Radar (MSR) and Slope Monitoring Radar (SMR). However, these systems are highly technology-based and very expensive (Farina and coli, 2013).

Global Positioning System (GPS): GPS is a suitable and potential tool for monitoring opencast slopes, landslides and slopes at civil engineering sites. Due to its low cost, it is effortless to integrate into other technologies like a cell phone. Sometimes, the GPS signals are inaccurate due to obstacles like buildings, trees and extreme atmospheric conditions like geomagnetic storms. Still, the present accuracy of GPS may not be enough to assess critical slopes in mines (Bond et al., 2007).

Time Domain Reflectometry (TDR): Time domain reflectometry is a new approach to monitor slope movement. The technology in the TDR is a coaxial cable and a cable tester. The basic principle of TDR is similar to that of radar. The deformation zone's relative magnitude, displacement rate and location can be determined immediately and accurately. The advantages of TDR are lower cost of installation, installation in deeper hole depths, remote monitoring and immediate determination of deformation. However, it cannot give the direction of movement and the actual amount of movement (Kane et al., 1996; Kane et al., 2007).

Digital Photogrammetry: If an object is photographed from two or more survey points of known relative positions with a known relative orientation, the cameras' relative positions of any identifiable object points can be determined. Aerial photogrammetry and terrestrial photogrammetry are extensively used in determining landslide movement studies. It can be used to monitor a large area, reduce fieldwork time and be affected by atmospheric conditions like dust, haze, etc. (Patikova, 2004).

The purpose of a slope monitoring system is to maintain safe operating practices for the protection of workers and equipment to provide warning of instability to minimize the impact of slope displacement. The deformations are to be continuously detected and monitored so that suitable preventive measures will be adopted. It is necessary to monitor any minor changes in the condition of benches and faces due to cracks in faces, crest loss and changes in water flow. Slope monitoring instruments are more valuable to measure slight movement and cracks that appear on a bench. Mapping and monitoring tension cracks formed along the slopes are traditional and reliable tools for identifying major failures (Vinoth et al., 2016).

Various types of slope monitoring equipment details as shown in Table.1, including their applicability and adaptability conditions in the field.

Table 1: Conventional Methods of Slope Monitoring

Technology	Slope coverage	Update Rate	Range	Deployment	In all weather conditions
Automated Tool Station Networks	Discrete points	Twice/day	2 km	Difficult	No
LIDAR	Broad	~Second	900m	Easy	No
SSR	Broad	~Minutes	850m	Easy	Yes
GPS	Discrete points	~Second	-	Difficult	Yes
TDR	Discrete points	~Second	N.A	Difficult	Yes
Photogrammetry	Broad	Hours	<150	Moderate	No
Micro seismic	Broad	Continuous	300m	Easy	Yes
Inclinometer	Discrete points	Daily	NA	Difficult	Yes
Piezo meters	Discrete points	Daily	N.A	Difficult	Yes
Crack Meters	Discrete points	Daily	N.A	Easy	Yes
OTDR	Discrete points	~Second	N.A	Difficult	Yes
String Potentiometer	Discrete points	~Second	N.A	Moderate	Yes
Shape Accel Array	Discrete points	~Second	N.A	Difficult	Yes

SLOPE MONITORING USING INTERNET OF THINGS (IoT)

The demand of the present situation for a slope monitoring system that can operate in real-time, transmit information to and fro, cost-effective, less complex, low power by considering the requirement of delay in data analysis and wireless, which is possible only with the observation and capturing of the data through the sensor.

Real-time monitoring of slopes is one of the prime necessities for large opencast mines. Wireless Sensor Networks (WSNs) are potent technologies used for real-time monitoring (Chang et al., 2013). WSN refers to a group of spatially dispersed and dedicated sensors for monitoring, recording the physical conditions of the slope movements and organizing the collected data at a central location (Baronti et al., 2007).

The WSN consists of mainly three components: sensor node, sink node or gateway, and processing unit, as shown in Figure 2. Sensor Node is also known as a mote and can gather, process sensory information and communicate with other connected nodes in the network. Sink Node is also known as gateway and it is responsible for receiving the sensor data and retransmitting data to the user or processing unit through the Internet.

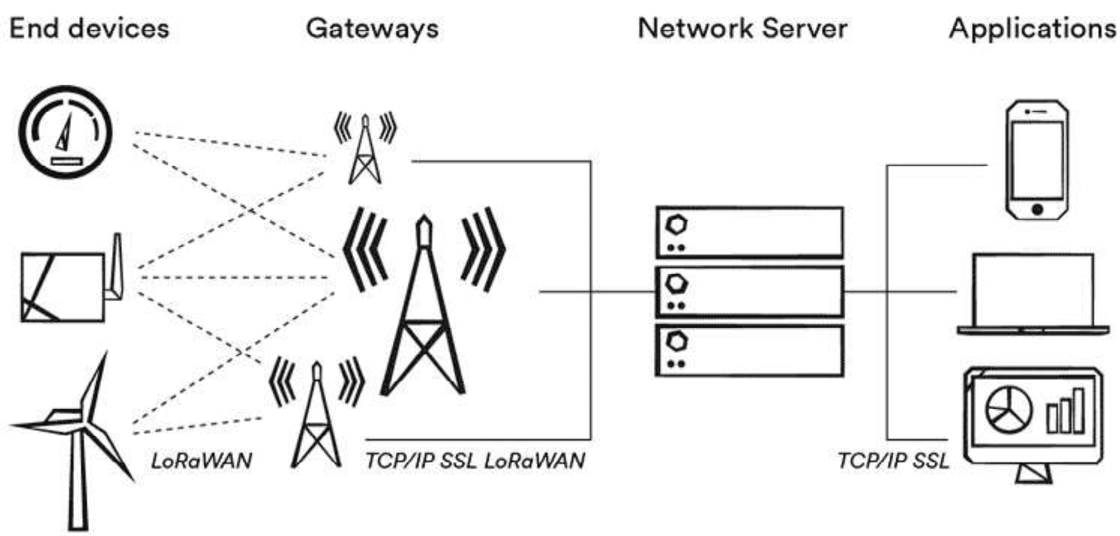

Figure 2. Structure of Wireless Sensor Networks (WSNs)

SLOPE DEFORMATION

Various researchers have monitored slope deformation in different types of formation. Some researchers have suggested the guidelines as shown in Table-2 for permanent displacement (cm) of slopes in opencast mines with specific site conditions for slope monitoring in the form of slope failure state scale (Nenad, et al., 2014).

Table.2: Guidelines for Permanent Displacement (cm) of Slopes

Sl. No	Failure state	Damage	Permanent displacement (cm)
1	Light	Ground shaking is the only effect	D<0.5
2	Moderate	Small cracks likely to form	0.5<D<5
3	Heavy	Major ground failure slope displacement likely	5<D<50
4	Severe	Extreme ground failure large slope displacement	50<D500
5	Catastrophic	Total failure slope failures large distances	D>500

Some other researchers have given critical pit slope velocities as shown in Table- 3(Coetsee, et al., 2020).

Table.3 Classification of Pit Slope Velocities for Planning

Sl. No	Movement class	Average velocity (mm/hr)	Average velocity (mm/day)	Displacement (mm/month)	Comment	Sensitivity to environmental factors, e.g. blasting, rainfall, runoff, etc.
1	Low creep	0.002	<0.05	<1.5	Possibly Stage 1 movements	Very low
2	Significant creep	0.002–0.004	0.05–0.1	1.5–3	Possibly Stage 1 movements	low
3	Definite movement of slope related to shear or displacement on structures	0.004–0.01	0.1–0.25	3–7.5	Could stabilize if strain hardening	Medium
4	Likely to fail sometime in the future	0.01–0.02	0.25–0.5	7.5–15	-	Medium to high
5	High chance of Failure	0.041	1	30	-	Medium to high
6	Pre-failure collapse Movements	<0.041	>1.0	>30	-	High

The above guidelines are given based on limited studies, only a few cases are given abaove and such similar studies are ported elsewhere.

CONCLUSIONS

As India is going for large and deeper surface mining projects it is essential to generate a large database on slope monitoring from different mines under different geo mining conditions to develop a suggested method of slope monitoring if not a standard method. It is the time for the academic institutes, research organization, industry and regulating bodies to come together and work on a generalised slope monitoring system along with trigger action plan to suite locally for all the mines.

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The Indian Mining & Engineering Journal, Vol. 60, No.12 December 2021, pp.21-26
Printed in India, @ IME Publications, ISSN 0019-5944

Instrumentation and Automation is the key to Strata Control in Underground Mines

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ABSTRACT

Strata control is a major concern during underground coal mining and needs special attention. Statistical data shows that strata control related incidents like fall of roof and sides continued to remain the single largest cause of fatal accidents in underground coal mines. Between two stages of underground coal mining, viz. development and depillaring; major threat comes during depillaring operation when pillars are extracted i.e., removing of the natural support. Proper addressing of safety issues and its management during depillaring is a great challenge for coal mining industry. This paper presents the overview of different mining conditions and justifies why instrumentation and automation is the key to strata control.

INTRODUCTION

We know that mining activities means working against nature. In case of coal mining by underground method, we know that coal seam or different layers of rock are formed naturally, i.e., they are stratified in a heterogeneous manner. Hence a small disturbance in their arrangement may lead to strata disturbance and consequently failure. As a matter of fact, we know that Indian mines are operating at shallow depths but to satisfy the increasing demand of coal in different sectors in the upcoming decades, we have to exploit the rich deposits present at higher depths. It can be very well understood from the formula that the load of strata at higher depths of working

$$Load\ at\ a\ perticular\ depth = Depth \times Avg.density\ of\ rock \times Area\ of\ Abutment\ Zone$$

will be tremendously high. In order to prevent the strata from failure we can distribute the load by supporting it. Supports may be of two types: -

(a) Natural Support
(b) Artificial Support

Natural support is the subject to pillar design and Artificial Support is required to maintain the gallery and working places in order. The subject of selection of Artificial support requires a crystal-clear wisdom about where to support and what kind of support to be used, i.e., the support which will suit the Factor of safety of the immediate roof, its RQD, its RMR, etc.

PRESENT STATUS OF UNDERGROUND COAL MINING IN INDIA

Nearly 61% of the total reserve of coal is estimated within 300m depth cover, distributed in all coalfields from Godavari Valley to Upper Assam. The prime quality coking coal of Jharia is available mainly in upper coal horizons while the superior quality non-coking coal of Raniganj is available in lower coal horizons. The quality coal of central India to Maharashtra is also available mainly in seams within this depth range. As a result, all the mines worked such seams extensively, primarily developing on pillars and depillaring with sand stowing. With the unfavourable economics of sand stowing and non-availability of virgin patches for further development, most of the mines have been working- splitting or slicing the pillars, winning roof or floor coals manually or with SDL, conveyor combination.

State	Resource estimate as on 01/01/2007 under depth			Total Reserve (Mt)
	0-300m	300-600m	600-1200m	
A.P	7922	6514	3024	17461
Chhattisgarh	32167	8614	669	41450
Jharkhand	44105	21707	8508	74320
Maharashtra	6789	2698	183	9670
Madhya Pradesh	12902	6727	148	19777
Orissa	44636	16139	1224	61999
West Bengal	12361	10975	4999	28335
Grand Total	155785	80636	18749	253012
%Share	61.24	31.66	7.35	100

STRATA CONTROL THROUGH INSTRUMENTATION AND AUTOMATION

Here we are going to discuss strata assessment in case of a Continuous miner panel. Let us first discuss about the Continuous miner panel having depillaring, we know that before starting any mining operation we go for thorough prospecting job, in which we drill a number of boreholes at specified distances. Based on these data we come across the layer's lithology, points within the strata where there is stress concentration (which in due

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course of time may affect the working) and on the basis of above data we also calculate the RQD, RMR, Load of the super incumbent strata, etc. Finally, we go for most suited pillar design, i.e., whether we should have a square pillar or a rectangular pillar.

Now after selecting the size of pillar, we go for the most suited size of galleries (so that the CM can operate effectively), then we calculate the cut-out distance and number of passes in which the gallery is to be developed. After the development stage is over, we go for depillaring operation (say here we are following straight line of extraction).

But before getting into the discussion of depillaring operations let us first discuss why are we going to monitor the strata through instrumentation: -

- We know that, unlike development, depillaring involves a very large area of exposure. So, if we are not going to monitor the strata then it will be just as throwing arrows at the target without aiming it.
- Secondly, there may exist surface features or residential area above the working. Therefore, working without proper knowledge about the effects of depillaring may result to loss of lives due to subsidence.
- Thirdly, even if there may not be any subsidence but the miners can be trapped at the place of working due to sudden roof fall and may result to loss of men and material.
- There may exist a few stresses concentration points in the strata which may not have encountered with the boreholes during our prospecting work. And during the working it may superimpose with the abutment pressure zone, finally resulting in the collapse of the roof.
- History is the evidence that rib pillars have a very important role in strata control. Hence if we are not knowing that what kind of strata exists above the working or what is the impact of the load of immediate roof on the working then we may choose a wrong dimension of ribs, which can again result in strata failure.

Let us discuss about the above points in brief:-

1. Increased area of Exposure

- As we know during development, we expose only a small area, but during depillaring the exposed area becomes very large and strata movement effects are observed up to greater height. Therefore, the load on the sides of the undepillared pillars becomes more. Hence it is very much required to go for scientific study through instrumentation and based on the data obtained, support the standing pillars (i.e., as per law at least two pillars ahead of the pillar being extracted should be supported properly).

2. Subsidence

- As already discussed, the area of exposure during depillaring is very high, and so is the abutment zone. Therefore, it is also very important to calculate the influence of the depillaring operation on the surface (i.e., the angle of draw, critical area, area of subsidence basin, etc)

3. Cut-out Distance

- Cut-out Distance is one of the most important factors which is to be calculated precisely before going for development and depillaring operations. Cut-out distance is defined as the distance up to which a continuous miner can cut in one go. It mainly depends upon the span of gallery and the nature of overlying strata.
- COD is calculated by trial and error in the field but numerical models based on a safe and stable roof sagging of 5mm are used to study the COD with varying nature of roof and floor.
- It can be calculated by the formula:

$$COD = 14.61 + 1.98E - 2.12W$$

Where:-

COD- Cut-out Distance
E- Elastic modulus of immediate roof (Gpa)
W- Width of gallery(m)

4. Dimension of Rib pillars

- We know that depending upon the method of winning coal pillars, the ribs are left, but these pillars are of irregular shape and it is very important to decide the dimensions of the ribs because they act as a natural support which prevents the burial of the CM due to fall of the hanging roof that may be caused by the Front Abutment pressure originated due to depillaring operation.

The size of ribs can be decided by the following formula: -

$$S = 0.52(H^{0.74})(R^{0.23})\ m^2$$

Where: -

S- Competent size of rib/snook (m^2)
H- Depth of cover (m)
R- CMRI-RMR

5. Design of RBBL

- Rib/snook formed alone cannot act against the goaf encroachment as it needs the support of breaker/ hinge line to break the bridging beam/ cantilever roof. Function of the breaker line is to enhance the strength of rib/snook against caving roof and prevent the encroachment inside the working area. Pillar/fender at the goaf edge experience fracturing of the sides (spalling) which leads to shifting of position of RBBLS by 0.5-2.0m towards the out-bye side depending upon the extent of spalling. After shifting the position, the efficiency of RBBLS is increased.

Based on field studies and numerical simulation observations, relationships are developed for the design of RBBLS at three different locations around the goaf edge:

At the very location of goaf edge (0 m out-bye from goaf edge) :-

$$RLH = 11.67(H^{0.58})(R^{-1.14})$$

For 1m out-bye from goaf edge:-

$$RLH = 66.32\,(H^{0.31})(R^{-1.26})$$

For 2m out-bye from goaf edge:-

$$RLH = 115.22\,(H^{0.13})(R^{-1.30})$$

6. Strengthening the pillars

- Based on stress mapping of the pillar we also require to support the sides of the pillar so that there is not chance of pillar spalling into the working or there is no chance of crushing or burst of pillars.

7. Relationship between roof sagging limit and roof fall during MD

- Based on the studies conducted by CIMFR (2019) by multivariate analysis of the roof sagging recorded from numerical models with variations in thickness and elastic modules of immediate roof, size of remnants of pillars and distance from goaf edge. By this analysis, the limiting roof sagging value can be calculated as:

$$C = 26.63 - 0.12D - 1.12E - 0.14A + 0.23T,$$

Where;

C- Roof sagging observed in model (mm)
D- Goaf edge distance (m)
E- Elastic module of immediate roof (Gpa)
A-Size of remnants left in or around goaf edge (m^2)
T- immediate roof thickness (m)

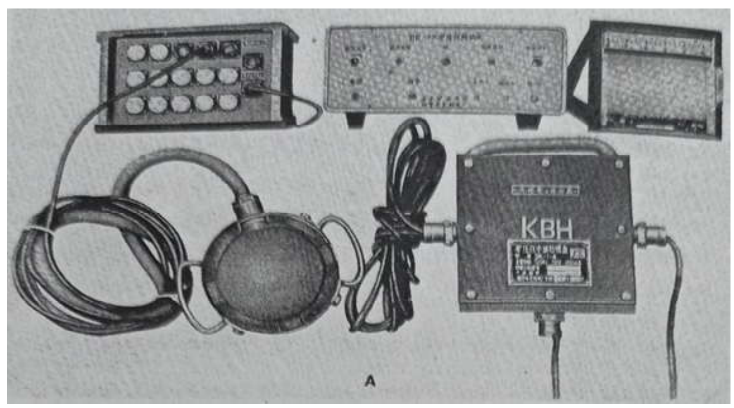
Taking into account the anisotropic & heterogenous nature of rock, a safety factor of 2 is taken for fixation of the THLV for a warning limit (s) in AWTT:- s= 0.5C

Therefore, to achieve these goals we need strata control monitoring through instrumentation and automation.
Let us now discuss different strata monitoring devices generally used in our mines.

1. Load Cell

- Load cells are of many types, let us discuss vibrating wire load cell. When the load P is applied on the pressure membrane, it deforms and pulls the supporting rods apart. The length of the wire mounted between the rods increases and consequently its resonant frequency changes.

When the magnetic coil in the exciter is excited, a wave is generated, which in turn causes the wire to vibrate in its resonating frequency. The signal is then picked up by the receiver and displayed on a readout meter and the load is displayed directly. The maximum capacity of the vibrating wire load cell is 50 tons. It can be used to measure prop loads or canopy loads of the powered support

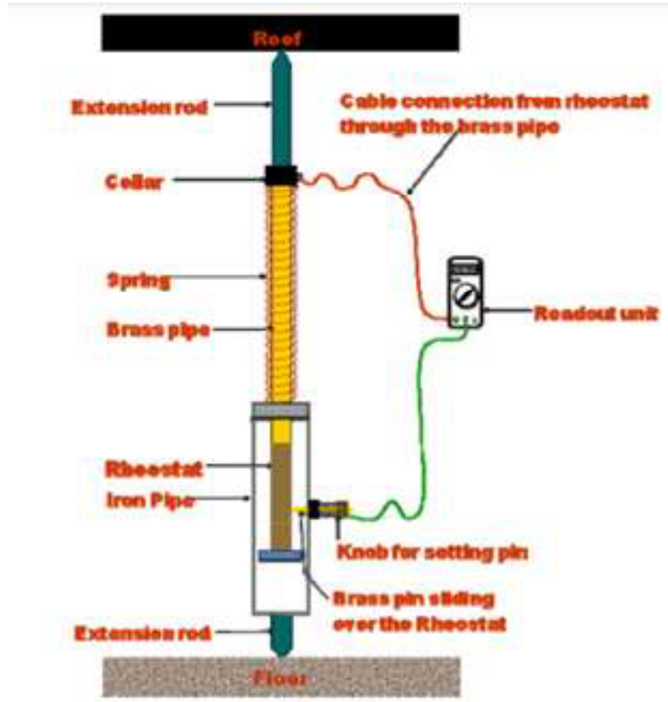


A vibrating wire Load cell

2. Extensometer

- Extensometers may be manual or self-recording type. Let us discuss the tape extensometer. It consists of a steel tape, a compression spring, a dial gauge, and a tensioning screw. During installation, the tape is extended to the nearest perforated hole and locked up there. The tape end is hooked to the roof anchor and the bottom hook of extensometer is attached to the floor anchor. The tensioning screw is turned to adjust the applied tension. The correct tension is obtained when the marker lines match in the correct tension indicator. At this time, the dial gauge reads the difference between two consecutive readings and this is the convergence between the two anchors.

Tape extensometer



Remote convergence indicator

3. Instrumented roof bolts

- For monitoring of load distribution along the full column grouted roof bolts, “instrumented roof bolts” are used, in which strain gauges are fixed along the length of roof/cable bolts at different intervals. These instruments are proposed to be installed at the locations of breaker line supports so that these may provide an idea of support performance during the depillaring operation.

4. Automatic warning tell tale

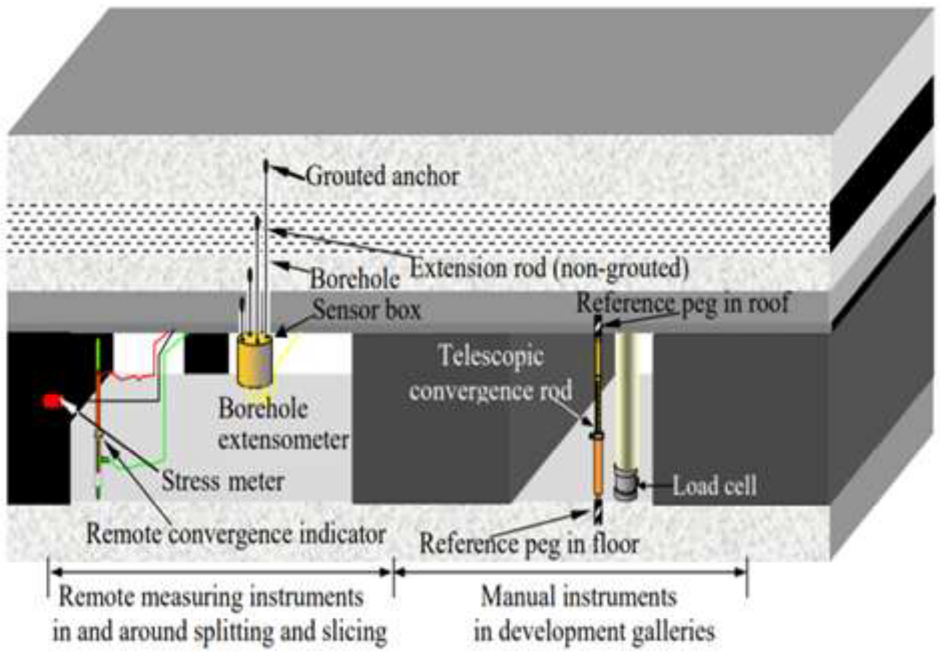
- We know that roof sagging is another very important parameter which should be determined precisely. Hence to detect the amount of roof sagging we use tell-tale devices

They may be different types but automatic tell tales are the most common one. In order to mount the instrument in the roof, we drill a hole and fix it. Now the tell-tale is fixed at a pre-set value, as soon as the roof sags to this limit an audio-visual alarm starts alarming its surrounding. Therefore, enough time is obtained to remove men and machinery from that point and take necessary preventive steps.

5. Stress meter

- Side falls and coal bumps are also a new concern for the underground mining world. Hence, to monitor the stress in the coal pillars it is important to choose selective points on the pillar and have proper stress measurement. Finally take necessary steps to prevent spalling of sides or bumps.

Stress meter

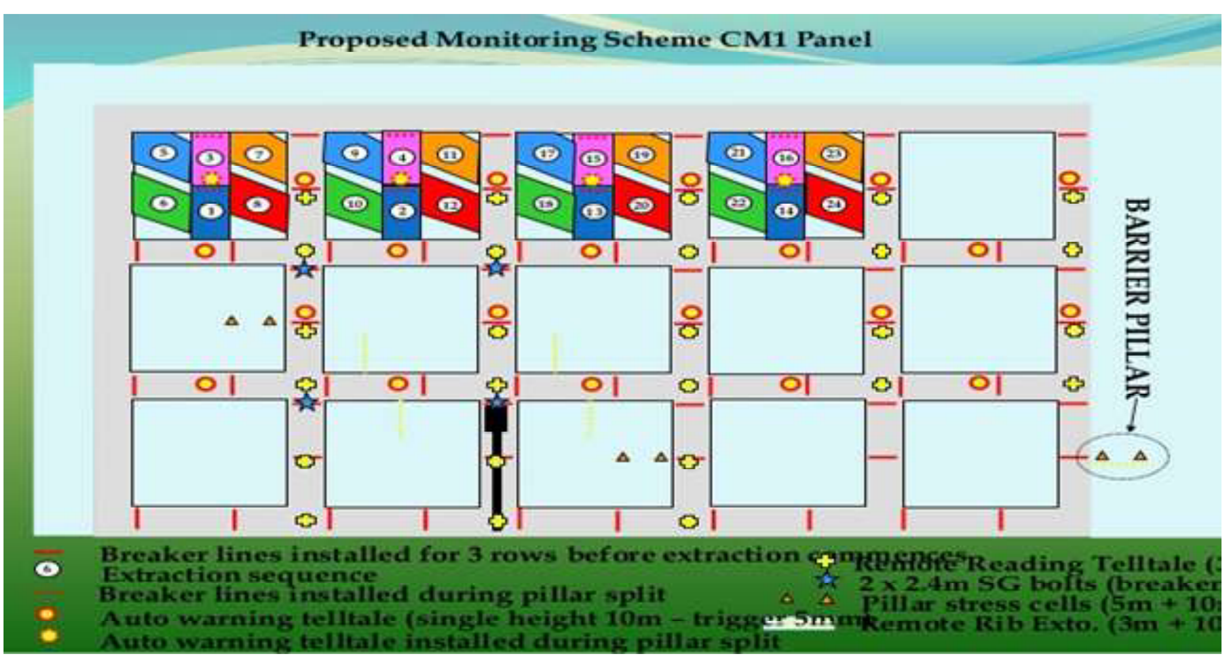


The figure above shows a typical sectional view of placement of placement of remote and manual instruments for underground strata movement monitoring.

6. Roof Bolt Based Breaker line support(RBBLS)

- RBBLS are the mounting of roof bolts mainly near goaf edges so as to prevent the goaf to puncture into the working. In order to fix the roof bolts first we go for stress mapping, in which we put a stress measuring device into the hole drilled in the roof. The devices note us with the point unto which stress is concentrated. Hence, we use a bolt higher than the stress point (2.5m in general) and strata is controlled effectively.

Figure given below shows a stratum monitoring scheme for a Continuous Miner Panel.



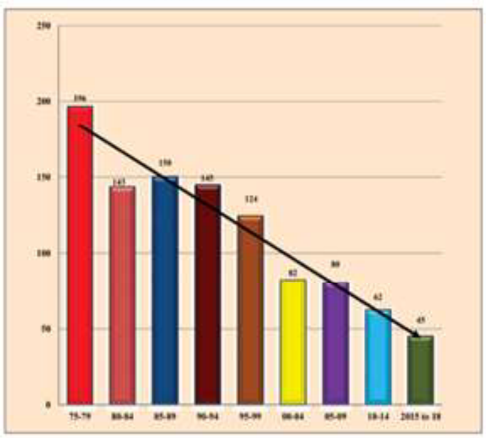
SOME STATISTICAL STUDIES

Here are some statistical studies of Coal India Limited which shows how strata control in the years has reduced its accident rates.

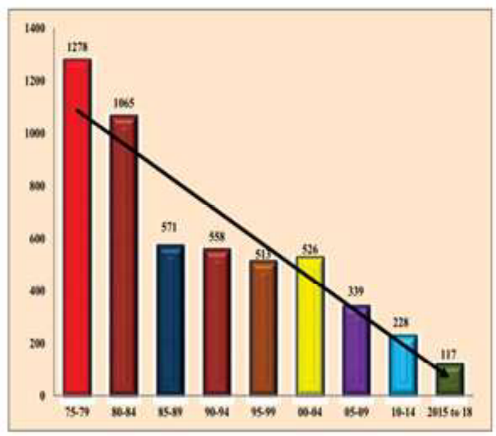
Comparative Accidents Statistics of CIL of 5 Yearly Average since 1975

Time frame	Av. Fatal Accidents		Av. Serious Accidents		Av. Fatality Rate		Av. Serious Injury Rate	
	Accident	Fatalities	Accident	Injuries	Per Mill. Te	Per 3 Lac Manshifts	Per Mill. Te	Per 3 Lac Manshifts
1975-79	157	196	1224	1278	2.18	0.44	14.24	2.89
1980-84	122	143	1018	1065	1.29	0.30	9.75	2.26
1985-89	133	150	550	571	0.98	0.30	3.70	1.15
1990-94	120	145	525	558	0.694	0.30	2.70	1.19
1995-99	98	124	481	513	0.50	0.29	2.06	1.14
2000-04	68	82	499	526	0.28	0.22	1.80	1.47
2005-09	60	80	328	339	0.22	0.25	0.92	1.04
2010-14	56	62	219	228	0.138	0.23	0.49	0.80
2015-18#	**36**	**45**	**112**	**117**	**0.08**	**0.19**	**0.21**	**0.49**

Trend of 5 Yearly Average Fatalities in CIL since 1975



Trend of 5 Yearly Average of Serious Injuries since 1975



CONCLUSION

Strata control especially in mechanized mines and also in mines at comparatively higher depths poses a challenge, but it is the only way for smooth and effectively carry out mining activity in our U/G mines. Through this paper it may be seen that for effective strata control it requires to determine the Cut-out distance, Size of ribs/ snooks, parameters which can affect the surface through subsidence (like angle of draw, etc), design of Goaf edge support, etc. which are applicable for Indian geo-mining condition. The determination of the above parameters is a complex job and it can only and only be carried out with the help of instrumentation and automation so that work in the mines can be done safely.

Looking at the statistical data, it is clearly depicted that strata control has played a vital role in controlling the accident rate. But we have not yet achieved the Zero death rate in our mines. Hence to achieve this goal, INSTRUMENTATION AND AUTOMATION IS THE KEY to know the strata conditions and to control it properly.

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The Indian Mining & Engineering Journal, Vol. 60, No.12 December 2021, pp.27-29
Printed in India, @ IME Publications, ISSN 0019-5944

Need for Changing Status of Underground Coal Mining in India

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ABSTRACT

Coal is one of the most essential resource of our country it is widely used for power generation and as a raw material in the industries. India has the fourth largest reserve of coal in the world and is the third largest coal producer in the world. However the country has to import coal from other countries to meet the demand of coal in the market. In India coal is mined by both underground and opencast method of coal mining. However the major production of coal comes from opencast mines in India the reason behind this is that around 45% of our reserve is under shallow depth of cover and because of less production cost open cast mining method is widely used. Production from underground mines in India has remained stagnant over the period of time and introduction of new art, mass production technologies is extremely limited. In India production from opencast mines is nearly 94% and that from underground mines is limited to 6%. Coal production from underground coal mines is declining and several underground mines are closed every year due to lack of introduction of mass production technologies and by conventional method of mining the cost of production of coal is high and recovery is less. As our 45% of coal reserve is under shallow depth of cover and due to increasing demand of coal and large scale mechanization ,the reserve under shallow depth of cover will be depleted in near future. Opencast method of coal mining has major environmental impacts and land acquisition possess serious challenges to operate a opencast mines. growing social awareness about environment is bridging the gap between cost of production by opencast and underground method. While by underground method of coal mining there are less environmental problems and the better quality of coal from the greater depth can be extracted by introducing mass production technologies in the underground coal mines.

With this background, this paper has been prepared on the basis of data collected from reports, research papers and articles. Here we have made an attempt to understand the need to change status of underground coal mining in India

INTRODUCTION

Coal, as a conventional source of energy, plays a very vital role in the overall economic development of a country. Coal plays a critical role in our economy, as about 71% of power generated in India is fossil fuel based out of which contribution of coal alone is about 60%. Coal based power generation is the cheapest form of energy and India has an abundant source of coal. Therefore coal is expected to continue as the main source of energy in our country at least for next few decades.the need of energy in India is growing at a CAGR (cumulative annual growth rate) of about 4.5% every year, it shows that demand of coal in the Indian market is likely to increase due to rising growth of population, industry and other infrastructures. Major coal consumers in India are thermal power plants, cement industry, textile industry, steel, aluminium and other small industries. In India coal is also used as a domestic fuel. The importance of coal is not only confined to energy sector, it also plays a vital role in overall economic development. India has fourth largest reserve of coal in the world (111.1 billion metric tons) and third largest producer of coal after china and USA. Though gap between demand and supply is so vast that India has to import coal from other countries to meet demands. India has long standing history of commercial coal production, start of commercial coal mining started back in 1774 in raniganj coalfields. raniganj and jharia coalfields started growing as major coal producing areas. Production rate in India before independence attained a level of 45 MT. growth of coal mining industry accelerated after India became independent in 1947. With rapid growth of industrialization demand of coal was increasing but coal production was unable to meet nation demand. Coal mines were nationalized between period of 1971-1973 and during nationalization period coal production was 68 MT (52 MT from underground mines and 16MT from opencast mines)

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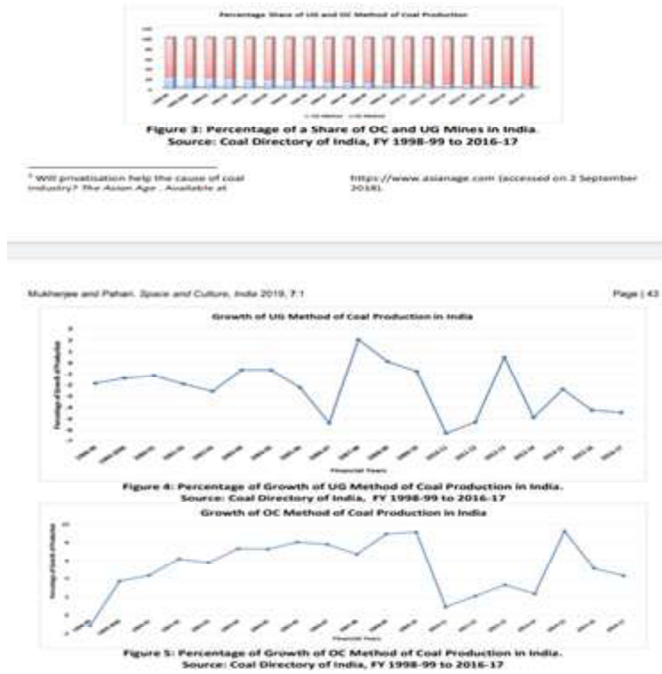
PRESENT STATUS OF COAL MINING IN INDIA

Coal production in India during year 2020-2021 was 716.08MT out of which production of coal from underground mines is 31.22 MT and from opencast mines coal production is 684.862 MT still India needed to import 214.995 MT of coal from other developed nations in order to meet the demand of coal in the market. In India coal is being extracted by both opencast and underground method of mining, but opencast method of mining is more dominant as compared to underground method. Currently India has 476 mines in operation among which 236 are underground mines, 215 are opencast mines and 25 mines are mixed in nature. Opencast mines are less in numbers as compared to underground mines but production from opencast mines is nearly 95% of total coal production this shows that production from underground coal mines remained stagnant post-nationalization. Opencast method of coal mining is dominating in India as majority of our reserve is under shallow depth of cover, high rate of production, safety concerns and high scope of applying modern technologies in the mines. The decision whether to go for opencast or underground mines largely depends upon stripping ratio. In opencast mines a major capital investment is associated with removal of overburden and if stripping ratio is higher more money will be spent to remove overburden and it may make mining uneconomical. Stripping ratio totally depends upon the depth at which coal is lying from the surface, if the coal seam is at greater depth then underground method of mining should be adopted. In India production of coal from underground mines has been limited it only contributes 5-6% of total coal production in India whereas, in other developed countries underground method of coal mining is dominating over opencast method and contributes more than 60% of total coal production. In India 90% of total underground coal production is produced by Board and Pillar method and rest is extracted by longwall method. The major drawback of board and pillar method is less recovery of coal as large amount of coal is locked in barrier pillars and ribs. Board and pillar is a cyclic method in which ore is exploited by drilling and blasting. Whereas in longwall method recovery of coal is high as it is a continuous method of mining but cost required to install longwall equipment set is very high which is not feasible for small size underground mines.



NEED FOR CHANGING STATUS OF UNDERGROUND COAL MINING IN INDIA

Though opencast mining method is more economical than underground mining method, opencast coal mines have a significant impact on the environment. In opencast mines the overburden removed to expose the coal seam is piled at suitable place near mines which forms overburden dumps, spoil tips and other landforms which bring changes in topography of that area. Opencast mines are responsible for land degradation and due to removal of top soil associated ecosystem, forest, displaced people, destruction of agricultural land, discharge of wastewater, are the main adverse impact on the environment due to opencast mining. Land acquisition is also one of the major challenges faced in opencast mining as it is practiced over a large area because it requires land for parking of HEMM, dumping of overburden, storing of coal, official buildings of mines, workshops. Mine water from opencast mines generally contains high level of dissolved solids, metals, oil, grease which requires treatment to prevent water pollution and this requires extra cost. Dust generation is more prevalent in opencast mines due to movement of heavy trucks and blasting, dust particles also reduces visibility around the mines area and can lead to lung diseases in person working in mines. These environmental problems caused by opencast mining are required to be dealt efficiently to protect the surrounding areas, animals and persons living therein, this requires extra cost which will lead to increase in production cost per ton of coal mined and somewhere reach to a point where opencast method of mining will become uneconomical and growing social awareness about environment is bridging gap between cost of production by opencast and underground mining method. Furthermore as the demand of coal is increasing and to meet the demand production of coal from opencast mines is increased with introduction of HEMM and as a result of that our coal reserve under shallow depth of cover will be exhausted very soon in the near future. To maintain a balance between demand and supply we have to extract coal from the deeper deposit which is possible by underground method of mining in combination with mass production technologies because at greater depth underground mining method is more suitable and economically feasible. To overcome the environmental related problems associated with opencast mining and to extract good quality of coal from the deeper deposit we need to extract the coal by underground method of coal mining with mass production technologies. One of the biggest reasons for less production from underground coal mines is lagging in introduction of mass production technologies in underground coal mines and to bridge gap between demand and supply it is essential to boost up production from underground mines.

In case of underground method of coal mining top soil is not damaged, generation of dust is less, land acquisition is easy as underground mining is practiced over a smaller area as compared to opencast mining, as a result of that environmental impacts by opencast mining can be minimized and good quality of coal from greater depth with high recovery can be achieved. The coal present under shallow depth of cover in India is of poor quality and their ash content is high. On average power plant consumes 0.70kg of coal to generate 1kwh of power in India but as we go deeper, quality of coal specially, non-coking coal improves with depth. With improved quality of coal efficiency to generate heat energy per unit volume of coal improves, it also minimizes the formation of greenhouse gases which are responsible for global warming and climate change. With the introduction of mass production technologies in underground mines high rate of productivity, good quality coal, less environmental problems, gap between demand and supply can be bridged.

CONCLUSION

Mining of coal in india is being practiced over the colonial period and after independence the production from underground coal mines remained limited due to lack of infrastructure and technological constraints. In India opencast mining method is dominant as to meet the demands more coal is being extracted from opencast mines with introduction of HEMM, but opencast mines have huge environmental implications and growing awareness among people about environment is the biggest reason of shifting to underground mines. With current pace of production coal reserve under shallow depth will be depleted in near future and to meet the requirements of coal as energy source we need to extract coal from the greater depth which is possible by introduction of mass production technologies in underground mines in India. The process towards implementation of improved underground mining with mass production technologies has already been initiated, Currently in India nearly 30-35 mines are being operated with continuous miner technology and giving promising results with daily method of working is adopted which is the safest and most productive method of mining. Indian coal mining industry is on its way for an ambitious 1 billion ton of coal production by 2023-2024. It is expected that underground coal mines will have a significant share towards its ambitious goal. To reduce the environmental problems caused by opencast mining and to achieve good quality of coal from greater depths we need to switch to underground method of mining. As the road map for underground coal mining has been laid, the share of underground coal production is expected to grow about 25% of the total 1 billion ton target by this period.

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The Indian Mining & Engineering Journal, Vol. 60, No.12 December 2021, pp.30-33
Printed in India, @ IME Publications, ISSN 0019-5944

Blast-Free Mining Technology- A Case Study

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INTRODUCTION

Economy of mine is dependent upon technology and innovation, but factors which are basis of economy are more dependent on Smooth implementation of such technology, In Indian Mining context, there are various legal and statuary bodies (IBM, DGMS, State DMG, MOEF & CC) those take care of the various norms and standard to be maintained based on Scientific study depending time to time. As Standards are laid down, some new technology or innovation in technology is need to be introduce.

There were various cases in Rajasthan, Karnataka, Odisha etc. where mining operation is need to be suspended for years or many are bounded with legal norms and standards. Specially in, Chittorgarh, Rajasthan various small scale and Major integrated Projects has been suffering due to restriction in drilling and blasting technology, obviously which is cost-efficient one. In 2008, Some local activists and people of the area, filed a petition stating that due to presence of Mining activity and adoption of Drilling and blasting in and around the Ancient Monument- Chittor Fort causing harm to these monuments and reducing its age. Various study like Blast Vibration, Seismography under guidance of CIMFR, IBM and State DMG has been carried out but Results were positive w.r.t. DGMS blast vibration Standards, which lead supreme Court to come up with the conclusion that within 10km periphery of the fort, no drilling blasting technology can be adopted in mining area, Since Major Small Stone quarry situated at Manpura, which is 550m far from fort periphery had to stop adoption of Drilling & Blasting Technology. Number of challenges and constraints has been raise to carry-out Mining Activity in that area. But Challenges and constraints are well to introduce something new. And Journey of Blast Free Mining Technology in the Area found its way to set-up a new mile stone in mining Sector. Various trial steps have been taken with Surface Miner, Terminator, Rock Breaker (scaling from Small Size to Larger one) by various firms and organization.

In Mining Terms, it is going to be fight within In-situ rock Strength and Mechanical Stress to have good Fragmentation. For the same, Various Geological Study, Physico-mechnical of Rock Properties Study is carried out. The major factors which were responsible for successful applicability of Blast-Free Technology are:

GEOLOGY AND ROCK PROPERTIES

Since Limestone encountering in the area is belonging to Lower Vindhayan Super Group.Limestone occurs in form of three narrow limbs separated by shale bands. Limestone is fine grained, light greyish, pale red, Pink and dark grey in colour. The limestoneoccurs as syncline and slant and introduce into each other limbs. CCI has carried out investigations in this area. The analysis shows variations in the grade with colour and silica content. The CaO content ranges 42-48%, Silica 5-25% and MgO about 1-5%.High variation in Silica Content results in variation strength of rock/limestone in the region.

Various studies result dictates Compressive strength of Limestone in the region 110-140 MPa. Whereas upper shale 67-80MPa. Since regions has direct outcrops of Shale – Limestone-Shale(Interband)- Limestone. Average thickness of Shale ranges 9-12m. below which slanted Limestone up to average 50m. is encountering. As per trial studies, Surface Miner were performing satisfactory in Upper-Shale Band which is obviously need to be excavated for exposing limestone. Whereas performance of Surface Miner in Limestone goes drastically down due to increasing strength but Performance enhances some areas due to geological cracks.

Due to performance abnormality, Introduction of Terminator finds its way for Limestone. Which Performed wellwith high impact energy which results in tear-wear of tool and its parts and results in high maintenance cost. Again an emerging technology like Rock Breakers and Rock Splitter are introduced. Technology selection and its implementation has always a different methodology of its efficient operation. Scenario of Trial has shown that for fulfilling production demand Rock Breaker and Rock Splitter along With X-Centric\Vertical Ripper is best combination in the region.

ROCK BREAKER

A Rock breaker is a powerful percussion hammer fitted to an excavator for demolishing hard (rock or concrete)

**Mining Engineer, JK Cement, Panna*

structures. It is powered by an auxiliary hydraulic system from the excavator, which is fitted with a foot-operated valve for this purpose. There is variety of Rock Breaker Available in market. The Majority of primary breakers are Epiroc HB-10000, Indico -10000, Small Size Breakers from Rammer. With these combinations of all breakers the primary breaking is being done to cater the demand of integrated Cement Plant along with certain challenges like Productivity(TPH), Fuel Consumption, challenges in Haul Road Maintenance, Quality Assurance during Scheduling of Breakers at Site Etc (Figure 1 (a) and (b)).

In Cement industry, some years ago Quality of Limestone was calculated in terms of Total Carbonates but now a days Lime Saturation Factor (i.e. LSF) based on 5radicals i.e. CaO, Al_2o_3, MgO, Sio_2, Fe_2o_3 is define Quality Limestone. For Perfect Clinker Formation, Limestone Quality of 106-107 LSF is required. Continuous Efforts made and Various Benches of Varying quality of 3-4m has been design along with Pre-quality prediction from Physical Sampling and Block Modelling with Datamine Software, Scheduling of Breaker Position with quality concern is being practice. Efficient operation is in practice with continuous monitoring of breaker operation at site and Machine with breaker attachment. Productivity of Breaker is primary dependent upon various Geological trend of Limestone deposit, Operation Skill of Breaker, Supervision of Breaker Deployment Site.

Figure: 1 a Showing working and 1 b showing working of Rock Breakers

HYDRAULIC SPLITTERS

In some of the Indian limestone mines in M.P. & Rajasthan, blasting operations were banned due to problems associated with blasting vibration and fly rocks and their impact of historical structures and closeness to villages. After studying the techno-economics of the use of surface miners, hydraulic rock breakers, splitters were also used on trial basis.

Hydraulic splitting technique was designed and introduced based on the tensile strength concept, which can be explained by the fact that the compressive strength in rocks is much greater than the tensile strength. Tensile strength is the stress at which a rock specimen fails under uniaxial tension. Today, based on the principle of the work, orientation, and type of the generated force, several hydraulic splitters have been manufactured and are in use.

A hydraulic splitting machine comprises of two parts: a splitter and a power station. The splitter consists of a power cylinder with multiple pistons or wedges (based on a machine model) that apply pressure into a drilled hole, pushing the rock toward the free face. The power station consists of a hydraulic pump, hydraulic pipe, and control panel.

A 100 mm dia. Blast hole is drilled to a depth of 1–3m; then, the power cylinder or wedge is inserted into the drilled hole. Water is continuously poured into the hole so as to ensure smooth movement and reduce temperature. A pressure up to 43 MPa can be generated through pistons or feathers to induce a stress that pushes the rock toward the free-face side (Figures 2). One study has reported that Hydraulic splitting machines can generate pressure of up to 43 MPa to induce stresses in rocks. In India, the hydraulic splitting method was successfully tested on trial basis at Sag mania Limestone mine of Satna Cement Works and Chittorgarh Limestone Mines (both of M/s Birla Corporation Ltd).

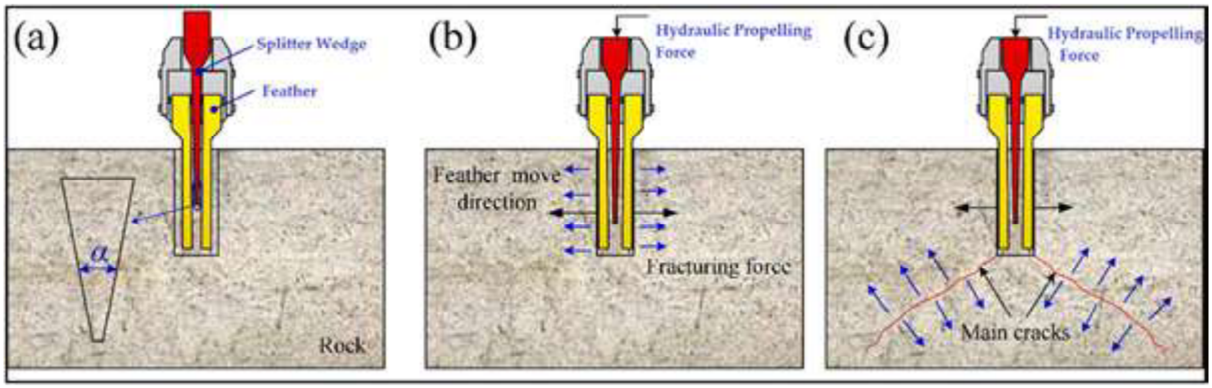

Figure 2: Rock breakage process using the hydraulic splitting method: (a) hydraulic splitter insertion, (b) hydraulic propelling force, and (c) induced fracture

X-CENTRIC/VERTICAL RIPPER

Devpur limestone mine of M/s Orient Cement Limestone Mine had used this system for ensuring crack free highwall on the benches for maintaining safe slopes. Very recently, some MCL mines like Kaniha OCP faced problem in OB benches where blasting was stopped. To ensure smooth production of OB, rippers were considered. X-centric/ vertical ripper attachment attached to hydraulic excavator was adopted on trial basis (Roul and Pujari, 2021). X-centric/vertical ripper attachment mounted on excavators broke the OB layer and the broken material was handled by shovel-dumper system.

DESCRIPTION OF THE RIPPER ATTACHMENT

The X-centric ripper (Fig. 4), is a hydraulic excavator attachment used for mass extraction of rock in mining. In general practice, ripper is fixed in a back hoe shovel replacing its bucket. It is a safe and easy alternative to drilling and blasting. The tooth of the ripper with the help of the vibration generated by the ripper penetrates the surface/ rock and breaks the rocks into pieces up to a depth of 1.3 metres in one go. The operator digs the rock at a spacing of 30cms one after another and the earmarked area is excavated which is loaded into dumpers for exposure of coal seams. It is designed for high volume production in quarries with low noise and high performance. Figure 4: Shows X-Centric Ripper & Its technical Specification.

MAX BRIO BR55 Model Vertical Ripper

Technical Specification
Height (mm): 3018
Length (mm): 1486
Width (mm): 928
Tooth (mm): 575
Applicable Weight (Tons): 43-55
Setting Pressure (Psi): 3556
Oil Flow (LPM): 290-310
Air Pressure (Bar): 3
Main Body Weight (Kg): 4360

CONCLUSION

The problems associated with blasting had resulted in stoppage of mining operations in many mines in India. To overcome this and to recover the precious ore, blast free mode is the only solution. As a result of which today India has the largest number of surface miners working in coal mines for coal production. Adoption of hydraulic splitters, X-centric rippers are gaining popularity due to their ease of operation and several other technical superiorities.

ACKNOWLEDGEMENT

Thanks are due to my erstwhile colleagues at Chittorgarh Cement Limestone mines of M/s Birla Corporation Ltd, and guidance from Prof G.K.Pradhan of AKS University, Satna, Sri Suraj Gupta, VP(Mines) of Birla Corp. and Sri Chandrakant Dhandale, Head(Mines)-JK cement, Panna.

The views expressed in the paper are of the authors and necessarily of the organisation of his affiliation.

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Transport of Paste Fill as Stowing Material in Underground Metal Mines

G. P Patil*

ABSTRACT

The scientist, engineers have developed some technologies to use alternative back filling materials in place of sand. The scarcity of land for keeping the tailings in the tailings dam, availability of water, safety of the dams necessitated using new technologies. Paste filling is the latest technology currently adopted globally. The conventional and currently adopted system of backfilling is to back fill the underground stopes by mill tailings. Use of paste fill as a back fill material has several advantages and is gaining popularity in Indian metal mines also. An attempt has been made in this paper to describe paste fill technology and also methods adopted to transport this into underground stopes.

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The Indian Mining & Engineering Journal, Vol. 60, No.12 December 2021, pp.34-38
Printed in India, @ IME Publications, ISSN 0019-5944

Quantifying the Performance of Resin Bolts and comparison of its efficacies vis-à-vis Mines safety

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ABSTRACT

This article introduces the significance of features of Rock bolts and its efficacy in providing reinforcement and strata strength in underground rock bolting. The items discussed include underground loading conditions, selection of rock bolt types, Testing procedure to assess the efficacy of Bolts during installation and compatibility between support elements basis the study conducted at Baroi Mines at Zawar Mala of M/s Hindustan Zinc Limited. The article touches upon that not only the material quality of the Rock bolt but also its design in terms of paddling, threading, shear pin introduction leads to higher reinforcement and thus the increase in safety aspects.

INTRODUCTION

Ground Support for underground mines is a comprehensive treatment of rock reinforcement and surface support technology for the benefit of underground-mine practitioners. "Rock Bolts" is the most widely used support element in support systems in underground mines and civil tunnels. Rock bolts are a type of drilled soil nail or anchor used when the ground to be stabilized consists mostly of rock materials. These are widely used for rock reinforcement in civil and mining engineering for a long period. Bolts function as hanging elements to fasten loose blocks to stable formation behind. Thus, it is important for bolts to be strong enough to sustain the dead weight of the unstable blocks. The most common type of bolt used in a mine is a Grout Anchored Rock Bolt which is made of a threaded bar of steel, or rebar. Once drilling is done and this steel bolt is inserted, cement grout or resin grout can be used as the grouting agent. A bearing plate is used on the fully grouted rock bolt on the surrounding rock face to create tension and stabilize the rock.

As rock bolt plays an integral part in mining operations, the design of rock bolt becomes critical and thus Minova has over the years developed rock bolts to cater to different needs of the mines. One such type of Bolt is Minova "SecuraTM Bolt" which consist of several unique features to work in all type of strata. Attempts are made in this article to study compare and summarize the advantages of "SecuraTM Bolt" over other locally manufactured bolts in India. The study was conducted at Baroi Mines in Zawar Group of Mines of Hindustan Zinc Limited.

1. GM Zawarmala Mines (HZL) BE Mining, Fcc (UR)
2. GM MRPL (India), B.Tech. Mining, PGDBA (Strategy and Finance)
3. Head Sales MRPL (India), BE Mining, PGDBA, FCC (R)
4. Head Geotech Baroi-Zawarmala, BE Mining
5. Key Accounts Lead MRPL (India), ME and B.Tech Mining

ABOUT MINES, GEOLOGY AND ITS SSR (SYSTAMATIC SUPPORT RULE)

About Mines

The Zawar group of mines, HZL is located 40 km southeast of Udaipur, Rajasthan State. The group consists of four underground mines: Mochia, Balaria, Zawarmala and Baroi that are being operated with Sub Level Open Stoping (transverse and longitudinal) method to mine zinc /lead /silver ore.

Regional Geology

- Complexly folded geological structure formed out of two distinct periods of tectonic activities (Post Aravalli & Post Delhi orogenies).
- Baroi occupy original northerly plunging structure generated out of Post Aravalli orogeny.
- Bara prospect is located on the south extension of dolomite limb of northerly plunging Zawarmala – Baroi folded structure. The host rock is subjected to intricate multi phased folding.

Systematic Support Rule's Recommendation

To ensure additional safety all the level developments including that in the waste and ore are systematically supported with rock bolts /cable bolts as per Systematic Support Rule (SSR).

Systematic support system in the form of rock bolts, wire mesh is installed in the excavation drives and cross-cuts to ensure long term stability of the strata and roof of development viz., drives and cross-cuts, ramp, incline etc. If poor ground or any geological discontinuity plane is encountered like faults and shear zones etc., some additional support elements are used in the form of Dowels/Steel sets and concreting and/or anything else as per the scenario.

To avoid hanging wall failure leading to in-stope dilution, cable bolts are being installed extending into the hanging wall to arrest excessive wall rock failure, especially in areas where the wall rocks are having low RMR or low angle dipping of ore lenses.

The designed SSR has been validated by CIMFR, Dhanbad to ascertain better stability of the shaft and capital developments through field observations, physical inspection of the area and three-dimensional numerical modelling. Also, the study is aimed to suggest possible remedial measures to safeguard present and future ground stability. The major recommendation is attached below.

From the empirical and numerical modeling studies the estimated rock bolting parameters for various locations are tabulated below. The pattern of rock bolting and cable bolting for various areas of the mine are shown in the table attached. Cable bolts are suggested only in the Ramp where "fair" rock mass of RMR <60 is encountered, at all the junctions occurring at a ramp section. Generally, 1.8 m long rock (full column resin) bolts are sufficient for the ground; however, for Ramp of 5.5 m width and for larger size excavations such as passing bays, washing bay, loading point and workshop, 2.4 m full column resin bolts are recommended by CIMFR.

Table 1.0: Designed support pattern for excavations with different dimensions by CIMFR

Stope	Size(m)		Empirical		Numerical Modelling						Remark
	W	H	Length of Bolt	Bolt spacing approx.	Rock Load Ht.	Bolt spacing in a row	Row Spacing	No. of Bolts	Support SF	Bolt Density	
Decline	5.5	5	1.77	1.64	1.25	**1.20**	**1.20**	5	2.42	0.69	2 rows side bolting
Ramp	4.2	3.5	1.64	1.45	0.75	**1.20**	**1.20**	4	3.53	0.69	Alt. side bolting
Haulage Drive	4.2	3.5	1.64	1.45	1	**1.20**	**1.20**	4	2.65	0.69	Alt. side bolting
Ore Drive	4.2	3.3	1.64	1.45	0.75	**1.20**	**1.20**	4	3.53	0.69	Alt. side bolting
Cross Cuts	4.2	3.3	1.64	1.45	1.25	**1.20**	**1.20**	4	2.12	0.69	Alt. side bolting
Loading Point	4.2	5.5	1.64	1.45	0.75	**1.20**	**1.20**	4	4.23	0.69	2 rows side bolting
UG Workshp/ Garage	5.5	4.5	1.77	1.64	0.75	**1.20**	**1.20**	5	4.04	0.69	2 rows side bolting
Washing Bay	8	5.5	2.00	2.00	1	**1.10**	**1.20**	8	3.33	0.76	2 rows side bolting; Cables @ 2mX2m
Passing Bay	8.5	5	2.05	2.07	1.25	**1.00**	**1.20**	9	2.82	0.83	2 rows side bolting; Cables @ 2mX2m
Sub Station	4.2	3.5	1.64	1.45	0.75	**1.20**	**1.20**	4	3.53	0.69	1 row side bolting
Conv. Haulage	3.6	3	1.59	1.35	1	**1.00**	**1.20**	4	3.09	0.83	
Conv. Ore Drive	3.6	3.2	1.59	1.35	0.75	**1.00**	**1.20**	4	4.12	0.83	
Conv. Cross Cuts	3.6	3	1.59	1.35	1.25	**1.00**	**1.20**	4	2.47	0.83	
Junctions 4 way	4.2	3.5			1.25	**1.20**	**1.00**			0.83	
Junctions 3 way	4.2	3.5			1.25	**1.20**	**1.00**			0.83	
Y Junction for Decline	5.5	5				**1.00**	**1.00**			1.0	2 rows side bolting; Cables @ 2mX2m
Brow Area	4.2	3.5	1.64		6						Addl. 3 rows of cable bolts (max. 8m length)

STUDY PARAMETERS

For conducting the study, HZL Zawar Geotech team along with MRPL (Minova Runaya Pvt. Ltd) team finalized some key parameters which determines the performance of Rock Bolts. Following parameters were covered under this comparison study:

- Tensile strength of the Rock Bolts across the bolt length
- Shear Pin breakout strength
- Resin Bolt bonding strength across the bolt length

MINOVA BOLT DESIGN

Rock Bolts plays a crucial role in any underground environment and thus its design is of utmost importance. With the above idea in mind, Minova has developed a unique product trademark as "Secura™ Bolt" for use in all strata conditions and environment of underground mines.

The unique design includes

A "**Paddle System**" to improve resin mixing and resin film shredding. Consistent and efficient mixing of resin capsule components provide higher bond strength in all borehole's diameters

Fig 1: Unique Paddle

A "**Special Design Thread**" which does not impact the tensile strength of rebar, thus enabling higher load bearing capacities. The high strength 'Nova' thread (R thread) profile includes a modified rope thread with large root and small crest areas

Fig 2: R-Thread

A "**High Strength Shear Pin**" which enables efficient torquing of bolts during installation.

Fig 3: High Strength Shear Pin

TENSILE STRENGTH TEST

Tensile strength of the rebar plays a crucial role to understand the load bearing capacity of the bolts. Higher tensile strength of the rebar will provide better load bearing capacity increasing safety. The tensile strength of the bolt was tested throughout its length to understand the impact of threading and paddling on the tensile strength.

a. TENSILE STRENGTH TEST AT CENTER

The center portion of both MRPL and local bolt is the rebar itself. Thus, understanding the tensile strength of bolt at the center will help us determine the material quality used to manufacture bolt. The test results for tensile strength of bolt MRPL and Local bolt is similar in nature

	MRPL	Local Bolt
Sample 1	671 MPa	675 MPa

a. TENSILE STRENGTH TEST AT THREADING

Threading of the rebar is generally carried out by cutting/shredding the rebar itself thereby reducing the tensile strength of the bolt. Minova Runaya proprietary technology helps make strong threads in a rebar without compromising the tensile strength of the rock bolt, thereby improving the load bearing capacity.

Figure 4: MRPL Thread

Figure 5: Local Thread

Upon visual inspection of threads, MRPL bolts thread is made without shredding the rebar itself whereas the local bolt thread is made by shredding the rebar. This shredding is the main reason for the reduction in the tensile strength of the local bolt.

	MRPL	Local Bolt
Sample 1	666 MPa	549 MPa

c. TENSILE STRENGTH TEST AT PADDLES

Further, the paddles which are a distinct feature of Minova Runaya bolts are also done in such a way that does not compromise the tensile strength of the rock bolt.

	MRPL
Sample 1	671 MPa

SHEAR PIN BREAKOUT TEST

A shear pin is an important feature in any rock bolt, which helps to determine whether the bolt has taken the respective load during installation.

	MRPL	Local Bolt
Sample 1	170 Nm	60 Nm

Fig. 6: MRPL Shear Pin

Fig. 7: Local Bolt Shear Pin

RESING BOLT BONDING STRENGTH

For a rock bolt to perform, the mixing of resin across the bolt length is of utmost importance. MRPL proprietary paddling features ensures that resin is thoroughly mixed throughout the bolt length, thus providing better load bearing capacity and safety in mining operations. To understand the mixing and resin bolt bonding test a special PUSH TEST was conducted.

a. TESTING METHOD

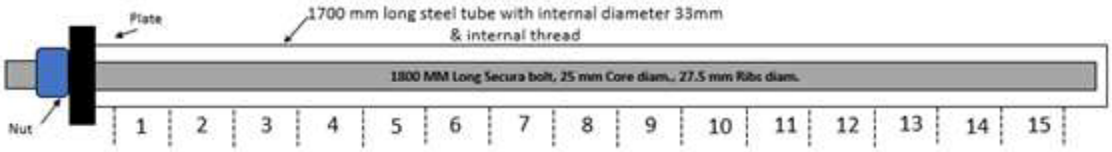
To conduct the test, a 1.7m long threaded steel tube with one end sealed (33mm I.D. internally threaded 1 1/4', 9 mm wall thickness) MS was made. In these tubes, Rock bolts were installed (2 MRPL bolts, 2 Local Bolts and 1 Imported MRPL Bolt) with identical resins to analyze the mixing and bonding of resin with the bolts.

The installation of Bolts in the tubes was conducted at Zawar North Baroi Mines. A 64mm hole was drilled where the tubes were placed and anchored. The installation happened with usual method to resemble daily operational conditions in the mines.

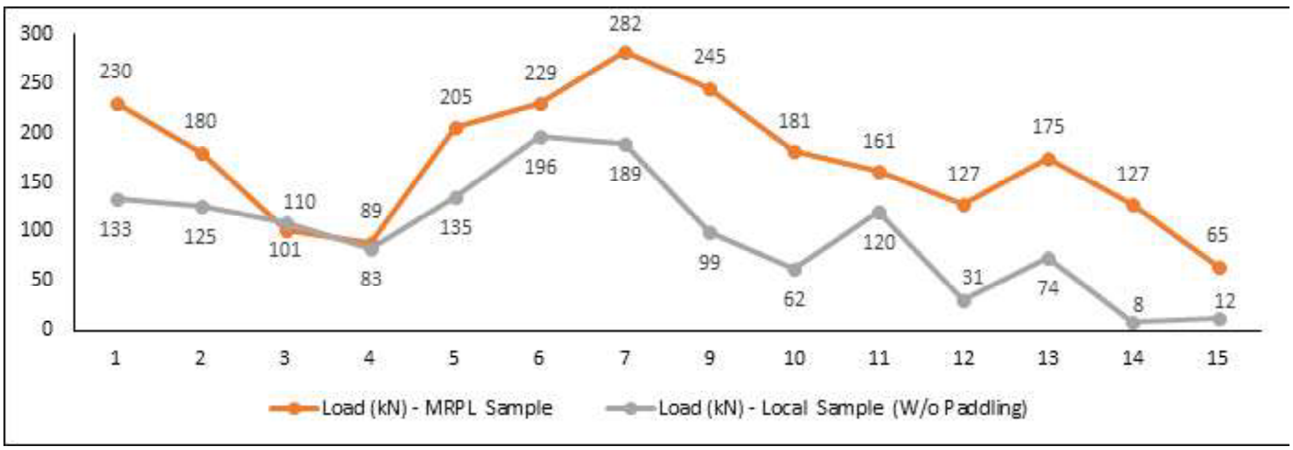
Figure 8: Ongoing Bolt Installation in Tubes at Mines

Figure 9: Complete Bolt Installation in Tubes at Mines

Figure 10: Tubes Post Installation



a. RESULT OF PUSH TEST



	MRPL Bolts	Local Bolts
Average Push Test	171 kN	98 kN

Note: Sample 8 for both MRPL and Local was cut along the cross section to study the resin mixing and thus not tested on push test. Individual push test graphs are given in appendix 1 for reference.

CONCLUSIONS

- Rock Bolts with nominal Paddled Dia of 24.5 mm - 30 mm leads to uniform mixing of the resins and thus attributes 81% of higher Resin-Bolt's strength (171 KN vs 98 KN)
- High Strength Shear Pin of strength 160-170 Nm should be incorporated in the Bolts to ensure the efficient torquing of Bolts during Installation.
- Rebar bolts usually fail at the thread in largely deformed rock masses. The thread reduces the load-bearing capacity by about 25% for a conventional 20 mm rebar bolt.

In case the load bearing capacity is of concern, an enlarged thread rebar can be considered as a substitute of conventional rebar bolt.

ACKNOWLEDGEMENT

We, at Minova Runaya Pvt. Ltd., would like to thank Hindustan Zinc Limited for providing us the opportunity to work and extending support during the execution of the work required for conducting the mentioned case study at Baroi Underground mine of Zawar Group.

Further, we would like to extend personal gratitude to Geotech Head and his team of Baroi Mines for their invaluable support, co-operation, and splendid hospitality. We would also like to thank management of Baroi Mines, Hindustan Zinc Limited to provide us all the support & help offered during the project.

The Indian Mining & Engineering Journal, Vol. 60, No.12 December 2021, pp.39-46
Printed in India, @ IME Publications, ISSN 0019-5944

Design of Suitable Method of Pillar Extraction to Protect Surface Structures Vis-a-Vis Empirical and Numerical Analysis

Dr. Singam Jayathu* Gokul Satheesh**

ABSTRACT

This paper presents evaluation of various approaches for stability of the pillars in underground coal mines for protection of surface structures. Empirical and Numerical models were used for estimation of Factor of Safety (FOS) for various conditions of extraction. From the findings, the suitable methods of depillaring and also measures to be taken for the smooth working while providing safety for surface structures were suggested.

INTRODUCTION

Considering impact on socio-economic and environmental scenario underground coal mining is a convenient option. Little needs of environmental clearances and land acquisition makes it a suitable method for coal extraction. Most Indian Underground coal mines adopt the Bord and pillar method for coal extraction. In this method the percentage of extraction of coal is below 25% to 30%. The remaining coal is left unextracted in the form of pillars supporting roof. Depillaring method increases the extraction percentage up to 70% to 80%. Depillaring leaves voids which may be filled with stowing or left as it is to allow caving. In this case study a detail investigation of extraction method is done for a typical underground mine.

MINE DETAILS

At the typical mine under study, there are Seam 1B, Seam 1A, Seam 1, Seam 2(Top), Seam 2(Bottom), Seam 3B, Seam 3A, Seam 3, Seam 4A & seam 4 in descending order of which Six seams are workable namely seam 1A, seam 1, seam 2(Top), seam 2(Bottom), seam 3 & seam 4. At present Seam 1, 2(Bottom) & seam 3 were being developed in the mine. The thickness of seam 1 was varying from 2.5m to 3.2m, the thickness of seam 2(Bottom) varying from 3.0m to 4.8m and thickness of seam 3 was varying 2.8m to 3.6m over the property.

There were five mine entries in two different sections of workings of the mine. There are Seam 1B, Seam 1A, Seam 1, Seam 2(Top), Seam 2(Bottom), Seam 3B, Seam 3A, Seam 3, Seam 4A & seam 4 in descending order of which Six seams are workable namely seam 1A, seam 1, seam 2(Top), seam 2(Bottom) seam 3 & seam 4. At present Seam 1, 2(Bottom) & seam 3 are being developed in the mine. The thickness of seam 1 was varying from 2.5m to 3.2m, thickness of seam 2(Bottom) varying from 3.0m to 4.8m and thickness of seam 3 was varying 2.8m to 3.6m over the property. The parting between seam1 and seam 2(Top) is about 25 m., seam 2(Top) & 2(Bottom) is 1.50m to 15.0m, seam 2(Bottom) & seam 3 is about 70m. All the seams were having gradient of 1 in 2.5 North 50^{R} 30’ East. All the seams were classified as Degree-I gassiness. Maximum depths of workings were reached up to 390m. Extraction in two panels NW-1& NW-2 by caving and panel No. 3S/SS-1, 3S/SS-2, 3S/SS-3, 3S/SS-4, 3S/SS-5 & 3S/SS-6, 3S/SS-7 and 3S/SS-8 by hydraulic sand stowing in no.3 seam are completed. Presently the panel no. 3S/SS-9 is under extraction.

Surface features such as PWD Road and Transmission line were present overlying the surface of SS-9 panel. The pillars underlying directly below the PWD road and transmission lines are pillar no 38,39,40 and 41 in this panel. In this study a scientific approach is undertaken to determine a suitable method of extraction under the surface structures.

Typical borehole strata section overlying the coal seams at the mine, indicates that the parting between the present workings of the seam 3 and 2 bottom section is about 60 m (Fig 1).

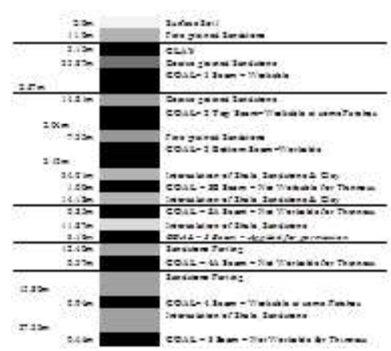


Figure 1: Borehole strata section overlying the coal seams

**Professor **MTech Scholar*
NIT Rourkela

Fig 2(a) shows layout of pillars (38, 39, 40, 41) in panel SS-9 proposed to be extracted under the surface features. Total thickness of the seam in this panel is 3.20 to 3.60 m. Rate of dip is 1 in 2.5 in the direction of N 50°30' E. The panel SS9 has coal reserves of about 1,50,000 Tons with 41 pillars standing on pillars with a life of about 24 months with the rate of extraction achieved with conventional depillaring with stowing and semi-mechanized loading with SDL's as in previous panels SS1 to SS8. Size of the panel is about 390 m X 220 m from 20 Level to 28 Level between 2 Dip to C Dip. Height and width of the workings are in the range of 2.5 to 3.1 m and3.2 to 4.8 m, respectively in this panel. Depth cover below surface is about 261 m (at 2D/21L) to 353 m (1D/28L). This seam was developed along the sandstone roof. Fig 3(b) shows details of Method of extraction of pillars with splitting and three slices being practiced in panel SS-9. Arrangements for stowing include the sand storage plant capacity of about 200 m^3, with rate of stowing of about 400 m^3 per day at the working panel. Overlying workable seams of #1 and 2 Bottom are partially developed over the SS9 panel.

METHOD OF EXTRACTION

Present conditions governing the extraction of pillars with SDLs in Panel No. 3S/SS-9 in conjunction with Hydraulic sand stowing method is as follows:

- The pillars in the area shall be divided into 2 equal parts with 4.2m width and 3.0m height by driving a central level split.
- The height of extraction is the full thickness of the seam (i.e., 3.0m to 3.6m). Splitting of pillar shall be restricted to two/three pillars along the level and two pillars along the rise direction from the pillar under extraction provided that where pillar extraction is about to begin, such splitting of the pillars shall be restricted to a maximum of four pillars.
- Each part of the pillar so formed shall be extracted by driving dip slices not exceeding 4.0 m. width and maintaining a rib of coal not less than 2.0 m and out by rib 3.0m judiciously in thickness against the adjacent goaf which shall be extracted rib of coal may be reduced judiciously on retreat.
- Not more than one slice shall be driven in a part pillar at any time.
- Keeping the above restrictions in view, the number and width of slices in each pillar shall be so adjusted that, while driving the last (out by most) slice, a block (rib) of coal, of 3.0m thickness, is also left against the adjacent original gallery. The block of coal may be reduced judiciously on the retreat from the original gallery.
- Driving of a new slice shall not commence until immediate in bye original galleries and in by slice are completely stowed and goaf edges are adequately supported.
- Extraction of pillars shall commence from the dip-in bye end and proceed systematically towards rise-out by side maintaining a diagonal line of faces and avoiding the formation of 'V' in the line of extraction.
- The diagonal line shall be maintained in two Stages-Stage 1 (From 21L to 24L in between 'C'Dip to 'N'Dip) and Stage 2 (From 21L to 29L in between 'N'Dip to '5'Dip).
- Stoppings shall be provided with water seals for draining out accumulated water. Sampling pipes will also be provided in dip most and rise most stoppings.
- Not more than two slices shall remain un-stowed in the entire panel at any time.
- The panels shall be placed under an experienced supervisory staff.
- The panels shall be inspected once at least each working day by an Under Manager.
- Due care will be taken while extracting coal in areas disturbed geologically or near fault planes etc.

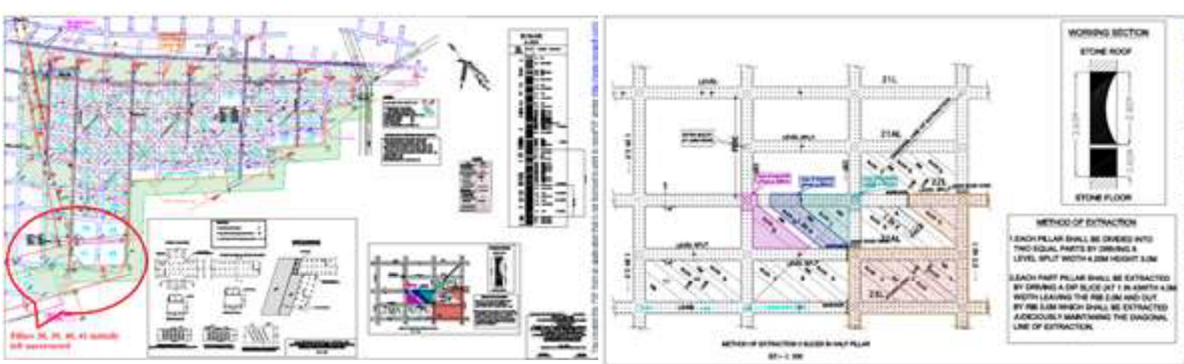


Figure 2: Present extraction method adopted

STABILITY OF WORKINGS vis-à-vis EMPIRICAL MODELS

In the view of many practical problems in achieving 100% compaction with any stowing practice worldwide, it is proposed to adopt the infallible system of partial extraction with adequate remnants and stowing under the sensitive structures such as PWD Road, Transmission line overlying SS9 panel. The key factor in the success of any partial extraction system is the long-term stability of the remnants left as protective structures in underground. The developed pillar arrays in the above two panels were evaluated with a view to arrive at the most feasible extraction method maximizing the coal recovery and minimizing the cause of instability of workings and disturbance to the surface. Many variants of partial extraction such as Non-Effective method of extraction, wide stall mining etc., under waterlogged workings were studied in some of the coal mines in India (Jayanthu, 1996). However, as stowing is a predominant system in this mine, different variants of stowing were only considered. The remnant stooks in association with sand stowing with the safety factor in the range of 0.6 to 1.0 are considered for long-term stability (Sheorey, 1993). Stability of the stooks in all the variants is estimated through empirical, and numerical model studies. The safety factor of the remnant stooks is calculated as the ratio of the pillar strength and the average pillar stress. The strength of the remnant stooks is calculated using the CMRI pillar strength equation (Sheorey, 1993), as given below.

$$S = 0.27 * \sigma_c h^{-0.36} + \left(\frac{H}{250} + 1\right)\left(\frac{w}{h} - 1\right)\text{MPa} \qquad (1)$$

Where,
S = Strength of coal pillar, MPa
σ_C = Uniaxial compressive strength of 2.5 cm cubes of coal, MPa
h = Height of extraction, m
H = Depth of cover, m
w = width of the remnant, m

The combined average compressive strength of the coal samples determined in SCCL laboratory was 21.5 MPa. The value of σ_c required in equation (1) can be estimated by using the relationship below:

$$\frac{\sigma_c}{\sigma_{c50}} = \left(\frac{50}{d}\right)^{0.18} \qquad (2)$$

Where,
σ_{c50} = Uniaxial Compressive Strength of 50 mm sample and,
d = diameter in mm of the specimen for which UCS is required

Although the pillars are in general square in cross-section, the equivalent pillar width is calculated wherever the pillars are rectangular using the relation proposed by Wagner (1974). Accordingly, the equivalent pillar width is given by

$$W_e = 4A / C_p \qquad (3)$$

Where,
W_e – equivalent pillar width, m
A – plan area of the pillar, m^2
C_p – the perimeter of the pillar, m
This value of W_e is substituted in place of w in equation 1.

The load on the remnant stook is calculated using Tributary Area Method. The average stress in the pillar is given by the following equation:

$$\sigma = \frac{A_p \gamma H}{A_s}\text{MPa} \qquad (4)$$

Where,
H = Depth of cover, m

A_p = Total area of influence = {(w_1+a+w_2) X (w_3+b+ w_4}, m^2
a = Length of the remnant, m , b = Width of the remnant, m
w_1, w_3 = Half of the width of the main gallery, m
w_2 = Half of the width of slice, m
w_4 = Half of the width of split, m
g = Unit rock pressure (MPa/m)
A_s = Area of the remnant = aXb, m^2

Safety factor = Strength / Stress (5)

By Sheorey (2000)
Subsidence (S)= 0.12x[1+5.9 tan h{0.38x(X-1.45)}]

Where,
X=width to depth ratio of working panel

Subsidence in underground due to backfilling mining is

$$W = H_2{*}(K_2 - 1) + H_3{*}(K_3 - 1) - e^{2.1\times(W/D)}$$

Where,
H_2& H_3 are fracture and sagging zone

K_2& K_3 are bulking factor of the respective zones.

Compressive strain at a point

$$E(-) = K \times S/H$$

Where,

$$K=1.4+24\times e^{-14.3\times(X-1)}$$

S= subsidence in mm
H = Depth of mining(m)
X=width to depth ratio of working panel

Tensile strain at a point

$$E(+) = K1 \times S/H$$

Where,

$$K1=1.35+28\times e^{-19.4\times(X-1)}$$

S= subsidence in mm
H = Depth of mining(m)
X=width to depth ratio of working panel

Different surface features and structures can sustain certain magnitude of ground movement which are called the safe limit of ground movements. The safe limit of maximum permissible subsidence movements to different surface features and structures for Indian geo-mining conditions (Anon., 1991) are given in Table 1.

Table 1: Safe limit of maximum permissible subsidence movements to Different surface features

Particulars of Structures	Damage limits
Railway line of jointed construction	Strain=3mm/m; Limiting operating gradient=1 in 100
Railway line of welded construction	No movement permitted
Buildings	Total elongation or compression=60 mm
Water bodies	Tensile strain=4.5 mm/m
Surface topography	Strain=3 mm/m
Forest cover (Slight impact)	Strain=20 mm/m
*As per Ministry of Environment and Forest, Government of India guidelines, the maximum permissible tensile strain and width of surface cracks in forest land are 20 mm/m and 300 mm, respectively.	

Various approaches are used to predict the Surface subsidence and Strain for understanding the effect on the surface overlying SS9 panel. Approaches with stowing methods considered the parameters such as total extraction thickness, percentage of extraction (R %), Equivalent width of the panel, Depth of Panel working etc. to estimate surface subsidence and equivalent strain(compressive/tensile) as follows:

$$S = ((H\_e * 0.0175)) \,/\, [1 + \{((w/H))/0.87\}\hat{}(-6.67)\,] \qquad (6)$$

Where,
S=equivalent strain (compressive/tensile) in mm
H_e=Total extraction thickness× percentage of extraction (R %)
W= Equivalent width of the panel (m)
H= Depth of Panel working (m)

STABILITY OF WORKINGS vis-à-vis NUMERICAL MODELS

Feasibility study involved estimation of Safety factor for pillars if they are extracted by different scenarios including the following:

i. Simple Splitting: Splitting the pillar into 2 parts by 4.2m split gallery
ii. Quartering: Splitting the pillar into 4 sections, by single slice and level splits of 4.2 m width.
iii. Splitting and 2 Slices: Splitting the pillar into 2 parts with 4.2 m split gallery, then making two 5m wide slices in each part of the pillar.
iv. Splitting and 3 slices: Splitting the pillar into 2 parts with 4.2 m split gallery, then making three 4m wide slices in each part of the pillar.
v. Widening of Development galleries: Widening Development galleries around the pillar to 8.4m.

The following assumptions are made for conducting the numerical model studies simulating the conditions of the SS9 panel at the mine:

- Sand stowing will take place in all excavations.
- Pillar Size centre to centre is 35 m
- Overlying strata is 350 m deep and mostly sandstone
- Excavation height is 3m
- Development Gallery width is 4.2
- Compressive Strength of coal is taken as 15.25 MPa. Other related properties are taken accordingly.

For the purpose of simulation of the different scenarios of extraction, a two-dimensional finite element modeling (FEM) was performed. The geometry that was analyzed in each case was a virtual cross-section of a pillar that depicted the depth of the mine working from surface to the working area.

The full depth of each excavation scenario was simulated in order to replicate the real in situ stress conditions during a mine working. The details of the geometries for different excavation scenarios were taken accordingly, details of which are summarized in Table 3. For the purpose of simulations, all variations were modeled for the different scenarios of excavation and the Factor of safety for each case was observed. Since worst-case scenarios are the limiting conditions in such simulations, higher values of parameters such as depth of working were taken, while average and low values of other parameters such as pillar width, gallery width, etc. were kept as a control model.

Table 2: Details of Geometry parameters in meters

S. No	Parameter	Max Values	Min Value	Avg. Value
1	Depth of Working	353	261	307
2	Gallery height	3.1	2.5	2.8
3	Pillar Width	36X36	34X28	35X32
4	Gallery width	4.8	3.2	4.0
5	Split Width	4.2	-	-
6	Slice width	5m	4m	-

The material properties for different layers were obtained from previously available reports and online resources. The overlying strata were assumed to be isotropic homogenous sandstone cover for the simplicity in simulation work. The criteria for failure were kept being Mohr Coulomb's failure criteria, with isotropic elasticity and plasticity characteristics. The materials are considered to be losing tensile strength and cohesion completely once failure occurs. The material properties used in the models are summarized in Table 4. For each of the excavation scenarios, an analysis was performed for both with stowing and without stowing cases. For the simulation of stowing in finite element modeling, the interaction between stowed sand and coal walls was simulated using a jointed interface with a friction angle of 45 degrees and no cohesive and tensile strength. The stowed sand was allowed to settle and compress with its own weight in order to simulate the actual stowing practices, resulting in effective filling of 60 to 70 % of the height of coal pillars with graded mechanical properties with respect to height. The hydrostatic pressure build-up due to stowing water was assumed to be negligible. Stook dimensions were taken as per extraction scenario. No extraction of stook was assumed.

Table 3: Material Properties for simulation work

S. No	Layer	Density (kg/m3)	Young's Modulus (MPa)	Poisson's Ratio	Cohesion (MPa)	Internal Angle of Friction (degrees)	Tensile Strength (MPa)
1	Sandstone	2700	20000	0.3	20	35	50
2	Coal	1500	1560	0.35	0.6	28	1.8
3	Sandstone	2700	20000	0.3	20	35	50
4	Stowing Sand	2400	1.0	0.45	0.2	32	0

COMPARISON OF EMPIRICAL AND NUMERICAL MODEL RESULTS

By applying approach 1 and approach 2 as suggested in Empirical Model Surface subsidence and Strain estimated by various empirical relations indicated very insignificant strain within 0.3 mm/m with stowing and hence are found to be within the safe limit of maximum permissible subsidence movements and no damage to the surface structures overlying SS-9 panel the mine (Table 4). Calculations and analysis are done for all extraction heights. The sample calculations presented are for 2.8m which is average height of extraction.

The factor of safety (FOS) was judged by both calculations through empirical models and simulations through numerical models. Both of these results are summarized in Table 6. FOS for various conditions of extraction including developed Pillar, stooks after splitting, and stooks after Quartering with empirical models was found to be 5.34, 2.59, and 1.48, respectively, with almost similar results by numerical models. Corresponding FOS with stowing in the numerical models was about 4.89, 2.44, and 2.44, respectively.

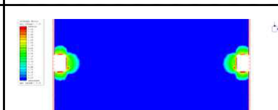
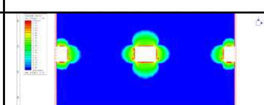
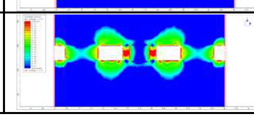
Percentage extraction and stability of the workings with various feasible methods of extraction of pillars are presented in Table 6. Keeping in view of the conservation of coal, it is also required to extract the coal from the

Table 4: Estimated Surface subsidence and Strain on the surface for varying depth covers with stowing operations in the conditions of the mine under study

Sl. No.	Depth of the panel (m)	Approach-1		Approach-2		
		Subsidence (mm)	Equivalent Strain (mm/m)	Subsidence (mm)	Tensile Strain (mm/m)	Compressive Strain (mm/m)
1	40	14.48	1.1025	14.48	0.4887	0.5068
2	60	9.05	1.1025	9.05	0.2036	0.2112
3	100	6.67	1.1021	6.67	0.0900	0.0934
4	120	4.58	1.1010	4.58	0.0515	0.0534
5	180	3.25	1.0808	3.25	0.0244	0.0253
6	220	2.57	1.0240	2.57	0.0163	0.0188
7	261	1.78	0.8894	1.78	0.0270	0.0381
8	300	1.06	0.6862	1.06	0.1614	0.1239
9	353	0.95	0.3944	0.95	2.0527	0.7408
10	400	0.14	0.2148	0.14	1.7669	0.3870

pillars to the maximum possible extent without causing any damage to the surface structures. Percentage in fraction with developed pillar, wide stall, only splitting, quartering, 1 split 2 of slices 5m width, 1 split 3 slices of 4m width, the percentage of extraction are respectively 22.56, 42.24, 33.12, 42.24, 54.31 and 57.51.

Table 5: Estimated Factor of safety by empirical and numerical models

Type of Excavation	FOS by empirical models	FOS by Simulation	FOS with Sand Stowing	Simulation Figures
Developed Pillar	2.169	4.08	4.89	
Splitting	1.141	2.3	2.44	
1 split 2slices (5m)	0.392	1.49	1.84	

Separate individual percentage of extraction is used for individual calculation of all extraction scenarios including the splitting, quartering, 2/3 slice, and wide stall. The FOS estimated through numerical and empirical models indicated more than about 1.5 with the options of splitting the pillar, and with quartering having one slice for which the FOS improved above 2 indicating long term stability of the workings with stowing. Therefore, two options are proposed for the SS9 panel workings below the surface structures ensuring its stability. For considerations of uncertainties of rock type/fractures etc., a higher FOS is considered to be safe as compared to critical FOS near1.0.

CONCLUSIONS

Based on the study of various alternative methods of extraction of pillars in SS-9 panel beneath PWD road, transmission line, the following variants of pillar extraction through reduction of pillars in arrays by splitting or thinning were evaluated.

a. Level Split of 4.2 m and 3 slices of 4 m width
b. Level Split of 4.2 m and 2 slices of 5 m width
c. Level Split of 4.2 m and dip slice of 4.8 m width
d. Level Split of 4.2 m
e. Wide stall mining with 8.4 m stall width

2. It is recommended that Splitting and single slice method in conjunction with hydraulic sand stowing under the existing geo-mining conditions may be followed with specific reference to conservation and stability of the workings, and surface structures.

3. The stability of the remnant stook with proposed method of extraction in the panel –SS9 is found to be

Table 6: Percentage extraction and stability of the workings with various feasible methods of extraction of pillars

Scenario	Stress on individual stook/residual	*Empirical – model-FOS of individual*	Numerical Simulation without	Numerical Simulation with stowing	% Extraction
1 split 3 slices 4m	21.0027	*0.3025*	1.2	1.59	57.51
1 split 2 slices 5m	19.5342	*0.3924*	1.49	1.84	54.31
Quartering	15.4519	*0.713*	2.3	2.44	42.24
Only Splitting	13.3448	*1.1416*	2.3	2.44	33.12
Wide stall 8.4 m	15.4519	*1.4013*	3.88	4.17	42.24
Developed Pillar	11.525	*2.169*	4.08	4.89	22.56

(a) (b)

Figure 3: Proposed method of extraction in SS9 Panel with level split and Single slice in conjunction with sandstowing beneath PWD road a) Method 1, b) Method 2

adequate in association with sand stowing.

4. It is also recommended to meticulously monitor strata movement including surface and sub-surface subsidence in the present overlying and practically approachable workings of Seam 2 Bottom during the extraction for better understanding of effectiveness and influence of stowing and formulation of related guidelines for future panels under the similar geo-mining conditions.

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The Indian Mining & Engineering Journal, Vol. 60, No.12 December 2021, pp.47-50
Printed in India, @ IME Publications, ISSN 0019-5944

Eco-Friendly Mining of a Mega Coal Mining Project

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INTRODUCTION

This coal mine project is located in Singrauli Coalfield, M/s Northern Coalfield Ltd.The Project is partly in the Singrauli district in MP and partly in the Sonebhadra district in UP.The project is well connected by both road & rail. Nearest railway stationShaktinagar is at a distance of about 5 Km and approachable by all-weather metaled road. The project is at a distance of 63 Km by road from Renukut in UP and 18 Km from Waidhan in MP by Ranchi-Rewa highway.

ECO-FRIENDLY MINING

Any mega coal mining project contribute to numerous ecological disturbances in respect of land, soil, water and air, in addition to socio-economic imbalances. Coal Mines of NCL Singrauli have a well-designed and systematically devised scientific approach to ensure minimum disturbances to flora and fauna. In addition to the various initiatives in the selection of method of mining, selection of HEMM, layout of the mine, efforts have been made over the years as per approved Mining Plan and EC(Environmental Clearance) Guidelines. Table 1, presents the salient features of this mine and Table 2, details of HEMM deployed at the Mine. This mine had been designed to excavate an annual 20.17Million Tons of coal production and 61.73 Million M^3 of overburden by dragline and shovel-dumper combination.Table 3, presents production trend of the mine. In a mega project HEMM play a vital role, the production is directly influenced by availability and utilization of the HEMM deployed. Table 4, presents the availability and utilization trend of important HEMM deployed at this mine.

Table 3 : PRODUCTION & OB REMOVAL during 2014-15 to 2020-21

Year	Coal Production (in Lakh Te)	OB Removal* (in Lakh Cum)
2020-21	201.68	617.27
2019-20	176.79	578.46
2018-19	155.00	522.27
2017-18	155.00	433.58
2016-17	140.12	580.64
2015-16	130.83	631.11
2014-15	108.20	253.87

**(Departmental and out sourced)*

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Table 2 : List of Heavy Earth Moving Mining Machinery deployed at Mega Open Cast Coal Mines

Sl. No.	Description	HEMM deployed
1.	Primary	Dragline (04) - 24M^3/96M Electric Shovel (14) -10 M^3 Hydraulic Shovel(01)-10 M^3 Surface Miner(02)–2.5 MT/annum Dumper(104)-120te&100te Drill (22)-311mm & 250mm Dozer (20)-850HP & 410HP Wheel dozer(03)-460HP FEL (02)-11.8 M^3 FEL(01)-6 M^3
2.	Secondary/support equipment	Water Sprinkler (08)-70 KL Water Sprinkler (04)-28KL Water Sprinkler (02)-09KL Fog Cannon Mist spray type dust suppression system (01)- 12KL Road swapping M/C (02)-R2850D Motor Grader (04) Tyre Handler (02) Fire Tender (02) – 8KL & 6KL Mobile Service Van (04)

Table 4, Presents the availability and utilization trend of important HEMM deployed at this mine

Equipt.	CMPDI Norms		FE 1		FE 2	
	%Avl.	% Utl.	% Avl.	% Utl.	% Avl.	% Utl.
Dragline	85	73	70.41	60.48	72.63	59.46
Shovel	80	58	67.15	39.23	68.41	34.53
Dumper	67	50	52.86	31.08	51.73	24.13
Drill	78	40	71.42	14.46	75.63	15.52
Dozer	70	45	62.76	16.91	59.59	12.36

Equipt.	CMPDI Norms		FE3		FE 4	
	%Avl.	% Utl.	% Avl.	% Utl.	% Avl.	% Utl.
Dragline	85	73	69.20	43.71	71.35	53.11
Shovel	80	58	67.29	33.30	66.25	39.00
Dumper	67	50	54.44	21.06	58.85	26.11
Drill	78	40	69.28	10.24	71.74	13.45
Dozer	70	45	62.01	7.98	67.12	12.01

Equipt.	CMPDI Norms		FE 5	
	%Avl.	% Utl.	% Avl.	% Utl.
Dragline	85	73	68.06	48.78
Shovel	80	58	50.42	34.76
Dumper	67	50	55.13	25.67
Drill	78	40	75.59	10.92
Dozer	70	45	66.83	13.52

Table 1 : SALIENT FEATURES OF THE PROJECT

Sl. No.	**Particulars**	**Details**
1.	Sanctioned Capacity	20 MTPA(Normative), 25 MTPA(Peak)
	Coal Production Target FY 2019-20	17.50 MTe
	Coal Production Ach. up to Jan 2020	15.02MTe
	Profit incurred in FY 2018-19	Rs. 974.2901 Crores
2.	Growth from 5MTPA to 20 MTPA	
	Date of Completion (Phase-I for 5 MTPA)	Year 1993-94
	Date of Completion (Phase-II for 10 MTPA)	March, 2004
	Date of Sanction EPR-20 MTPA	25.11.2017
	Schedule Date of Completion (Phase-III for 20 MTPA) (on going Project)	March ,2022
3	Sanctioned Capital (Rs. Crores)	Rs. 1255.17 Crores (10 to 20 MTPA) Rs. 2718.37 Crores (integrated 20 MTPA)
4	Linkage	Basket Linkage mine for pit head power plants of M/s NTPC, M/s UPRVUNL & Western/Northern India Power Plants to meet any shortfall from respective linked mines of NCL.
5.	Environment Clearance/ Constraints	17.5 MTPA; 26.12.2019
	For Enhancement of EC for 25 MTPA	Public Hearing has been conducted on 08.02.2019
6.	Mine Leasehold Area	2390.722 (Hectares) (Acquired- 1752 Ha & 638.722 Ha. to be acquired)
7.	Method of Working	Surface Miner, Combined System of mining deploying Shovel-Dumper & Dragline both
8.	Mineable Reserve	334.02 (M.Te) (as on 01.04.2016)
	Balance Reserve as on 01.02.2020	274.03 (MTe)
9	Total Overburden	1540.67 (M^3) (as on 01.04.2016)
	Balance Overburden as on 01.02.2020	1346.72 (M^3)
10.	Balance life as on 01.02.2020	15 Years
11.	Average Stripping ratio as on 01.02.2020	4.81 (M^3/Te)
12.	Manpower Sanctioned	2745
13.	Coal Seam	**Coal measure strata sequence** OB-40 to 100m Purewa Top Coal – 9 m OB Parting – 30-35 m Purewa Bottom coal seam- 10 m. Dragline bench(OB)-52-65 m Turra Coal seam – 18 m
14.	Average Grade of Coal	Based on GCV, G8-G11 (Avg.- G10)

Eco-friendly mining (Causes & Control Measures)

The following tabulated format presents some of the key areas where adequate attention is needed.

<table>
<tr><th>Types</th><th>Causes</th><th>Measures to contain/control pollution</th></tr>
<tr><td rowspan="5">AIR</td><td>Loading, unloading, transporting of OB/Coal</td><td rowspan="31">DUST
-Wet drilling
-Automatic dust collector in drill machine & CHP
-Optimization of blast pattern
-Minimization of drilling/blasting (by use of Surface Miner , Highwall Miningetc. with pick face flushing)
-Isolation of dust generation point & use of dust collector at the point
-Use of Dragline, high capacity & new generation hi-tech HEMMs

WATER
- Provision of STPs/ETPs
-Neutralization of ground water
-Water reclamation, water shed, Rain harvesting, water treatment &Recycling of industrial water

GENERAL
-Thick afforestation, Green belting
-Preventive/schedule maintenance of HEMMs, silencer & ear plug
-Land Reclamation, Scientific Dump Geometry & Bench Geometry
-Use of heat exchanger, air conditioner, AC cabin in HEMMs & job rotation
-Maintenance of EMP
-Risk assessment & Risk management

LEGISLATIVE
Following various norms as framed by various Acts and Rules, (including Mine Closure conditions) in respect of Mining of Coal, significantly reduces the pollution level at the source of generation and during its dispersal.

BLASTING/ROCK BREAKING
-Selection of bulk SME and delay system as per the guidelines drawn on the basis of scientific studies.
-No blasting during high wind condition
-Deck Charging
-Avoid Secondary Blasting
-Use of Rock Breaker

HAUL ROAD and WORKING BENCHES
-Black topping of all service road
-Limit the speed of all vehicle
-Proper dozing of the floor of the working benches (free from undulating ground)
-Dust suppression

CHPS
-Air tight control room in CHP, Sub-Stations, HEMMs, Computer Room etc.
-Thick Green Belt(with Tall Trees)
-Dust EXTRACTORS in CHP & other equipment
-Settling Pond
-Silt arrester (Siltation Pond)

ILLUMINATION
Maintaining illumination level as per DGMS guidelines by Adequate lighting of all equipment (including all HEMM), Street light all over of haul road and light vehicle road, Coal yard and OB dump, Coal Handling Plant, Workshop & all offices and residential colony.

TRAINING
Initial & refresher training, induction training, job based training as per module [TCRT (theoretical classroom training), OTJT (on the job training) and OT (oral test/feedback)], simulation training at different training center in India and abroad i.e., IIMs, IITs, IICM, MDI, CETI& vocational training center.</td></tr>
<tr><td>Drilling & blasting Operation</td></tr>
<tr><td>Crushing 0f Coal by Crusher (including MOBILE CRUSHER) & CHP transfer points</td></tr>
<tr><td>Movement of HEMMs (by Tyres& overloading)</td></tr>
<tr><td>Burning of Coal in stock yard & faces (due to oxidation of Coal)
Diesel burning due transportation of HEMMs & other vehicles
High speed of transport equipment</td></tr>
<tr><td>WATER</td><td>Contamination of SPM of OB/Coal & other solid matters</td></tr>
<tr><td></td><td>Oil, Grease & other lubricants</td></tr>
<tr><td></td><td>Washing of HEMMs & other vehicles</td></tr>
<tr><td></td><td>Presence of Pyrites in the strata</td></tr>
<tr><td></td><td>AMD (Acid Mine Drainage)</td></tr>
<tr><td></td><td>Presence of Ash due to burning Coal</td></tr>
<tr><td></td><td>Work shop</td></tr>
<tr><td>NOISE</td><td>Movement of HEMMs & other vehicles</td></tr>
<tr><td></td><td>Drilling & Blasting</td></tr>
<tr><td></td><td>Operation of different type of machineries in the mine & surrounding areas</td></tr>
<tr><td></td><td>CHP & Mobile Crusher , Work shop</td></tr>
<tr><td>LAND</td><td>Excavation</td></tr>
<tr><td></td><td>Lose OB due to dumping</td></tr>
<tr><td></td><td>Water due to rain in rainy season</td></tr>
<tr><td></td><td>Unscientific dumping of OB &formation of benches</td></tr>
<tr><td></td><td>Factor of Safety of dump/benches</td></tr>
<tr><td></td><td>Geological Disturbances</td></tr>
<tr><td></td><td>Oxidation of shale/inferior coal indump</td></tr>
<tr><td>HEAT
& HUMIDITY</td><td>Oxidation of coal</td></tr>
<tr><td></td><td>Operation of different type of Machineries</td></tr>
<tr><td></td><td>Functioning of CHP/Work shop etc.</td></tr>
<tr><td>OTHERS</td><td>Blast Vibration</td></tr>
<tr><td></td><td>Machinery Vibration influencing health of Operators</td></tr>
<tr><td></td><td>Lowering of ground water</td></tr>
<tr><td></td><td>Damages to flora and fauna</td></tr>
<tr><td></td><td>Socio-economic imbalances</td></tr>
</table>

LABORATORY FACILITIES

To ensure quality of air, water, soil, their physical, chemical, biological criteria are tested and standardscompared. Sample collection, analyses and examination is undertaken at regular interval. All out efforts are being made to ensure maintenance of all the parameters as per prescribed BIS standards.

WASTE MANAGEMENT METHODS

For OB handling/disposal, handling liquid waste, colony waste etc.(Waste water management- sources characteristic, techniques of treatment, Acid mine drainage- occurrence, effects and treatment techniques. Solid waste management for mine spoils)

- Waste Dump Disposal Technique- The total volume of OB will be removed internally & 134.00 Mm3 has already been dumped in external dump & reclaimed technically and biologically.
- Preservation of top soil for future use
- Total Mine Water Discharge 12.62 Lakh m3/year- We are using the total mine discharge water except some water loss due to evaporation, infiltration & other mining activity.

MINE CLOSURE PLAN

The conditions as per Approved Mine Plan etc. covering (financial provisions, implementation, standards for closure criteria, system approach for mine closure & development of closure plan) are strictly adhered to. MCP of this mine was approved on Date 26.03.2012 and an amount of Rs. 8424.58 Lakhs deposited in Escrow account till Date 31.03.2021.

CONCLUSION

The above details enumerated/listed show how in a mega coal mine project having state-of-art HEMM and methods, ensuring eco-friendly mining is a gigantic task. However, separate departments and testing facilities enable the management to maintain a balance as per approved plans and regulations as laid down.

ACKNOWLEDGEMENT

The views expressed are of the author and not necessarily of the organization where he is currently employed.

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The Indian Mining & Engineering Journal, Vol. 60, No.12 December 2021, pp.51-54
Printed in India, @ IME Publications, ISSN 0019-5944

Use of Cracking Compound for in Situ Rock Breaking in Mines

Suyash Mishra* KumarRahul Ratan* Deepak Kumar Rana* Himanshu Raghuvanshi*

ABSTRACT

Use of explosives as a primary rock fragmentation is the cheapest and popular method of in-situ rock breaking. In locations where explosives cannot be used due to closeness to buildings, structures, villages etc, the only rock breaking method is 'blast-free technique'. Under the blast free techniques surface miner, use of rock breakers, and rock splitters are the techniques which are based on mechanical energy being used to break or fragment. The other method which is now gaining more use is 'use of expansion cement or chemicals' to break the rock by cracking.In India ACCONEX was the first such expansion cements which were used to crack and break any type of rocks. But since last few decades a number of expansion chemicals are manufactured and used in India. They are based on a product from limestone, added with some additives. An attempt has been made in this paper to present the use of this chemical for breaking of rocks in quarries.

INTRODUCTION

An expansive chemical is added to the bye product of cement or limestone powder. When water is added in a selective proportion so that the mixture is flowable easily. After pouring this into a small diameter hole of not more than 32 mm dia., cracks are formed. The crack dimension is influenced by the quality of the chemical, proper chemical water mix, spacing between holes and burden of each hole. Atmospheric temperature had a significant role in the time taken to crack..

EXPANSION MECHANISMS

Figure 1, explains the crack mechanism. Here, the spacing is more important and so far it is based purely on site trial basis. There are two theories which dictate expansion action. They are –

- Crystal Growth Theory (CGT)
- Swelling Theory (ST)

In Crystal Growth Theory (CGT), the growth from the surfaces of expansive particles is the main cause of expansion whereas in Swelling Theory (ST) expansion is caused by water-adsorption and expansive characteristics of the chemical gel which forms by a through solution mechanism. In case of the expansion chemical used in India expansion occurs after the slurry has been set. As expansion occurs, the cement is restrained by the formation and by the casing so that expansion produces a self-stress in the cement. As casing diameter is reduced by temperature and pressure reductions, the restraint is removed and the self-stress is relieved. The cement thus maintains a shrink-fit around the casing, and an expanded fit against the formation so that superior bonding is obtained. It has been observed that after cracks are formed there is change in colour and the entire gel/slurry is converted into powder.

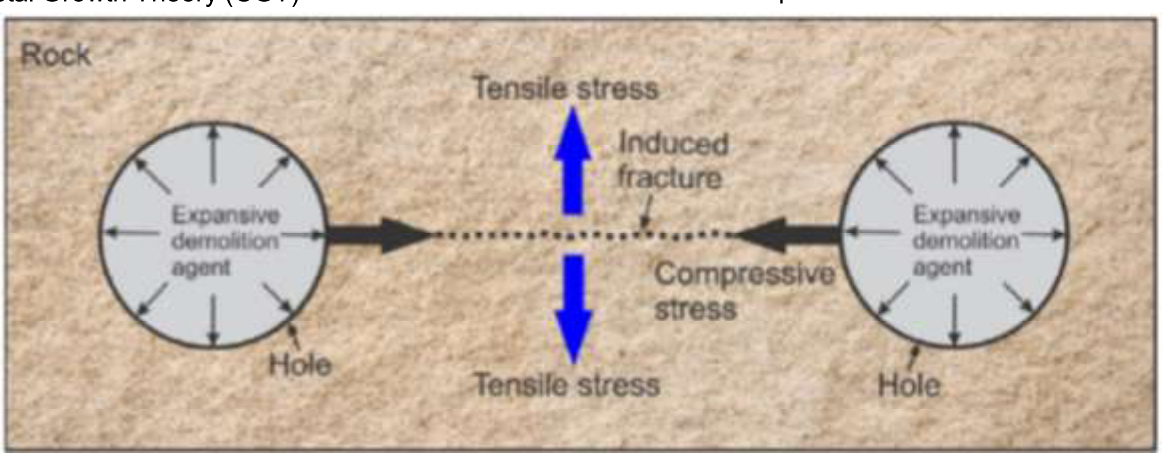

Figure 1, Showing Mechanism of rock breakage by expensive chemical agents in tow drilled holes
(Source : Shang J, Zhao Z, Aliyu MM. Stresses induced by a demolition agent in non-explosive rock fracturing. Int J Rock Mech Min Sci.2018;107:172–80. March 2017. doi: 10.1016/j.ijrmms.2018.04.049.)

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APPLICATION

Use of this compound is quite proven and it has several distinct advantages over use of explosives and mechanical means of rock sizing in-situ. Table 1, explains the comparison of different methods of rock breakage.

Table 1, Showing comparison of rock breakage methods

	Explosives	**Use of Chemical compounds**	**Use of hydraulic splitters & Hyd. Rock Breakers**
Fragmentation	Not uniform	Only cracks are developed	
Noise Quality	Inferior	No noise	Inferior
Ground Vibration	A problem	Negligible	
Dust/gas	A problem	Negligible	A problem
Flyrock	A problem	Negligible	A problem
Safety	A serious concern due to handling of explosive material	Safe	Safe
Economics	Cheapest	Very high cost	Costly
Skill needs of users	Very high due to handling of explosives (as per provisions of Mines Act and Indian explosive Rules)	Trained manpower on use of chemicals and operating hydraulic excavators etc can undertake the jobs easily.	
Regulations related to Safety, Health & environment	When adopted in mines are directly under the various Rules framed as under Mines Act 1952, Indian explosive Act and Rules etc and other environmental regulations.	No clear guidelines are available for use in Mines under provisions of CMR & MMR. Currently it is purely as an civil engineering activity. Other Acts and Rules on Environment is applicable.	

FIELD OBSERVATIONS

Based on literature survey & fieldwork, the field application norms have been derived. They are – (a)Drill holes - best suited for 32mm diameter Jackhammer holes, (b) Hole spacing and burden – Any edge of the strata is considered as the burden and it is usually 0.40 m., and (c) Hole burden is usually same as burden. The burden and spacing parameters can be optimised after few trials in the same strata.

The other parameters which influence in the selection of chemical type, burden and spacing etc are –

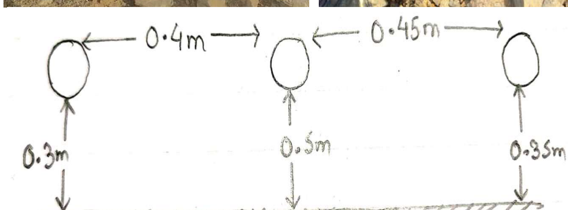
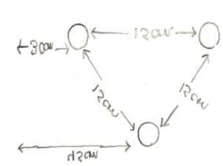
- chemical composition,
- fineness and age of cement,
- water-cement ratio,
- depth of the hole and quantity of gel poured (normally entire hole is filled up)
- mixing time,
- admixtures,
- curing,
- strata and atmospheric temperature, etc

Field trial is presented in a tabular form as below (Figure 2 3 & 4) –

CASE STUDY

Use of Cracking Compound in in-situ Hard Rock of Granite Block (Unpublished Report by Dr G.K.Pradhn)

The large size boulders were hard rock and were composed of Granite, Fine-Grained,, with very thin clay and or quartzite intercalations. Weathering was noticed on the slope of the hill slope, which was covered by clay and a green belt. The entire hard rock had no cracks, folds or faults. Seeing the rock conditions, the RQD (Rock Quality Designation) indicator for compaction of the rock can be + 95.

Location & Time	Sequence of charging and Observations
Low grade limestone Quarry I, near Satna 23-10-2021 at3.00 pm (Figure 2)	Since no jack hammer drilled hole were available we tried to use in few prominent cracks. The gel compound solution with sufficient water was poured into few minor cracks/fissures, into a cylindrical shaped paper pipe. Except for one or two cracks on contact points of the cylindrical pipe with the rock. hammer drill hole.  
Low grade limestone Quarry II, near Satna 23-10-2021 at 4.00 pm(Figure 2)	In another adjacent quarry where jack hammer is used to drill 32mm holes of 1-2 feet depth, holes were drilled on a block with burden and spacing of 0.3 to 0.4 m respectively. The average compressive strength is 80 to 100 MPa, . The gel solution was poured into three holes. On the next day after a gape of 13 hours few fractures on the rock were observed.   
Low grade limestone Quarry I, near Satna 24-10-2021 at10.00 am (Figure 3)	Three holes were drilled in a triangle arrangement with varied burden and spacing. 5 kg compound with 1 litre of water, mixed and poured into the hole. After two and half hours, we observed cracks having 2-2.5 inches of crack length after 2 hours.   

In-situ measurement of the hardness expressed as Schmidt Hammer Number was recorded and the values were converted to Compressive Strength in MPa. It was observed that the Compressive strength values varied from 120 to 150 MPa. Taking the average value it is in the region of 140MPa.

The summary of the experiment is stated below –

i) No. of holes - 10
ii) Dia. of holes: 32 mm by Jackhammer
iii) Average Depth of holes - 5 ft.
iv) Average Burden as measured in the site - 300 mm
v) Average spacing as measured in the site - 250 mm
vi) Hardness of the rock as measured by Schmidt Hammer is 140 MPa.
vii) Total Qty. of chemical used - 20 kgs.
viii) Qty. of chemical mixed with water (1.5 liters for every 5 kg chemical) - 1.7 to 1.9 kg.

Excavation of the cracked zone - by Rock Breaker attached to 210 HP excavator. The total time taken to excavate the area of the cracked zone is 36 min.

Total block size of the cracked zone - 1.9 x 0.70 x 0.70 = 0.931 Cubic M.
Total hole meterage - 15.24 M
Qty. of excavated material per M is 0.061 Cubic M.
Cost per kg of the chemical: Rs. 50/-
The total cost of chemicals Rs. 1000/-
6. To undertake more experimental trials of excavation by using FAST CRACK (5 to 25 Degree).

Figure 4 : Photographs showing crack development on an in-situ hard granite block

CONCLUSION

Use of cracking compounds are not new but in Satna-Rewa-Katni region it was used on experimental basis for the first time. The trial results are quite encouraging. There are few iron ore mines in Chattisgarh where entire iron ore is produced by using cracking powder.

ACKNOWLEDGEMENT

We are really thankful to our B.Tech(Mining) project guide Dr G.K.Pradhan, who had organised the trials. The Case Study was from an Unpublished Report on Use of cracking compounds in a civil engineering excavation site near NMDC Kirandul complex in Chattisgarh.

National Seminar on Sustainable Development of Mineral & Coal Resources
17-18th December 2021

Venue: AKS University, Satna

The Indian Mining & Engineering Journal, Vol. 60, No.12 December 2021, pp.55-59
Printed in India, @ IME Publications, ISSN 0019-5944

Sustainable Development Through Innovation : A Case Study of Century Cement Limestone Mine, UTCL

B.P.Mishra*

ABSTRACT

Energy and fuel saving is utmost important for sustainable development. Through energy and fuel conservation, we not only save the environment but also increase the productivity & Profitability.

At times, tiny and steady efforts have large returns. We, at Baikunth Cement Works,UTCL are engaged in the business of manufacturing of Portland Cement for which Limestone is supplied from Century Cement Limestone Mines. We have made some practical and tiny efforts during mining of limestone, which has resulted into energy and cost saving. Some of these efforts has been narrated in this paper.

INTRODUCTION

Baikunth Cement Works which was earlier under the Century Cement is presently under UltraTech cements Ltd. Its captive limestone mine commenced production on 30th November 1971 and currently has a Mining lease area of 237.003 plus 74.843 Ha. Plant Commissioned in 1974 (Capacity 6 Lakh TPA). The present annual production capacity the mine is 1.8 Million Tonnes of limestone.

Initially (in 1971), the area was plain Bhatta (barren) land,devoid of any vegetation, generally with murrum – soil cover & rocky ground which is about 0.5 m to 3.0 m thick.. The area was devoid of any nala, river & water reservoir(Figure 1).

Figure 1 : The history of mining

SUSTAINABLE DEVELOPMENT

By doing Scientific studies and drawing a plan for Sustainable Mining, thye management had addressed the third and most important challenge that is Mineral Conservation. The cement grade of Limestone has an average CaO > 45.0% and MgO < 1.0% (Cut off Grade of Limestone is CaO% - 38%, MgO%- 4%). Initially the reserves was sufficient only for 20years with then capacity of Cement Plant (0.6 Million Tonnes Per Annum), however with conservation and new methods of mining,

**Vice President(Mines),Century Cement Works, UltraTech Cements Ltd, Baikunth*

augmenting detailed exploration, procurement of sweetener grade limestone from nearby non-captive mines, sufficient reserve is left at present. Also reclamation was resorted with feeding the old low grade stock/dump and consuming them after dry beneficiation (Wobbling). Changes in screens also helped the mine to conserve limestone.

Under sustainable mining program the mine had taken UP Energy saving/ conservation efforts as an effective measure.

ENERGY CONSERVATION INITIATIVES

In opencast mining operations the major consumables are HSD, Lubricant and Tyre. They are also the major components of expenditures. Sustained efforts helped the mine to adopt new techniques to optimize their use.

Areas involving fuel saving, increased life of machinery parts,

(A) Excavators –

(i) Avoiding or minimizing shifting of track mounted machines: [Shifting of machines is an unproductive job]

- by well planning (Better planning of blasted material).
- more than one machine is placed at same face.
- by minimizing no. of days of blasting.
- Long and wide faces allow better quality control & and less machine shifting.

(ii) Fuel (Diesel) Saving in Hydraulic Excavators – Savings due to shifting of excavators for blasting :

- If a machine is shifted for blasting, it takes around 30 minutes (including both way shifting)
- Let, No. machines to be shifted at same faces - 2 Nos.
- Diesel consumption of excavator - 40 Ltrs / Hr
- Per day diesel cons. for shifting - 2x0.5x40 = 40 Ltrs
- If per week two days of blasting has been reduced,
- Saving per week - 2x40 = 80 Ltrs

Thus Annual saving is : 80 x 50= 400 Ltrs (Saving in one face), in terms of Rs. 0.4 lakhs.

(iii) Fuel (Diesel) Saving Excavators - hydraulic excavators for other purpose : this can be over few lakh rupees due to shifting of excavators and resultant idling.

(iv) Increased life of HEMM parts (ex: Track chain) – by regulating movement of excavators, against a previous life of 6000-8000 Hrs presently it could be improved to 14000-15000 Hrs

(v) Increased Life of track rollers been almost doubled from previous 5500 Hrs to present 10000 Hrs.

(B) Selection of blast hole diameters : Switching over to 4" diameter from 6" dia. holes,thereby improving blast fragmentation, more productivity of excavators as well as ultimate saving inclusive power of crushing unit.

(C) Optimisation of blast hole pattern and blasting norms – this has also resulted in improvement of shovel loading rate. In 2013-14 the average cost of drilling and blasting rose from Rs. 12.27 per tonnes, to Rs. 12.87 per tone, in 2014-15. This has translated into improvement in shovel productivity increase, from 250 TPH to 270 TPH for the same period. and power consumption of crusher has been reduced . Subsequently, the uniform sizing of blasted material resulted in savings in power consumption in the processing plant. In 2013-14 the consumption of electricity was 3.36 KwH/T was brought down to 3.08 KwH/T in 2014-15.

(D) Fuel consumption in dumpers – In any dumper, fuel consumption influences the total overall cost of transportation. Apart from the volume handled, fragmentation of the ROM, haul road condition, number of curves on the haul road, gradient, dust concentration on the haul roads, visibility, illumination, skill of the operator, quality of maintenance also influences the fuel consumption.

In this mine many changes in the system of the engine were introduced with a view to save fuel.

(i) With the use of magnetic resonators in dumpers fuel savings was 5%(previously 19 ltr /Hr reduced to 18 tr / Hr). (Figure 2).

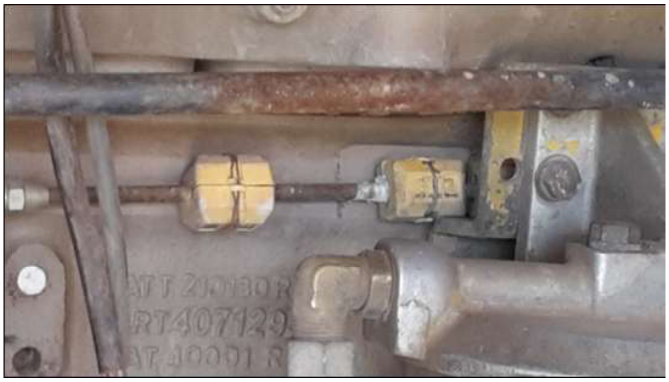


Figure 2 : Use of magnetic resonators in dumpers

(ii) In dumpers Quantum Series Engine (QSM) has been used for fuel saving-which resulted in saving of 6 litres of diesel per Hr (from 19 litres/Hr to 13 litres/Hr).(Figure 3)

Figure 3 : Showing QSM Engine in dumpers

(iii) Battery is maintained always in good condition for quick start.
(iv) Use of electronic fuel pump (ECM).
(v) Dumper refuelling (Figure 4).

Figure 4 : Showing Dumper fuel refilling by mobile diesel dispenser

Previously,each dumper was brought to diesel pump for refilling causing wastage of fuel and manpower. One estimate showing fuel saving by this system is explained below -
A dumper, if goes to diesel pump for refilling and back, takes about half an hour.
Per day about 8 dumpers goes for refilling.
Diesel consumption of dumper/ hr = 18 Liters
Diesel saving per day : 18 x 0.5x 8 = 72 Liters
Diesel saving per year : 300 x 72 = 21,600 Litres
(vi) Similarly for Tyre inflating- Previously each dumper as brought to the air compressor station for tyre inflation. By laying a pipeline connected to a compressor along the dumper parking area with several air nozzles and valves, dumper tyres can be inflated at the parking place itself.(Figure 5).

Figure 5 : Dumper inflation system

Resultant fuel saving is - a dumper, if goes to air compressor for tyre inflation and back, takes about half an hour.

Per day about 4 dumper goes for tyre inflation.
Diesel consumption of dumper/hr = 18 Liters
Diesel saving per day :18 x 0.5x 4= 36 Liters
Diesel saving per year : 300 x 36 = 10,800 Litres

(E) Frequency of Blasting - Long blasting faces instead of 2-3 small blasts, using bulk SME explosives helped in planning larger blasts thereby reducing drill movement and shifting, reduction in blasting time and number of days of blasting improved production hours.

(F) Lubricants : Hous keeping, storage, handling of lubricants before use is one critical area which contribute to its optimum use. During use in any HEMM, adequate care is needed for filling in a dust free environment.

(i) Leakages contribute to almost 10 to 15% of lubricants used in Indian mining industry. To check this mines have to draw SOPs and also evolve a system of detection and rectification to arrest leakages. Oil Leakages has been reduced by-

- By planning, changing all the hydraulic hoses as a kit at recommended interval.
- Avg. life of all the major components are monitored and suitable replacement action is taken
- Centrifuging the used hydraulic oil & reusing it.
- Concentration of machines i.e. placement of more than one machine at same loading point always allow at least one machine to be available for preventive maintenance.

By implementing the above aspects, lube oil consumption was brought down from 0.016 litr/tonne to 0.012 litre/tonne of limestone production.

(ii) House Keeping of Lube Oil Storage Room – Spillage free oil room is essential for safe handling as well as protection against fire etc.(Figure 6)

Figure 6 : Houxsekeeping in a Lube Oil store

ELECTRICAL ENERGY SAVING

The rise in cost of electricity, emphasis on Energy Conservation as per provisions of Energy Conservation Act of 2001 and Amendment in 2010, mandatory Energy

Audit , efforts were made to study the consumption pattern, wastage, and scope for replacing existing gadgets with more efficient systems. The mine had also resorted to frequent measurement, testing and regular maintenance of the instruments/switches as perthe OEM. Some of the energy saving areas are stated below :

1.Pumps : Electrical energy is being used only for Dewatering Pumps

- Previously, 150-180 HP (115 -135 KW) Centrifugal Pumps were used for mine dewatering. These pumps were replaced by 75 HP (56 KW) Submersible Pumps, with same Water capacity. This has resulted in a saving of 60-70 KwH power per hour
- In rainy season on an avg. 5 pumps runs for about 10Hrs per day, Thus saving per day is : 5X60x10 = 3000 KwHr

Figure 7, shows the open aqua-duct (named Baikunth Ganga), water channel built to carry the pumped water by gravity, upto the mine top upto a water reservoir. Thus about 1 Km. of pipeline was dismantaled. This has increased the pumping efficiency.

Figure 7 : Baikunth Ganga

MINE ILLUMINATION(FIGURE 8)

- Use of portable genset for illumination by installing portable towers with generator sets, which can be shifted to working faces , could reduce number of fixed lighting towers.

Figure 8 : Portable Illumination system

Other areas : Dumper tyre life not only influences the cost of transportation, but also seriously cause production disruptions. The last few years saw sever non-availability of dumper tyres in the market. In order to ensure better tyre life the following steps were taken –

- Cold tyre inflation is done by virtue of this : air leakages has been eliminated.
- Use of portable tyre cage during tyre inflation : safety & confidence level of fitter increased (Figure 9).
- Regular cleaning of loading place by small pay loaders
- Stone ejector rod at dumpers for tyre protection (Figure 10).

Figure 9 : Portable Tyre cage

Figure 10 : Stone Ejector Rod

We thankfully acknowledge the management of UltraTech Cement Ltd for their valuable guidance.

The Indian Mining & Engineering Journal, Vol. 60, No.12 December 2021, pp.60-67
Printed in India, @ IME Publications, ISSN 0019-5944

Discomfort level from Blasting vibration: Case study in NCL Mines

Sayeed Ghori* Rajen Mech**

INTRODUCTION

Presently Northern Coalfields Ltd use bulk explosives for blasting to the tune of Two lakhs metric tonne every year, which is highest in any coal producing companies in India. This huge usage of bulk explosives for blasting and the consequence, primarily ground vibration in and around Singrauli township is always in limelight with the public and local print media.

In spite of implementing every scientific measure to control ground vibrations, the effect is still at large. Therefore, a study was carried out with a team from NCL. The projects selected for the study were Dudhichua, Jayant and Nigahi where the effect of blast and vibration is felt the most in Singrauli township.

STUDY OF BLAST INDUCED GROUND VIBRATION LEVEL

For the purpose of the study, 5 stations were selected in Singrauli Township to measure the PPV readings which almost covers the total township of Singrauli. Five Sets of vibrometer instruments were fixed with a dedicated team from NCL and Bulk Explosive Suppliers.

Blasting in all the three projects (namely Dudhichua, Jayant and Nigahi) undertaken exactly at the same time and PPV readings at vibration monitoring stations were recorded. The data related to bench parameters, explosives consumed, maximum charge per delay and initiation pattern was also recorded. This was done to understand the blast induced ground vibration level, when blasting in these three projects are conducted at the same time. Recording at Projects and vibration reading at stations were analysed.

CASE STUDY

Objective

i. Instances of high ground vibrations felt in and around Singrauli township which resulted in high publicity in print media.
ii. To study the actual ground vibration recordable through scientific instrument.
iii. Recommend to further lower the ground vibration in and around singrauli township.

Projects identified for undertaking the detailed the study are -

A) Dudhichua,
B) B) Jayant, &
C) C) Nigahi

Brief description of the study

During the month of May'21, there was high publicity in the local print media with regards to high ground vibrations being felt in and around Singrauli Township. Even before May'21, there was some instances of publications in the media however it short lived. Now, in order establish that the ground vibrations in and around Singrauli is within the DGMS permissible standard as under: -

Type of structure	Dominant excitation Frequency, Hz		
	<8Hz	<8-25 Hz	>25 Hz
(A) Buildings/structures not belong to the owner			
(i) Domestic houses/structures (kuchha brick & cement)	5	10	15
(ii) Industrial Buildings (RCC & Framed structures)	10	20	25
(iii)Objects of historical importance & sensitive structures	2	5	10
(B) Buildings belonging to owner with limited span of life			
(i) Domestic houses/structures (kuchha, brick & cement)	10	15	25
(ii) Industrial buildings (RCC & framed structures)	15	25	50

- To accomplish is purpose, few prominent places in and around Singrauli township was selected where vibrometers were set to record ground vibrations due to blasting which are as: -
  a) Morwa Thana
  b) Shiv Mandir, Singrauli Town

**General Manager, Block B **Chief Manager (Mining), Prodn. Deptt. Northern Coalfields Ltd, Singrauli*

c) Ayappa Mandir, Nearing Jayant Boundary
d) NCL HQ
e) BPCL Petrol Pump

The distance from the projects edge with measuring stations are as under: -

Point No	Location	Distance from Location /point (in Km)				
		NCL HQ	Morwa Thana	Petrol Pump	Ayappa Mandir	Shiv Mandir
1	Nigahi OB Edge	5.50	5.00	4.50	4.10	2.80
2	Jayant OB Edge	2.70	2.30	2.35	1.00	1.40
3	Dudhichua OB Edge	3.50	3.60	4.30	2.30	3.80

Study period - 1st June to 5th June 2021

MODALITIES OF THE STUDY

i. For the purpose of the study. a team consisting of two officials from production department HQ, blasting Managers of Dudhichua, Jayant and Nigahi along with representatives from M/s IOCL. M/s IDL and M/s Solar.
ii. A WhatsApp group was created with all the team members and vibration station monitoring team. All communication of blasting time and readings of ground vibration was circulated in the WhatsApp group.
iii. All timing noted in vibration reading as well as blasting time was the MOBILE TIME, to avoid any time difference.
iv. Blasting time with No. of holes, dia of holes, place of blasting, quantity of blasting material charged along with initiation system was noted and uploaded in the WhatsApp group.
v. Similarly, at the ground vibration monitoring stations, all vibrations recorded are circulated with time and reading.
vi. Compilation was done at HQ production department.

Observations

i. PPV reading of all stations was studied and reading which has maximum value was noted from top downwards along with time.
ii. Taking time as mainframe, blasting done during that particular timing with maximum PPV value was note from the blast reports received from Projects.
iii. All PPV readings recorded when blasting done at Projects at the same time frame was studied.
iv. All PPV reading more than 0.300 PPV which is generally perceived by human body was studied.
v. Corresponding to the above PPV readings, blast done at Projects with quantity of explosives used and initiation type is tabulated.

Date 1st June 2021

Blasting & PPV reading time		Vibration Reading (mm/sec)					Qnty of expl Used (Kg)
		NCL HQ	Petrol Pump	Shiv Mandir	Police Station	Ayappa Temple	
1:34 PM	Nigahi	0.267 (01:34:30)	No Trigger	0.215 (01:34:01)	No Trigger	No Trigger	19000
1:39 PM	Nigahi	0.496 (01:39:39)	0.25 (01:39)	0.213 (01:40:59)	No Trigger	No Trigger	11000
1:24 PM	DCH	0.437 (01:24:27)	No Trigger	No Trigger	No Trigger	No Trigger	10000
1:34 PM	DCH	0.267 (01:34:30)	No Trigger	0.215 (01:34:01)	No Trigger	No Trigger	12700
1:25 PM	DCH	0.294 (01:25:55)	0.51 (01:25)	No Trigger	No Trigger	No Trigger	17000

From above, it can be seen that at the same timing 01:34:30, blasting at Nigahi as well as Dudhichua triggered at the same time, corresponding to this time reading of two place i.e. at NCL HQ as well as Shivmandir,Singrauli recorded @ 0.267 & 0.215 ppv. However, the quantity of bulk used was 19000 Kg at Dudhichua and 12700 Kg at Nigahi. This reading must be because of Resonance effect. Similarly, at Dudhichua, blast done at 1:24 PM and 1:25 both recorded 0.437 and 0.294 at NCL HQ and 0.51 PPV at Petrol Pump, this also could be the effect of Resonance.

Blasting at Nigahi BLA (W), which gave a PPV reading of 0.496 (HQ), 0.25 (Petrol Pump) & 0.213 (Shivmandir) needs further study.

Date 2nd June 2021

Blasting & PPV reading time		Vibration Reading (mm/sec)					Qnty of expl Used(Te)
		NCL HQ	Petrol Pump	Shiv Mandir	Police Station	Ayappa Temple	
1:12 PM	Nigahi	0.173 (1:12)	No Trigger	0.279 (01:12:37)	No Trigger	No Trigger	3375
1:13 PM	Nigahi	0.347 (01:13)	No Trigger	0.345 (01:13:09)	0.254 (01:13:56)	No Trigger	12700
1:24 PM	Nigahi	0.229 (01:24)	0.7 (01:24)	0.210 (01:25:22)	No Trigger	No Trigger	900
1:34 PM	Nigahi	0.276 (01:34)	No Trigger	No Trigger	0.349 (01:34:24)	No Trigger	13100
1:40 PM	Nigahi	0.244 (01:40)	No Trigger	0.436 (01:41:13)	No Trigger	No Trigger	22000
1:44 PM	Nigahi	0.449 (01:44)	No Trigger	0.209 (01:45:34)	0.333 (01:44:43)	No Trigger	28000
1:56 PM	Dudhichua	1.427 (01:56)	No Trigger	0.549 (01:56:53)	No Trigger	0.953	30000
1:16 PM	Dudhichua	0.307 (01:16)	No Trigger	0.302 (01:16:17)	No Trigger	No Trigger	8000
1:32 PM	Dudhichua	0.457 (01:32)	4.32 (01:32)	0.263 (01:33:39)	No Trigger	No Trigger	7500
1:54 PM	Dudhichua	0.489 (01:54)	No Trigger	0.210 (01:54:01)	No Trigger	No Trigger	16000
1:26 PM	Dudhichua	0.402 (01:26)	No Trigger	0.290 (01:27:02)	No Trigger	No Trigger	13000
1:53 PM	Dudhichua	0.197 (01:53)	No Trigger	0.639 (01:53:38)	No Trigger	No Trigger	11500
1:12 PM	Jayant	0.229 (1:12)	5.33 (01:12)	0.279 (01:12:37)	0.25	No Trigger	12480
1:19 PM	Jayant	0.221 (01:20)	No Trigger	0.351 (01:20:06)	No Trigger	No Trigger	9520
1:57 PM	Jayant	0.339 (01:57)	No Trigger	0.524 (01:57:02)	No Trigger	No Trigger	13944

- On day 02/06/2021, as it can be seen from the chart, blasting done at 1:12, Blasting was done simultaneously at Jayant and Nigahi and PPV recording was done at all the 4 stations except at Ayappa Mandir. This could also be the effect of Resonance.
- Blasting at 1:56 PM Dudhichua (S/D Dept) with 30 Mt of explosives (Electronic firing), where ppv reading could be recorded in 3 stations ranging 1.427 (HQ), 4.32 (Petrol Pump) & 0.953 (Ayappa Mandir). This type of blasting to needs further study to minimize the PPV readings at Singrauli township.
- Timing of Jayant Blasting at 1:57 PM could also attribute to the above.

Date 3rd June 2021

- Similar to the above dates, Blasting done at 1:24 PM, triggered PPV reading in all the stations except Petrol Pump. The quantity of explosives used was 37 MT, S/D (W) used electronic as initiation system This type of blasting needs further study to reduce the PPV readings. Simultaneously Jayat and Dudhichua also blasted at 1.24 & 1.23 PM. Needs study.
- Blasting at 1:18 at Jayant D/L (E) with 17 Mt of explosives also need to be reduced in PPV readings.

Date 3rd June 2021

Blasting & PPV reading time	Project	Vibration Reading (mm/sec)					Qnty of expl Used (Te)
		NCL HQ	Petrol Pump	Shiv Mandir	Police Station	Ayappa Temple	
1:11 PM	Nigahi	0.348 (01:12:44)	No Trigger	0.374 (01:11:39)	No Trigger	No Trigger	2170
1:21 PM		0.981(01:21:48)	No Trigger	No Trigger	0.333 (01:21:46)	1.207 (01:21:25)	3200
1:24 PM		1.301 (01:24:20)	No Trigger	0.993 (01:25:06)	1.38 (01:25:15)	3.302 (01:24:55)	37000
1:26 PM		No Trigger	No Trigger	0.202 (01:26:27)	No Trigger	No Trigger	2000
1:29 PM		0.160 (01:29:10)	No Trigger	No Trigger	No Trigger	No Trigger	5200
1:32 PM		No Trigger	No Trigger	No Trigger	No Trigger	No Trigger	26000
1:36 PM		0.254 (01:36:47)	No Trigger	0.220 (01:36:57)	No Trigger	No Trigger	22000
1:56 PM		No Trigger	No Trigger	0.225 (01:56:16)	No Trigger	No Trigger	27500
1:01 PM	Jayant	No Trigger	No Trigger	No Trigger	No Trigger	No Trigger	20190
1:03 PM		No Trigger	No Trigger	No Trigger	No Trigger	No Trigger	12466
1:18 PM		0.159 (01:19:06)	0.95	0.264 (01:18:47)	1.27 (01:18:52)	3.493 (01:18:31)	17000
1:20 PM		0.343 (01:20:27)	No Trigger	0.205 (01:20:40)	No Trigger	No Trigger	2760
1:21 PM		0.981(01:21:48)	No Trigger	0.211 (01:21:45)	No Trigger	1.207 (01:21:25)	9400
1:22 PM		0.487 (01:22:45)	No Trigger	0.256 (01:22:24)	0.730 (01:22:45)	No Trigger	10340
1:24 PM		1.301 (01:24:20)	No Trigger	No Trigger	0.413 (01:24:21)	3.302 (01:24:55)	8980
1:24 PM	Dudhichua	0.547 (01:24:54)	0.51	0.215 (01:25:01)	0.318 (01:24:04)	No Trigger	12000
1:29 PM		0.519 (01:29:51)	No Trigger	No Trigger	No Trigger	No Trigger	4500
1:30 PM		0.615 (01:30:59)	No Trigger	No Trigger	No Trigger	No Trigger	22000
1:32 PM		No Trigger	No Trigger	No Trigger	No Trigger	No Trigger	9000
1:20 PM		No Trigger	No Trigger	No Trigger	No Trigger	No Trigger	8000
1:23 PM		0.587 (01:23:26)	No Trigger	No Trigger	1.57 (01:23:31)	No Trigger	21000

Date 4th June 2021

Blasting & PPV reading time	Project	Vibration Reading (mm/sec)					Qnty of expl Used (Te)
		NCL HQ	Petrol Pump	Shiv Mandir	Police Station	Ayappa Temple	
1:28 PM	Nigahi	0.262 (01:29:16)	No Trigger	0.210 (01:29:02)	0.318 (01:28:39)	No Trigger	22000
1:35 PM		0.371 (01:35:19)	0.13	0.262 (01:36:56)	No Trigger	No Trigger	19000
1:38 PM		0.918 (01:39:28)	No Trigger	0.221 (01:39:33)	No Trigger	No Trigger	30000
1:40 PM		0.469 (01:40:49)	No Trigger	0.293 (01:41:25)	0.524 (01:40:36)	No Trigger	31000
1:44 PM		0.207 (01:44:48)	0.38	1.142 (01:44:16)	0.699 (01:44:18)	No Trigger	145000
1:53 PM		0.644 (01:53:24)	No Trigger	No Trigger	No Trigger	No Trigger	2500
1:01 PM	Jayant	No Trigger	0.76	No Trigger	0.365 (01:01:31)	No Trigger	15510
1:05 PM		No Trigger	No Trigger	No Trigger	0.635 (01:05:40)	No Trigger	10430
1:10 PM		No Trigger	No Trigger	No Trigger	0.270 (01:09:53)	No Trigger	16500
1:23 PM	Dudhichua	1.153 (01:23:59)	No Trigger	0.224 (01:23:02)	0.413 (01:24:21)	No Trigger	10000
2:15 PM		No Trigger	No Trigger	No Trigger	No Trigger	No Trigger	16300
2:20 PM		No Trigger	No Trigger	No Trigger	No Trigger	No Trigger	20000
1:30 PM		0.248 (01:30:43)	No Trigger	0.209 (01:30:57)	No Trigger	No Trigger	13000
1:44 PM		0.186 (01:44:39)	No Trigger	0.558 (01:44:19)	No Trigger	No Trigger	7000
1:48 PM		0.256 (01:48:47)	No Trigger	0.209 (01:48:49)	No Trigger	No Trigger	10000

Summary

i. From the ground vibration readings taken during 1st to 5th June 2021, it is clear that the PPV readings are within the Permissible Limit's Standards prescribed by DGMS.

ii. As per a paper published in Environmental and Earth Sciences Research Journal (*Vol-7 No 3 September 2020 pp 109-115), "Vibration* Discomfort Levels caused by Blasting according to Gender is as Under: -

Perception and annoyance level evaluation in terms of gender

PPV (mm/s) for Women	PPV (mm/s) for Men	Limit Level of
0.80	0.80	Perception
0.84	0.84	Not Annoyed
2.27	2.27	Slightly Annoyed
5.05	10.4	Moderately Annoyed
16.7	17.4	Extremely Annoyed

Date 5th June 2021

Blasting & PPV reading time	Project	Vibration Reading (mm/sec)					Qnty of expl Used (Te)
		NCL HQ	Petrol Pump	Shiv Mandir	Police Station	Ayappa Temple	
1:31 PM	Nigahi	No Trigger	2.29	0.416 (01:31:05)	No Trigger	No Trigger	29000
1:33 PM		0.434 (01:35:36)	1.21	0.211 (01:34:49)	0.349 (01:34:24)	No Trigger	1200
1:38 PM		No Trigger	0.25	0.220 (01:39:59)	No Trigger	No Trigger	15000
1:40 PM		No Trigger	No Trigger	0.210 (01:40:02)	0.524 (01:40:36)	No Trigger	13100
1:43 PM		No Trigger	No Trigger	0.312 (01:43:26)	0.381 (01:43:53)	No Trigger	15000
1:43 PM		No Trigger	1.02	0.290 (01:43:23)	0.699 (01:44:18)	0.508 (01:44:21)	9500
1:46 PM		No Trigger	0.25	0.204 (01:48:02)	No Trigger	No Trigger	34000
1:01 PM	Jayant	1.931 (01:04:46)	0.32	0.220 (01:02:57)	0.365 (01:01:31)	0.508 (12:59:44)	23010
1:08 PM		No Trigger	0.32	0.308 (01:08:23)	0.270 (01:09:53)	2.921 (01:08:36)	14425
1:16 PM		No Trigger	0.25	0.437 (01:16:08)	0.429 (01:16:03)	1.143 (01:15:36)	8120
1:38 PM	Dudhichua	No Trigger	3.94	0.220 (01:38:09)	No Trigger	No Trigger	29000
1:26 PM		1.766 (01:25:39)	1.91	1.086 (01:26:06)	No Trigger	1.651	63000
1:20 PM		0.181 (01:21:30)	No Trigger	0.212 (01:20:57)	0.333 (01:21:46)	No Trigger	6000
1:36 PM		No Trigger	No Trigger	0.308 (01:36:10)	No Trigger	No Trigger	28000
1:42 PM		No Trigger	0.76	0.347 (01:42:46)	No Trigger	No Trigger	10000
1:46 PM		No Trigger	0.25	0.209 (01:46:49)	No Trigger	No Trigger	6500
1:31 PM		No Trigger	1.46	0.294 (01:31:02)	No Trigger	No Trigger	12500
1:30 PM		0.355 (01:29:45)	No Trigger	0.251 (01:30:04)	No Trigger	No Trigger	10000
1:27 PM		No Trigger	No Trigger	No vibration	0.318 (01:28:39)	No Trigger	4500

NCL conducts 5-6 blast per day in different project hence daily blasting activities can be felt by people living in the proximity to the Areas where explosives are used. They can be uncomfortable with the blast induced vibration, even if the vibration levels are within the permissible limits for the structure according to the regulation. In these circumstances the problem turns from a structural damage problem into people's complaint and lawsuits about these complaints.

The sensitivity of human body is more than 10 times greater than that of building. The Human response to the blast induced vibration can be physiological and/or psychological.

The threshold of human perception for blast vibration ground motion is around 0.762 mm/sec. The PPV reading of our blasting is generally ranging from 0.1 mm/sec (minimum) to 3.3 mm/sec (maximum). Most of the time it is less than 0.50 mm/sec but sometimes it goes more than 1.0 mm/sec. But all these values are within the permissible limit of DGMS guidelines. People living close to mining areas in which explosives are used for excavation should not feel uncomfortable during blasting operation. In order to avoid this issue human perception of blast induces vibration is being considered and blasting operation is being performed by taking into account human discomfort level Ground vibrations is inevitable with

iii. The summary of the study conducted during 1st to 5th June 2021 is presented below showing the Perception and Annoyance level is as under: -

Date	Summary of PPV recorded at Different Measuring Stations (PPV mm/s) vis-à-vis Perception and Annoyance level					
	NCL HQ	Petrol Pump	Shiv Mandir	Police Station	Ayappa Temple	Place of Blasting
1st June 2021	< 0.8.	< 0.8.	< 0.8.	< 0.8.	< 0.8.	
2nd June	< 0.8.	< 0.8.	< 0.8.	< 0.8.	>0.8 (0.953)	
3rd June	>0.8 (0.981		>0.8 (0.95)		> 0.8 (1.207)	Nigahi
	> 0.8 (1.301)		>0.8 (.993	>0.8 (1.39-8)	>2.27 (3.302)	Nigahi
	>0.8 (0.981))				>0.8 (1.207)	Jayant
	>0.8 (1.301)				>2.27 (3.302)	Jayant
				> 0.8 (1.57)		Dudhichua
4th June	>0.8 (0.918)					Nigahi
	>0.8 (1.153)					Dudhichua
5th June		2.29				Nigahi
		1.21				Nigahi
	>0.8 (1.931)					Jayant
	>0.8 (1.766)	1.91	>0. 8 (1.086)		>0.8 (1.651)	Dudhichua

blasting and PPV reading below 0.80 m/s is negligible and can be allowed at different stations as per the perception and annoyance level.

PPV reading above 0.8 mm/s is generally perceived by human body and needs to be taken into consideration for reduction. In the study, except in few PPV reading stations, all PPV readings were normal. However, utmost care should be taken by projects to reduce the PPV readings at Singrauli township within 0.5 to 0.8 PPV.

SUGGESTED MEASURES/RECOMMANDATIONS

1. There is a correlation with quantity of explosives used for blasting and PPV reading. Therefore, the present practice should be continued. However, delay per kg charge should be reviewed whenever the level of PPV increases in Singrauli Township beyond 0.80 mm /s.
2. Charging and blasting in the following patches should be under strict supervisions for quantity of explosives charged, delay used, and initiation system.
    i. Dudhichua West
    ii. Jayant full Mine
    iii. Nigahi East.
3. Continuous, up gradation of system improvement in blasting is followed in NCL by using latest technology of blasting through electronic detonators, Nonels etc Dragline and Shovel (Dept) blasting should be blasted only with electronic detonators: -
    - Use of NONEL in HOE Benches in Dudhichua (W), Jayant (Full) Nigahi (E).
    - Stemming column should be increased in top Benches to avoid fly rock.
4. Dragline Blasting at Nigahi Projects is done with Pre splitting, as a result, ground vibration from Nigahi Project as recorded in the study period showed minimum PPV, in view of this, since Jayant and Dudhichua project is very close to Singrauli Township, adoption of Pre splitting at these Projects must be made to mandatory.
5. Blast timing should be staggered in all the three projects, as it is seen from the study that whenever, any blast takes place simultaneously, the PPV reading is increased, this may be the effect of Resonance. Therefore, timing of Blasting can be staggered

(***Which can be formulated after consultation with Projects***).

6. Awareness drive amongst the local population of Singrauli township can be formulated with active participation of PRO, NCL. Banners/postering/glow sign boards/hoardings at prominent places for local public to know the limits of Ground vibrations and remove the fear psychosis amongst the populations.
7. Demarcation of Danger zone on the ground may be ensured by concern project either by signboard or cutting trench.
8. To eliminate blasting Operation, NCL has commissioned 8 nos. of Surface Miner in different projects for cutting of coal and also to promote green environment.

CONCLUSION

During analysis of PPV reading with date/time wise, it was observed that blasting done simultaneously in two different projects gave a high PPV readings, this could have been due of the effect of **"Resonance",** therefore in the recommendation after the study, time of blasting was staggered in all the three projects. From the ground vibration reading taken 1st to 5th June 2021, it was observed that all the PPV readings were within the Permissible Limit as laid down by DGMS Standards.

According to the study published in the 'Environment and Earth Sciences Research Journal (Vibration Discomfort Levels Caused by Blasting According to Gender, by Tugce Ongen, Gurcan Konak, and Dogan Karakus, Vol-7 No 3 Sept 2020 pp 109-115)' – *"Peak particle velocity and scaled distance graphs were plotted and survey data related to perception and discomfort level have been evaluated for men and women, separately, using these graphs. The lower perception limit which is the same for women and men is 0.836 mm/s. But discomfort levels are affected by gender. It means that different annoyance levels were obtained according to gender. As the peak particle velocity increases, annoyance levels change according to gender. For example, while the moderately annoying level is 5.05 mm/s for women, it is 10.4 mm/s for men"* during the study period most of the PPV readings were below or less than 0.08 mm/s. This was recommended for implementation in projects.

Acknowledgement

Thanks are due to our colleagues in the Production Department, Projects (of Jayant, Dudhichua, and Nigahi), and the management of NCL for undertaking this study.

The Indian Mining & Engineering Journal, Vol. 60, No.12 December 2021, pp.68-72
Printed in India, @ IME Publications, ISSN 0019-5944

Effect of Accuracy in Timings of Delay Detonators on Intensity of Blast Induced Ground Vibration

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ABSTRACT

Ever-increasing demand of coal and metal have forced the mining industries to perform a big size blast in open pit and as well as in underground mines. In these circumstances, role of delay timings become very significant. In India, currently cord relays and MS connector with detonating fuse and Nonel delay detonators (shock tube) are very common. In recent time, electronic delay detonators have also been usen at large scale in open pit and underground metal mines. The delay-time accuracy in delay detonators play a very important role in controlling ground vibration as the calculation of maximum explosives weight per delays is mainly rely on this. In general, each detonator has an allowable error range of delay-time due to the difference in manufacturing process. In the initiation network, the errors of delay-time often accumulate gradually as the number of detonators increases. Therefore, theoretical delay-time and actual delay-time with error in the detonating network have been discussed in this paper based on the delay-time errors of detonators. The comparative test of blast-induced vibration has also been carried out using the NONEL and electronic/digital delay detonator. The test results showed that the very good quality of Nonel/digital electronic detonator must be used while blasting in sensitive locations in order to control the vibration. In this paper, the actual firing time of different delay detonators were analysed at open pit Coal and Iron mines and at underground lead-zinc mine. The impact of scattering in detonator timing on vibration and fragmentation has been analysed.

INTRODUCTION

Global industrialization and high prices of alternative energy sources have driven demand for coal and metalliferous minerals, which in turn has encouraged the worldwide market for mining industry. The manifold increase in demand of coal and minerals has necessitated to increase the production pace of mining industry, which ultimately require large production blast in open pit and in underground mines. Blasting is still one of the most efficient and cheapest methods for excavation in mines, hydropower projects, highways and tunnel. Thus, the demand of commercial explosive is scaling new heights in the Indian mining and civil industries. In the present scenario of growing demand of coal and metalliferous minerals, a synergistic approach integrating the knowledge of rock-explosive interactions will play a pivotal role for achieving optimal explosive energy utilization with enhanced productivity [4].

A great improvement in blasting technology occurred with the application of delayed blasting in the 1940's and 1950's. Although the technique was originally developed to provide improved fragmentation through control of lateral and forward blast relief but the time spreading of the blast energy also resulted into lower peak ground vibrations, flyrock and air-overpressure. Blasts are normally carried out using delay intervals within a row, between rows and more recently within the holes. Very often, it is reported that production blasts generate vibration two to three times higher than those produce from single charges despite the same charge weight within 8 ms delay interval. Singh and Roy [3] demonstrated the damage due to blast-induced vibration to reinforced concrete and cement mortar structure using blast vibration monitoring. Blair [1] proved the influence of charge weight on blast vibration during surface blasting and underground blasting, which showed that the charge weight have a great impact on surface blasting but less on underground blasting.

Most of the researchers have confirmed that millisecond blasting technique was the most effective method to control blast-induced ground vibration by using accurately designed delay gap among the blast holes [5]. Seismic properties during blasting in different geological conditions optimise the delay-time [2, 6]. Qiu et al. [5] reported the stress wave superposition characteristics in short-delay blasting with numerical simulation.

The mechanism of delay-time in different kinds of detonators has nothing in common. At present, high-precision detonators and digital electronic detonators are most commonly used in hole-by-hole initiation technology

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[7]. The former provides the delay-time through chemicals in detonators, and the latter use electronic chips. Both of them have delay-time errors. The delay errors of detonators would affect blast-induced vibration by changing the initiation time of blast hole. So far, few research studies concentrated on delay-time errors of detonators. This paper focuses on investigating the influence of delay-time errors of detonators on blast-induced vibration thorough theoretical analysis and field experiments.

TESTING OF DELAY DETONATOR TIMING AND ITS ANALYSIS

The different method/instrument have been used to determine the actual firing time of delay detonators viz. Delay time velocity meter using breaking wire technique, VOD recorder by using VOD trace graph between the initiation and detonation time of detonators and most recently by using High speed video camera (>500 fps) by calculating the interval between the actual ignition and firing time of detonators after analysing the video data.

The delay-time of surface detonators in open-pit deep hole blast generally adopted 17 ms, 25 ms, 42 ms, 65 ms and 100 ms. The down-the-hole delay-time in blast hole were commonly available of 250 ms, 400 ms, 450 ms and 500 ms. In underground metal mines, NONEL delay detonators of 200 ms to 7500 ms is very common. In recent times, electronic/digital delay detonators are replacing NONEL at many metalliferous open pit and underground (UG) mines.

Figure 1 represents the scattering data recorded with the help of Data/VOD recorded for a delay of 6300 ms at one of the UG mine of Hindustan zinc Limited (HZL). The scattering test results of Nonel delay detonators at Iron ore mines of Tata Steel Limited is presented in Figure 2. Experimental setup for actual detonation time recording with the help of High-speed camera along with its detonation view is presented in Figure 3. Graphical presentation of the design firing vs actual firing time of Nonel delay detonators used in UG mines of HZL is depicted in Figure 4. The result of actual firing time detonation of electronic delay detonator is shown in Table 1 for two numbers of test setup.

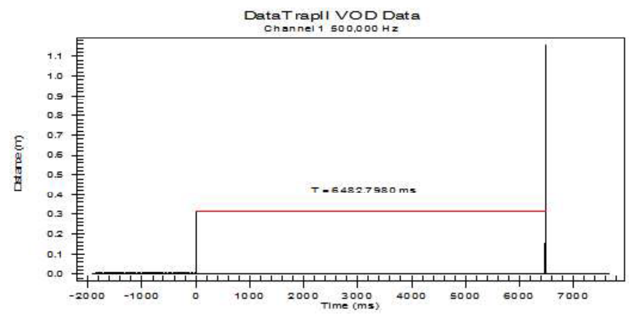

Figure 1. Signature of quality control test of Long Delay Series (LDS-6300ms) showing the actual firing time of 6485ms using VOD/Data trace graph

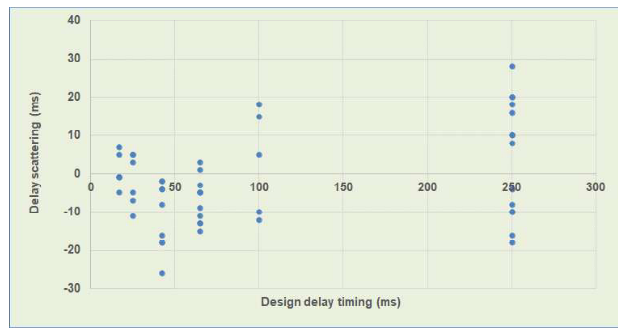

Figure 2. Scattering in Nonel delay detonator recorded at Iron ore mines of Tata Steel Ltd

Figure 3: Testing of delay scattering of different delays used in underground mines of Hindustan Zinc Limited with the help of High-speed camera and its analysis with the help of ProAnalyst software.

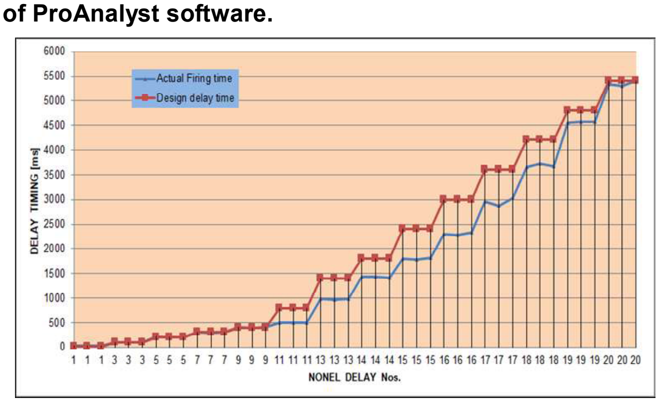

Figure 4. Graphical presentation of the designrd firing vs actual firing time of Nonel delay detonators used in underground mines of Hindustan Zinc Limited

Table 1. Result of delay scattering test conducted for electronic delay detonator at UG mines of Hindustan Zinc Limited

S. No.	Design delay timing (ms)	Actual Firing timing (ms)	Scattering (ms)	% of scattering
Test-1				
1	0	0	0	0.00
2	65	64	-1	-1.54
3	100	99	-1	-1.00
4	250	250	0	0.00
5	450	450	0	0.00
6	600	600	0	0.00
7	900	901	1	0.11
Test-2				
1	0	0	0	0.00
2	1200	1200	0	0.00
3	1800	1801	1	0.06
4	2100	2102	2	0.10
5	2800	2802	2	0.07
6	3300	3304	4	0.12
7	4100	4106	6	0.15
8	5300	5302	2	0.04

IMPACT OF SCATTERING IN DELAYS ON BLAST INDUCED VIBRATION

The drilling and blasting parameter at Sonepur Bazari Project, plan showing blast design layout along with the initiation sequence and output of simulated blast design practiced at Dragline bench of Sonepur Bazari project along with detonation timing contours and number of decks detonated vs. detonation time is shown in Figure 5.

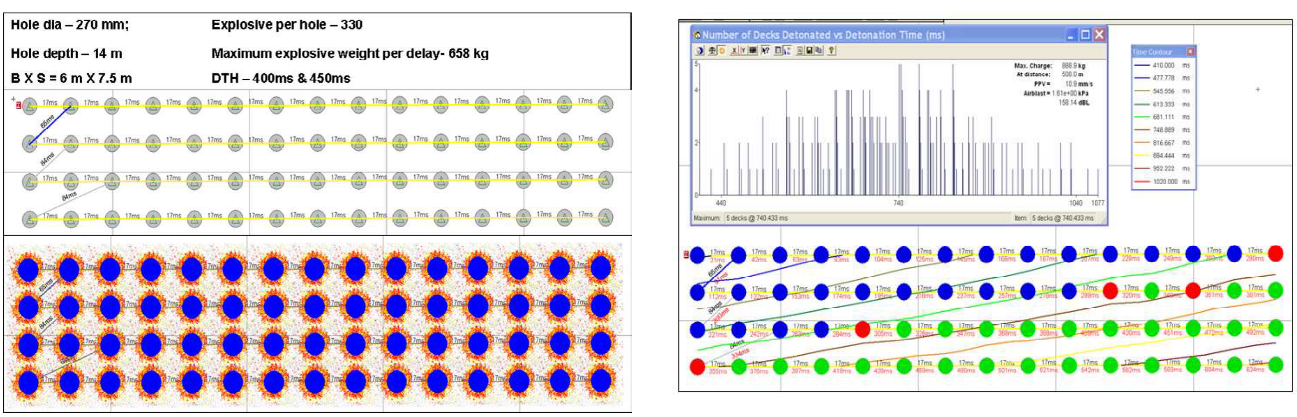

Figure 5. Plan showing blast design layout along with the initiation sequence and simulated blast output of Sonepur Bazari project

The change in explosives charge weight per delay (Q_{max}) for the blast design shown in Figure 5 due to scattering was simulated by JKSimblast software using Monte Carlo simulation. The simulation output is shown in Table 2. Fifteen experiments were simulated with scattering percentage of 1 to 15. The scatter diagram showing the trend of variation in explosives charge weight per delay with increased scattering percentage is shown in Figure 6.

Table 2. Change in explosive charge weight/delay due to scattering in detonator timing

Designed experiment number	% of scattering	Q_{max} (with designed delay)	Q_{max} (with actual delay)
1	1	658	889
2	2	658	1021
3	3	658	1021
4	4	658	889
5	5	658	1350
6	6	658	1152
7	7	658	1021
8	8	658	988
9	9	658	1021
10	10	658	1218
11	11	658	1251
12	12	658	1119
13	13	658	1218
14	14	658	922
15	14	658	1218

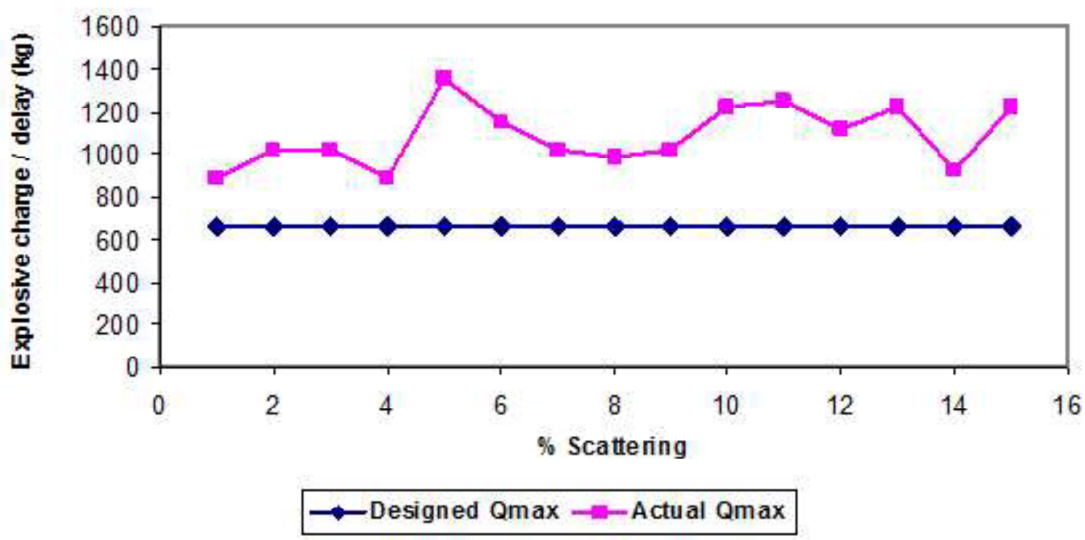

Figure 6: Trend of variation in explosive charge/delay with increased scattering percentage

CONCLUSIONS

The recorded delay scattering data indicates that the value is in higher side in case of Nonel delay detonator in comparison to electronic delay detonators. The Monte Carlo simulation technique using JKsim blast software also indicated the increase in explosive weight per delay by increasing scattering percentage in delays. The comparative test of blast-induced vibration was also carried out using the NONEL and electronic/digital delay detonator. The test results showed that the very good quality of Nonel/digital electronic detonator must be used while blasting in sensitive locations in order to control the vibration.

The maximum recorded scattering percentage in Nonel delay detonators were up to ±43 % (up to 18ms) in case of surface delays (17 ms, 25 ms, 42 ms, 65 ms and 100 ms). The delay scattering value in case of long delays (200 ms to 7500 ms) used in underground metal and for tunnels were recorded up to ±29 % (up to 684ms).

In case of electronic delay detonators, the maximum scattering value of only 6ms was recorded at higher delays (> 4200ms). The scattering in delays play pivotal role in increasing ground vibration by increasing the explosives weight per delay. The higher values of scattering are also responsible for poor fragmentation and generation of flyrock caused by change in the designed delay sequence.

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