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The papers published in this volume were also presented at the International Conference on Safe & Sustainable Mining Technologies, IConSSMT 2024 held at AKS University, Satna (M.P) during19-21 February 2024. The two technical papers, Climate Change - Sustainable Mining and Need for Accelerated Development of Coal by D N Prasad and Rock Fragemntation Research in Mining & Port Construction- Some Applications, by Prof. V.M.S.R. Murthy were the Key Note Papers. Authors who have not attended the Conference, their papers were not published in this volume.

Book Review

Essentials of Mineral Exploration And Evaluation

Authors Dr S.M.Gandhi And Prof B C.Sarkar
Published in 2016 by Elsevier.**ISBN-13:** 978-0128053294 **ISBN-10:** 0128053291

This book will serve as a useful handbook for geologists, mining engineers, exploration professionals, or environmental consultants and Policy planners. looking to elevate your expertise and stay ahead in an ever-evolving field? The contents will sharpen their approach, to tackle the latest industry challenges, and make informed exploration decisions.

⬛ For Geologists and Exploration Professionals: Gain in-depth insights into the geological, geophysical, and geochemical techniques essential for discovering concealed deposits.

⬛ For Environmental Consultants and Sustainability Experts: Learn practical methods to balance exploration demands with environmental conservation.

⬛ For Mining Investors and Project Managers: Understand the economic factors that impact mineral evaluation and decision-making in volatile markets.

It will meet the challenges of the Mining Industry -

Struggling with identifying and evaluating viable mineral resources while balancing economic and environmental pressures? This comprehensive guide offers:

✅ Cutting-edge methodologies to minimize exploration costs while maximizing resource discovery.

✅ Sustainable mining practices to help meet global standards and improve corporate social responsibility.

✅ Insights into leveraging technology like GIS, remote sensing, and 3D modeling to stay competitive and efficient.

This book also offers a thorough overview of methods used in mineral exploration campaigns, evaluation, reporting and economic assessment processes. Full of illustrations it cover the state-of-the-art exploration techniques and evaluation of mineral assets being practiced globally, this up-to-date reference offers balanced coverage of the latest knowledge and current global trends in successful mineral exploration and evaluation. From mineral deposits, to remote sensing, to sampling and analysis

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Determination of Powder Factor by Comparing Explosive Energy with Rock Strength

A Parida* S R Mallick*

ABSTRACT

Rock blasting is one of the dominant method of excavation of rock mass by using chemical energy. Different rocks have different hardness that depend on mechanical properties of rock. Higher the strength of rock, higher is the explosive energy required to break it. In the Current Investigation, Gabbro shown higher strength compared to other rocks. The rock strength is the function of compressive strength, tensile strength, shear strength, young's modulus, shear modulus and passion ratio etc. Powder Factor plays a vital role in rock blasting which is the function of rock energy per unit volume and explosive energy per kg. This paper presents higher the strength of rock, higher is the powder factor (kg/m^3).

***Key words:** Rock energy, Explosive energy, powder factor, compressive strength, tensile strength, shear strength, young's modulus, shear modulus and passion ratio*

INTRODUCTION

Large open cast mines are planned to meet the growing demand of minerals. Opencast mining projects is designed for high production rates required large size blasts and huge quantity of explosives to be charged in controlled manner to break rock. Explosive with high velocity and high density can break more rock. Study of rock mass characterisation helps in selection and optimum usage of explosive in bench blasting. So breakage of rock is possible when explosive energy matches the energy of rock. Rock energy is the combination of strain energy and fracture energy (Mohsen and Morteza, 2011). The strain energy is the potential energy stored in the rock where fracture energy is shear energy. Strain energy is the function of tensile stress and young's modulus where shear energy is the function of shear stress and shear modulus. Slurry/Emulsion based explosive have had a large increase in usage on surface mine as it provide safety and security, excellent resistance to water, increased velocity of detonation. Mostly slurry/emulsion based cartridge explosive are two types, one is base or cap-sensitive and other is column charge. Both explosive show different velocity of detonation but their combined effect fracture and displace the rock. The average of energy of both type explosive is considered in this paper. An optimized blast design is one that will break or move rock to the required fragment size that depend upon powder factor. The quantity of explosive is required to break the unit volume of rock is known as powder factor (Jimeno C.L et al., 1995). During rock blasting, amount of explosive energy (Kcal /Kg) is realised depend upon chemical composition of explosive and energy distribution inside the rock mass to fracture the rock when rock particle are unable to recover to its original position or beyond the elastic limit. Elastic strain energy describes if an external force applied on a rock body, the body will extend a certain limit at a given period of time and then recover to its original position where as if the body acts by an external force beyond the elastic limit, then fracture will created, after some period total brakeage will observed in rock mass. So during rock blasting, the fracture will be observed due to both tensile and compressive wave. Both compressive and tensile wave generated a new wave that is called shear wave when to wave cross each other. So when rock sample is tested by applying load, it brakes due to both lateral and longitudinal strain and their ratio is known as Poisson ratio. Same as when explosive is detonated inside the blast hole, explosive energy try to release out the blast hole, due to stemming explosive energy expands spherically in the form of compressive wave towards free face and converted to tensile wave due to reflection. For this reason all rock properties is considered to determine rock energy and then to compare with explosive energy to determine powder factor.

OBJECTIVE

The objective of this study was to determine rock energy

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and explosive energy, correlation among them to find powder factor for different type of rock such as gabbro, dolomite, limestone and sand stone.

SITE DESCRIPTION

Rock samples such as gabbro, dolomite, limestone and sandstone are collected from different mines. Gabbro formation is intrusive in nature occupies the southern eastern part of boula Nuasahi ultramafic belt belongs to Bangoor chromite mines. The limestone and dolomite beds at Birmitrapur in the district of Sundargarh are observed to have general east-west trend dipping at an average angle of 650 due south, although horizons having low angle (150 - 200) dip due north are encountered. This is normally due to the presence of asymmetrical folds in both limestone and dolomite horizons. The sandstone are collected from Jagannath Colliery(OCP) of the Talcher Coalfields. Jagannath Colliery is situated near the Balanda village of Angul district in Odisha and located in central part of Talcher coal fields.

(1) Sandstone

(2) Gabbro

(3) Limestone

(4) Dolomite

METHODOLOGY

This section describes the rock energy derivation by considering compressive strength, tensile strength, shear strength, young's modulus and Shear modulus for determination of powder factor by comparing with explosive energy.

COMPRESSIVE STRENGTH

Uniaxial compressive strength is the ultimate compressive stress of the rock specimen failure under uniaxial compression conditions and denoted by

$$Compresive\ Strength = \frac{P}{A}$$

Where, P= failure load and A=specimen cross sectional Area

TENSILE STRENGTH

Brazilian Test is a laboratory based test for indirect measurement of tensile strength of rocks. In this test, a disc of material is subjected to two opposing normal strip loads at the disc periphery. The applied load is P (N) on thin disc has a radius R and thickness L and denoted by

$$Tensile\ strength = \frac{2P}{\pi DL}$$

SHEAR STRENGTH

Shear strength is the maximum resistance to deformation due to shear displacement caused by shear stress. It is determined from surface frictional resistance along the sliding plane interlocking between the individual rock grains and cohesion in the sliding surface of the rock.

$$Shear\ stress = C + \sigma tan\emptyset$$

C=cohesion, σ=Normal stress and $\emptyset$=friction angle

YOUNG'S MODULUS

Young's modulus is a measure of the ability of a material to withstand changes in length when under lengthwise compression and also referred to as Young's modulus is equal to the longitudinal stress divided by the strain.

$$Young's\ modulus = \frac{Longitudinal\ stress}{strain}$$

SHEAR MODULUS

The shear modulus is one of several quantities for measuring the stiffness of materials and also describes the material's response to shear stress.

$$Shear\ Modulus = \frac{Shear\ stress}{Shear\ strain}$$

ROCK ENERGY

Rock energy is the combination of elastic strain energy and shear fracture energy (Mohsen and Morteza, 2011). Elastic strain energy describes if an external force applied on a rock body, the body will extend a certain limit at a given period of time and then recover to its original position where as if the body acts by an external force beyond the elastic limit, then fracture will created, after some period total brakeage will observed in rock mass. So during rock blasting, the fracture will be observed due to both tensile and compressive wave, which is shear in nature.

$$Rock\ energy = Elastic\ strain\ energy + shear\ fracture\ or\ strain\ energy$$

Where, $Elastic\ strain\ energy\ per\ volume = \frac{\sigma^2}{2E}$ and

$$Shear\ strain\ energy\ per\ unit\ volume = \frac{\tau^2}{2G}$$

EXPLOSIVE ENERGY

The energy will be realised during detonation of explosive, converted to large volume of gases and shock pressure energy. The shock energy creates fracture in the rock mass and gas pressure expands the fracture and to displace the rock.

POWDER FACTOR

Powder factor is the amount of explosive used to break the unit volume of rock. It is alternatively derived from by dividing rock energy with explosive energy.

$$Powder\ factor(\frac{Kg}{m^3}) = \frac{Rock\ energy\ per\ unit\ volume}{explosive\ energy\ per\ unit\ mass}$$

ANALYSIS

In hard rock mining, blasting is the most productive excavation technique applied to fragment insitu rock to the required size for efficient loading and crushing. Powder factor plays a important role in blasting. Four type of hard rock as Gabbro, Limestone, dolomite and sandstone were

considered for study. As stated above rock properties are determined by laboratory based experiment to determine rock energy. Average energy of slurry explosive in the range of 600 to 1100 kcal/Kg is considered (Pradhan, 1996: Pradhan & Kate, 2005). Powder factor (kg/m^3) was determined by dividing rock energy with explosive energy.

Rock type	σ_c MPa	σ_t MPa	τ MPa	Y, GPa	G, GPa	Rock Energy per unit volume	PF, Kg/m^3
Gabbro	120	15.2	5.4	9.8	4.08	15.36	4.31
Dolomite	85	8.4	3.67	7.2	3.13	7.05	1.98
Limestone	70	7.3	3.18	8.3	3.51	4.65	1.30
Sandstone	50	5.2	2.74	6.8	3.03	3.22	0.90

($\sigma_{c=compressive\ strength}$, $\sigma_{t=tensile\ strength}$, $\tau=shear\ strength$, $Y=youngs\ Modulus$, $G=Shear\ Modulues$, $PF=Powder\ factor$)

CONCLUSION

Ten to twelve rock samples for each rock type was taken for laboratory experiment to determine mechanical properties for prediction of powder factor. The result shows higher is the rock energy, less is the powder factor. Gabbro shows higher rock energy of 15.36 KPa per m^3 whereas sand stone shows comparatively less rock energy of 3.22 KPa per m^3. Slurry explosive is considered for study purpose. The rock properties such as compressive strength, tensile strength, shear strength, young's modulus and shear modulus were determined as the rock energy is the combination of elastic strain energy and shear fracture energy. It is concluded that gabbro needs more amount of explosive to break the unit volume of rock as it is hardest among all rock.

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Implementation of Intelligent Transport System to Improve Safety Standard in Opencast Mines-A Review

A Biswal* S R Mallick*

ABSTRACT

Opencast mine plays a vital role in supply of mineral for growth of country. The HEMM causing accident due to human failure. So to avoid accident by implementing Intelligent Transport System (ITS), an artificial intelligent system is to be introduced to vehicles & infrastructure. A large range of technology application has been developed in recent years to eliminate problems and improve standard of safety in opencast transport system such as DAAAS, ADAS, ATMS and EMS. Research at regional level may include a potential role of ITS towards making of Smart Mines.

Keyword: ITS, safety, DAAAS, ADAS, ATMS and EMS

INTRODUCTION

Mineral consumption is growing faster than the world population growth as the standard of living is increasing. Accordingly the mining industry is producing more and more mineral to solve the mineral supply crisis. So use of machineries (HEMM) is increasing resulting high threat to safety, health & environment

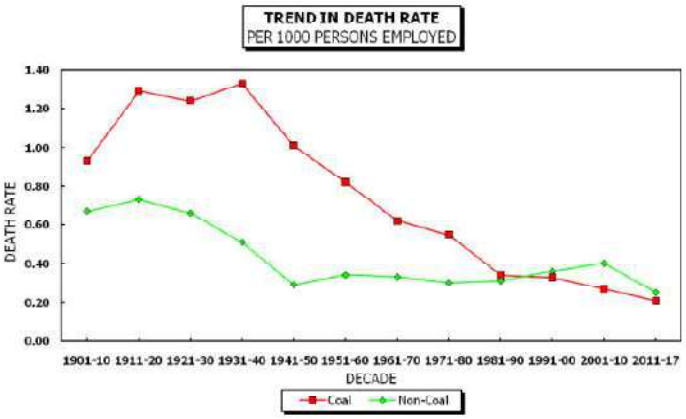
Although steps are taken towards safety the rate of death remain more or less same from 1940s in non-coal mines and the death rate per 1000 person employees also is more than the coal & oil mines *(Table-1.)* During the year 2017, in coal mines the fatal accident was 18% due to dumper , 15% due to trucks/tippers and 18% due to other machineries and in non-coal mines 8% due to dumper,2.5% due to trucks/tippers. But the serious accidents due to other machineries in non-coal mines was 29%. Analyzing the data, the HEMM & trucks/tippers and other machineries causing accidents are mainly due to

(a) Human failure.
(b) Lack of Real Time Information about infrastructure (road, berm , lighting etc.)
(c) Mechanical failure.

The above problems could be eliminated up to a large extent by implementing **Intelligent Transport System (ITS),** an artificial intelligent system.

What is Intelligent Transport System (ITS)

Intelligent Transport System (ITS) is technology (like computers, sensors, controls, communications, electronic devices etc) introduced to vehicles & infrastructure for improvement of safety to save live, time, money, energy & environment. It is the artificial intelligence integrated to the machineries & infrastructure that help the driver to take corrective measures or by taking automatic action in event of detected hazard.



Components of ITS

The components of Intelligent Transport System (ITS) are mainly classified into

i) Data Acquisition.
(Sensors, Cameras, GPS, Automatic Vehicle Identifier (AVI), Automatic Vehicle Locator (AVL) etc.)
ii) Data Analisation.
(Data Processing Unit/Data Management Centre)
iii) Driver Information.
(Cell Phone, Advisory Radio, On Board Screen, SMS, Variable Massaging Signs etc.)
iv) Communication Tool.

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Fig-1: Components of ITS

APPLICATION OF ITS IN OPENCAST MINES

A large range of technology application has been developed in recent years to eliminate problems and improve standard of safety in opencast transport system. Followings are classified considering the area/section of application in Indian opencast mines.

A) Driver Authentication & Accident Avoidance Systems (DAAAS)

Many accidents are occurring due to entry or driving by un-authorized persons, drunken driving, fatigue etc. Normally, DAAAS contains following sub-systems considering opencast mining operations -

Human Identification System

Fingerprint Authenticated Vehicle Starter - This system protects un-authorized driving of dumper/tipper. This system allow only authorized person to switch on the dumper/tipper through finger print scan.(fig-2)

Fig-2: Fingerprint Authenticated Vehicle Starter

UN-AUTHORIZED PERSON IDENTIFICATION SYSTEM

This system checks identification & number of persons present inside the dumper/tipper cabin. A passive infrared sensor is used to identify the humans & sends a warning to the driver.

ALCOHOL DETECTION SYSTEM

This system is designed to shut down the ignition system if the detected value in driver's cabin is higher than the permitted value. The MQ3 gas detecting sensors measures the level of alcohol present inside the driver's cabin and transmits the measured data to the processing unit/controller. If the detected value is higher than the permitted value then the ignition system of the dumper/ tipper will shut down.

i) Drowsy Driver Detection system

This system considers the eye blinking, change of face shape etc to warn the driver for his drowsiness .A small monochrome security camera pointed directly towards the driver's face takes photos and analyses using information obtained for the binary version of the image. If the system finds eye's of driver closed 05 consecutive takes, it considers that the driver is sleeping and warns the driver (Fig-3). The system works under reasonable lighting conditions and also when the eyes cannot be found.

Fig-3: Drowsy Driver Detection system

A) Advanced Driver Assistance Systems (ADAS)

This systems help driver to control and avoidance of accident providing calculated information or taking automated action in the event of detected hazard. Its sub-systems are-

i) Proximity Warning System (PWS)

Large haul Dumpers/Trucks have operator visibility and illumination issue. These problems are converting to accidents. Blind spots creates problem for driver. Sometimes the mirrors are not suitable or short outs the problem. Realizing this, the DGMS advice to use the Proximity Warning System (PWS) for elimination of this type of problems. When an object/person comes to the sensing area it warns to the driver. This device takes account of blind zone, braking capacity of dumper/tipper and operator's reaction time. (Fig-5)

Fig-5: Laser Proximity Wireless System

ii) Extended Safety Mechanism

These warning devices fitted to dumpers/trucks give prior information to driver about mechanical/human failures or any hazardous issue generated in the dumper/tipper.

- ***a) Seat Belt Warning System –*** It warns driver if he is driving without wearing seatbelt.
- ***b) Dumper Body Up/Down Indicator –*** If the dumper/tipper body remained in up condition it warns the driver.
- ***c) Overload Indicator–***If the dumper/tipper is overloaded it gives warning to the driver.
- ***d) Over speed Controller-*** when the driver operates the dumper/tipper more than permitted speed it warns the operator and keeps the dumper within the permitted speed.(Fig-6)
- ***e) Rear Vision Camera-*** It helps to the driver to clear view of back side of the dumper/tipper on the on-board screen when reversing. It is works also at night with poor illumination.(Fig-8)
- ***f) Automatic Fire Detection & Suppression System (AFDSS) –*** It features with high speed infrared optical detection device, central control, fire suppressing agent storage cylinder, installation accessories. The high-speed infrared optical detector detects fire in milliseconds and activates high quality fire suppression agent by automatically or manually depending upon the severity. The system can instantly differentiate between open fire and hydrocarbon signature from non-threatening source eliminating false action. (Fig-4)

Fig-4 AFDSS kit

Fig-6: On-board speed controller screen

iii) Anti-Collision System

Anti-Collision system warns the driver about possible forthcoming collision. The system collects data by special types of sensor or GPS or RFID or ultrasonic etc which suitable for the purpose, then processed and give warning information to the driver for necessary protective action. More advanced technology is developed that automatically brake or steer the dumper/tipper to a safer lane to avoid collision.(Fig-7)

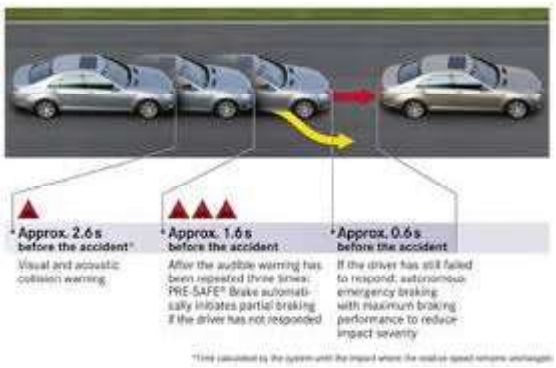

Fig-7: Advance Vehicle Control System

Fig-8: Rear Vision Camera & LCD Screen

C) Advance Traffic Management System (ATMS)

With the help of latest technology like CCTV, GPS, AVI, AVL, Communication, Massaging etc the Central Traffic Management Centre receives data , processes it and conveys information to the drivers and infrastructures for smooth movement of vehicles (Fig-11). According to the intensity of work, technology incorporated ATMS sub systemized as

i) ***Operator Independent Truck Despatch System (OITDS)***

All the trucks/dumpers/tippers fitted with GPS antennas and receivers/IP radios connected with Base Centre where a Computer radio transmission is available. On the monitor it displays real time locations of mining operation. According to excavator status the allocator allots dumper to the required excavator by giving voice massage through IP radio (Fig-10). OITDS minimises shovel wait time, shovel saturation, truck/dumper wait time, truck/dumper cycle time.

ii) GPS-GSM Based Vehicle Navigation System

This is the advance version of GPS based OITDS.GPS generally locates the dumper/truck position. For automatic vehicle position it is necessary to transmit the location information in real time. GSM/GPRS is used for purpose and transmits information to the tracking server. It uses GSM for SMS and GPRS for direct TCI/IP connection. The system stores this information in the tracking server and only authorised users can access via website over the internet. The Google map may be incorporated to see the real time locations of vehicle on the Google map. This helps to monitor and control the dumpers/trucks.(Fig-11)

D) Emergency Management System (EMS)

When an accident occurs, this system automatically gives information to the nearest Emergency Service Centre. This transmits accurate information about the locations and site detail. The Emergency Service Centre despatches rescue team without any delay to the site and also give information to other drivers and concerns. This system helps to reduce response time, to save live and to reduce re-occurrence of accidents. (Fig-9)

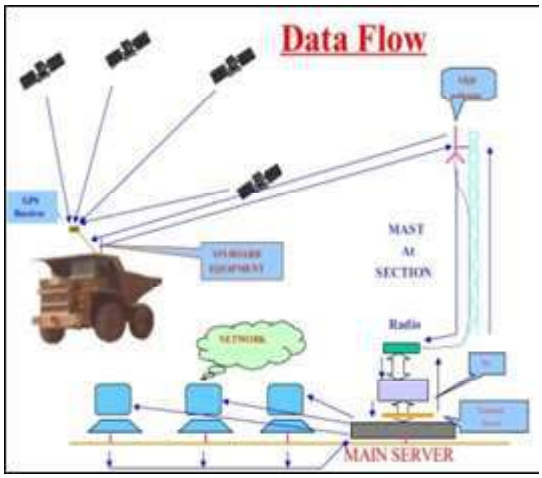

Fig-10: Data Flow of GPS based OITDS

Benefits of ITS:

- Ø Improves standard of safety.
- Ø Rate of accident comes down.
- Ø Improves machinery performance.
- ➢ Increases productivity.
- ➢ Better supervision.
- ➢ Improves environment standard.

Fig-9: Emergency Management System

- Improves health standard.
- Better traffic flow.
- Lower production cost.
- Optimum use of machineries & manpower.
- Increases business activity.
- Improves working atmosphere.
- Easy data keeping.

CONCLUSION

Increasing machinery population in Indian surface mining industry hikes the potentiality of accident. In near future integration of new technologies will play a vital role to neutralise the increasing hazards. Indian mining industry have incorporated ITS to some extent. For successful application more extensive and urgent integration of advanced technology and concept is required. So it is in need of systematic & in – depth research. Research at regional level may include a potential role of ITS towards making of ***Smart Mines*.**

In the other hand the role of the government/the regulatory authorities/the mining owners/planning organisations/ machinery manufacturers/policy makers/institutions are very important to make successful implementations of ITS.

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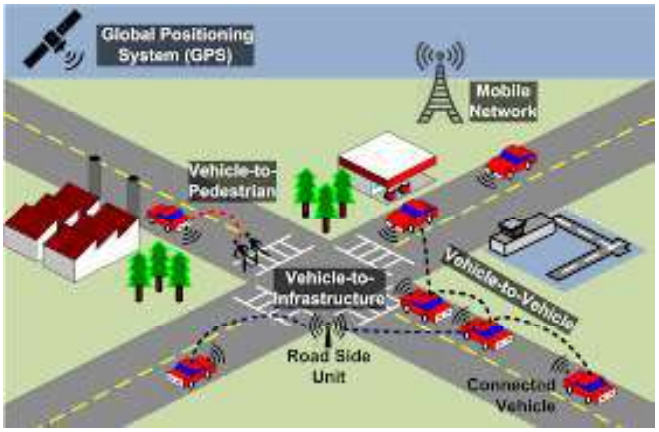

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Application of IoT to Predict Blast Induced Ground Vibration for the Enhancement of Safety during Blasting

Dr. Manas Kumar Mallick * Prof. (Dr.) Gyanindra Kumar Pradhan**

ABSTRACT

The quickest and least expensive method of rock fragmentation in mining is blasting. The use of explosives during blasting not only fractures and shifts the rock, but it also has some negative effects on nearby structures that could result in their demolition. The use of contemporary technologies such as Minimate plus, Micromate, and Mini Seis III is used to detect, log, and track ground vibrations. The wire-based, costly, and laborious approach is one of the main disadvantages of traditional systems. This study suggested a low-cost, wireless, Internet of Things (IoT) monitoring system for blast-induced ground vibrations in order to get around these restrictions. The developed prototype makes use of an Arduino-based microcontroller, a SW-420 vibration sensor, and additional signalling devices. The importance of IoT in the mining industry for maximizing output, profit, and safety is another major topic of this essay.

Keywords: Rock fragmentation, Blast induced ground vibration, Internet of Things (IoT), Wireless Sensor Network

INTRODUCTION

The mining industry is essential to any country's economic growth. Among its many benefits are job creation, tax revenue, economic stabilization, and GDP contribution. There are several techniques to conduct mining operations. The most popular rock fragmentation excavation techniques in the mining industry are drilling and blasting. For rock extraction mining, blasting is a more economical approach. But blasting is dangerous for the environment and for people. Based on research findings, a mere 25% of the explosive energy is utilized for the purpose of fracturing and moving the rock mass. The remaining energy is dissipated by various means such as noise, vibrations of the ground, fly rock, backbreak, air pressure, and other processes (Ataei and Sereshki 2017) A major problem among all the adverse effects is ground vibration. Although they cannot be completely eliminated, ground vibrations are an inevitable part of the rock blasting process and can be somewhat reduced (Khandelwal and Singh 2009). Figure 1 illustrates the significant harm that the blast's vibrations cause to the surrounding buildings and structures. Consequently, in order to determine the acceptable limits and guarantee mine safety, it is imperative to detect, log, and keep an eye on ground vibrations. Modern technologies like Minimate plus, Micromate, and Mini seis III are frequently used to measure ground vibrations. Wires are used by current ground vibration monitoring systems to gather and send data from the field. Additionally, wire-based prototypes are limited to usage in a specific area, and if the wires are destroyed, the devices become unusable. Therefore, it is crucial to create a low-cost wireless monitoring system for blast-induced ground vibrations using the Internet of Things (Gupta and Gupta 2017).

To address the aforementioned constraints, a wireless blast-induced ground vibration monitoring system based on the Internet of Things must be developed (Hu et al. 2013). This study presents a completely optimized, dependable, cost-saving methodology that even inexperienced personnel can adopt.

LITERATURE REVIEW

Numerous researchers worked on the enormous project of studying blast-induced ground vibrations and employing IoT based devices to detect them. Pramanik et al. 2018, explored the potential of the IoT for optimizing productivity, profit, and safety in mines while also developing an internet-based system for monitoring blast induced ground vibration. After talking about the negative effects of blasting, Ragam and Nimaje 2019, created a wireless prototype with an accelerometer, radio frequency module, and microcontroller unit and measured vibration levels in terms of PPV. Artificial Neural Networks (ANNs) and low-cost Wireless Sensor Networks (WSNs) were used by

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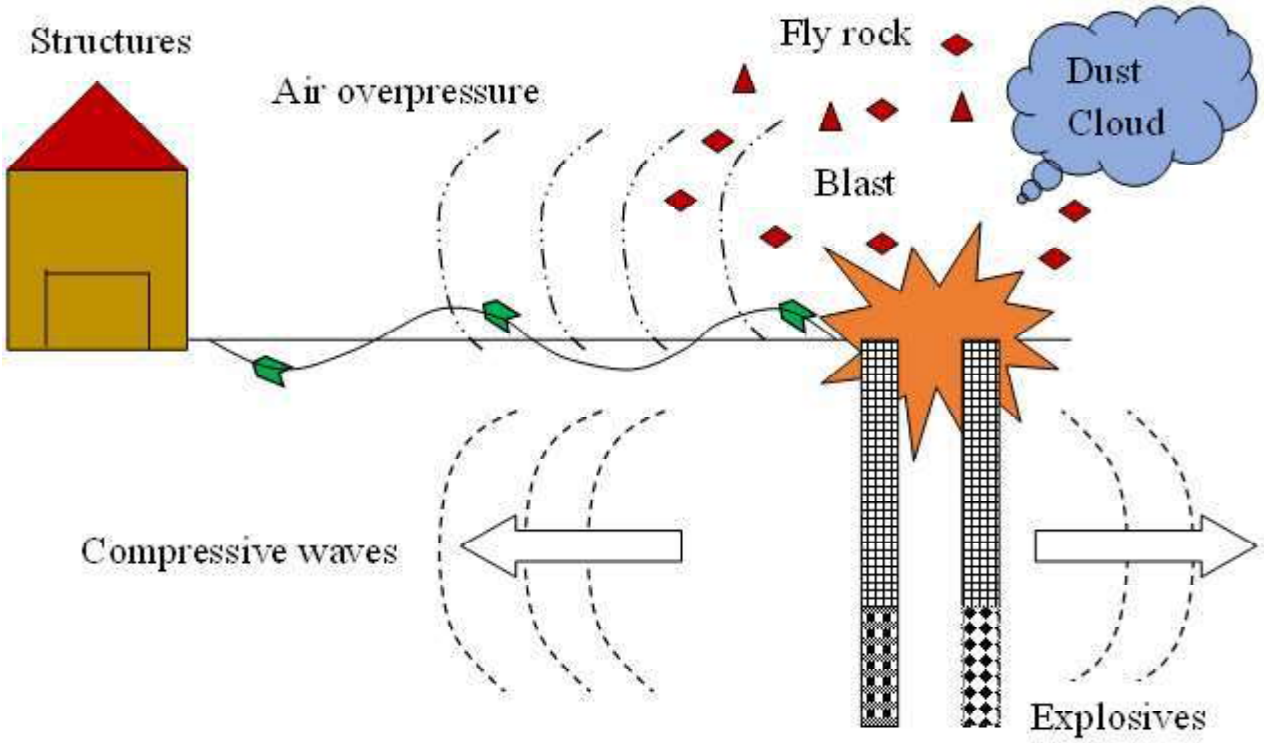


Figure 1: Environmental effects of blasting

(Nimaje and Ragam 2018) to forecast PPV. Zigbee technology was also used for data transfer (Ragam et al 2016)

Table 1: Tabular presentation of Literature Review

Techniques	Major Findings	Reference
Wireless Sensor Network (WSN) and IoT	Real time monitoring of ground vibrations	Pramanik et al. 2018
Wireless monitoring system	Low-cost wireless vibration monitoring system to monitor PPV	Prashanth & Nimaje, 2019
Wireless monitoring system and prediction through Artificial Neural Network (ANN)	IoT based blast-induced ground vibration system	Ragam et al. 2018
Long-Range Wide Area Network (LoRa WAN) connectivity integrated with WSN	Data transmission -reception in a non-line of sight condition	Ragam et al. 2019
Vibration sensor S W-420 along with Arduino Uno microcontroller board	Determine the appropriate vibration classification	Pakpahan et al 2021
MEMS-based accelerometer wireless sensor systems	Low-cost monitoring applications such as blast -induced ground vibration (BIGV) and structural health monitoring (SHM).	Ragam & Sahebraoji, 2019

MATERIALS AND METHODS

To develop the prototype, knowledge of WSN and IoT is essential. To fit the site's requirements, a prototype that makes use of contemporary technologies was created.

Internet of Things

In order to ensure that the network gains value and service through data exchange with the maker, operator, and other connected devices, the Internet of items (IoT) is a network made up of physical items or objects integrated with electronics, sensors, and connectivity. It is important to note that there are several definitions of the internet of things in the literature because it has been defined from different angles. The seeming ambiguity in the concept of IoT could potentially be attributed to its composition of the two words "things" and "the internet." While the second word favours generic objects, the first word promotes a networked perspective (Priyana et al. 2018, Pakpahan et al. 2020)

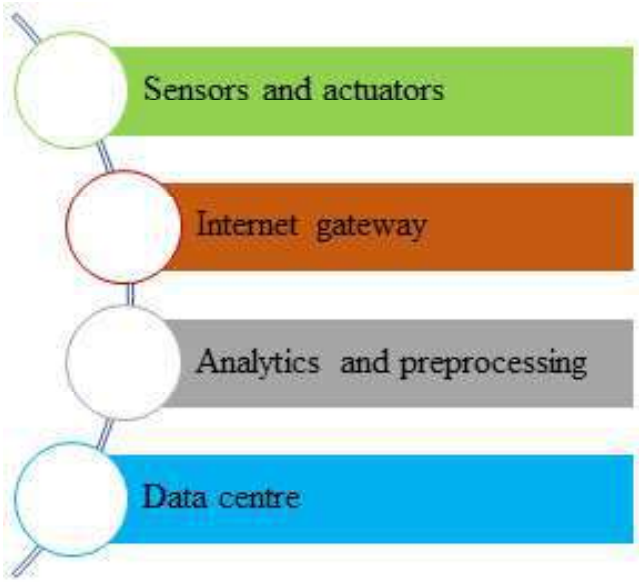


Figure 2: The Schematic architecture of IoT

IoT in Mining industry

The mining industry uses the Internet of Things (IoT) to optimize output and costs, enhance safety protocols, and develop artificial intelligence requirements. Owing to the numerous advantages it offers, a large number of important mining companies are organizing and evaluating how to start their virtual journey and digitalization in the mining industry to manage everyday mining operations (Majid et al. 2022)

The performance of the equipment can be monitored by sensors and other devices to optimize costs and boost productivity (Kwon et al. 2006). To monitor blasting, ventilation, and toxicity levels in real time utilizing IoT in underground mines to ensure the safety of personnel and equipment. The focus of maintenance is moving from preventative to predictive. Within the mining business, emergency circumstances arise almost every hour and are highly unpredictable.

Wireless sensor network in IoT framework

WSN is a network of several spatially dispersed autonomous nodes that monitors an area, gathers information about it, and disseminates it (Kim et al 2008). There are thousands of wireless sensor nodes in the world, and each one has a limited supply of memory, bandwidth, computation power, and sensing capacity. Prior to delivering the environmental data to a base station or sink for processing and analysis, they gather and store it (Lynch and Loh 2006). The sensor nodes can speak to one another by radio signals (Srivastava 2015). With the use of a network of sensor and routing nodes called WSN, physical conditions like wind, temperature, vibration, and many more may be predicted. After processing data from minute nodes, these networks deliver it to the operators (Waseem et al 2013).

Development of wireless sensor system

The Arduino Uno microcontroller, SW-420 vibration sensor, and additional indicator components make up the prototype. Vibrations are detected by the SW-420 vibration sensor from various angles. The parts of the sensor function as a when it detects no vibrations. In the meantime, the switch will open and close in accordance with the transfer rate of vibrations when the sensor picks up a vibration or shock. This module provides a variable virtual output based on vibration strength by combining an adjustable potentiometer, a vibration sensor, and an LM393 comparator chip. By adjusting the potentiometer, the sensitivity can be adjusted to the appropriate level (Ooi and Wang 2014).

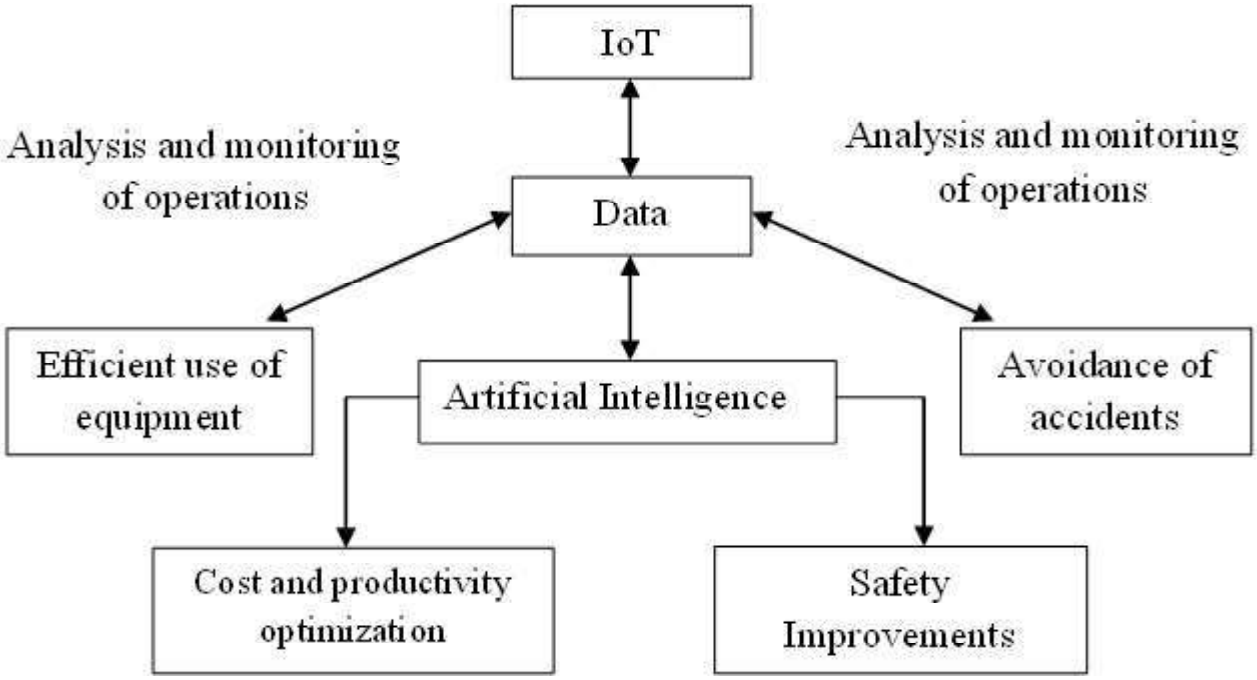


Figure 3: Flowchart of IoT in mining

Table 2: Specifications of SW-420 vibration sensor

Sl. No.	Parameters	Specifications
1	Voltage	3.3 -5.0 Volt DC
2	Output	Digital (0 and 1)
3	Sensor size	3.2 cm x 1.4 cm
4	Detecting distance	760 nm – 1100 nm
5	Detecting angle	16^0
6	Signal	15mA

Arduino is an incredibly user-friendly open-source hardware and software platform built around microcontrollers. The Arduino is an inexpensive control board that is easy to program and can be connected to a variety of hardware. It can be used by anyone working on a project.

Arduino uses input from a range of sensors to sense and affect its environment (Zhou et al. 2013). Table 3 illustrates the connections listed for the prototype:

Table 3: List of components for the prototype

Sl. No.	Name of the component	Connection
1	SW-420 vibration sensor	The Arduino board's three ports 3.3V, GND, and PIN 9 are linked to the sensor's three pins, VCC, GND, and DO, respectively.
2	Buzzer	PIN 3 and GND are linked to the buzzer's positive and negative terminals, respectively
3	LED lights	The positive terminals of the Green, Yellow, and Red LED lights are linked to PINs 10, 12, and 13, and the negative terminals are connected to GND.
4	Arduino board	The laptop is linked to the Arduino boar d's USB port in order to obtain power and to serially monitor the readings. An additional option for the power supply is a 9V battery

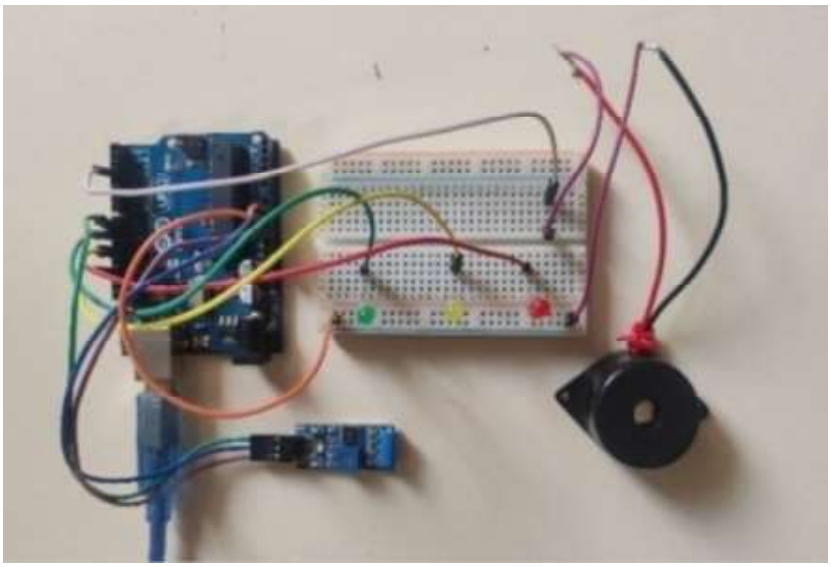
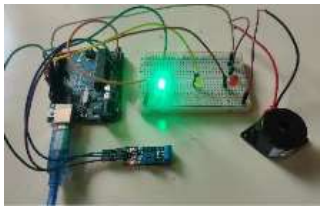
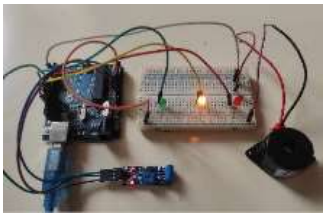
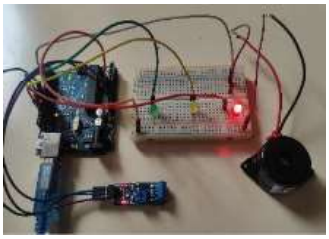


Figure 4: Developed prototype for monitoring blast induced ground vibration

RESULTS AND DISCUSSIONS

The following analysis and evaluation are done on the data that is sent from the sensor to the microcontroller.

Table 4: Measurement of vibrations and their indication

Sl. No.	Visual Indication	Serial Monitor	Remarks
1		Measurement= Low vibration	Green light
2		Measurement= Medium vibration	Yellow light
3		Measurement= High vibration	Red light

Flowchart of the monitoring system for sensor unit

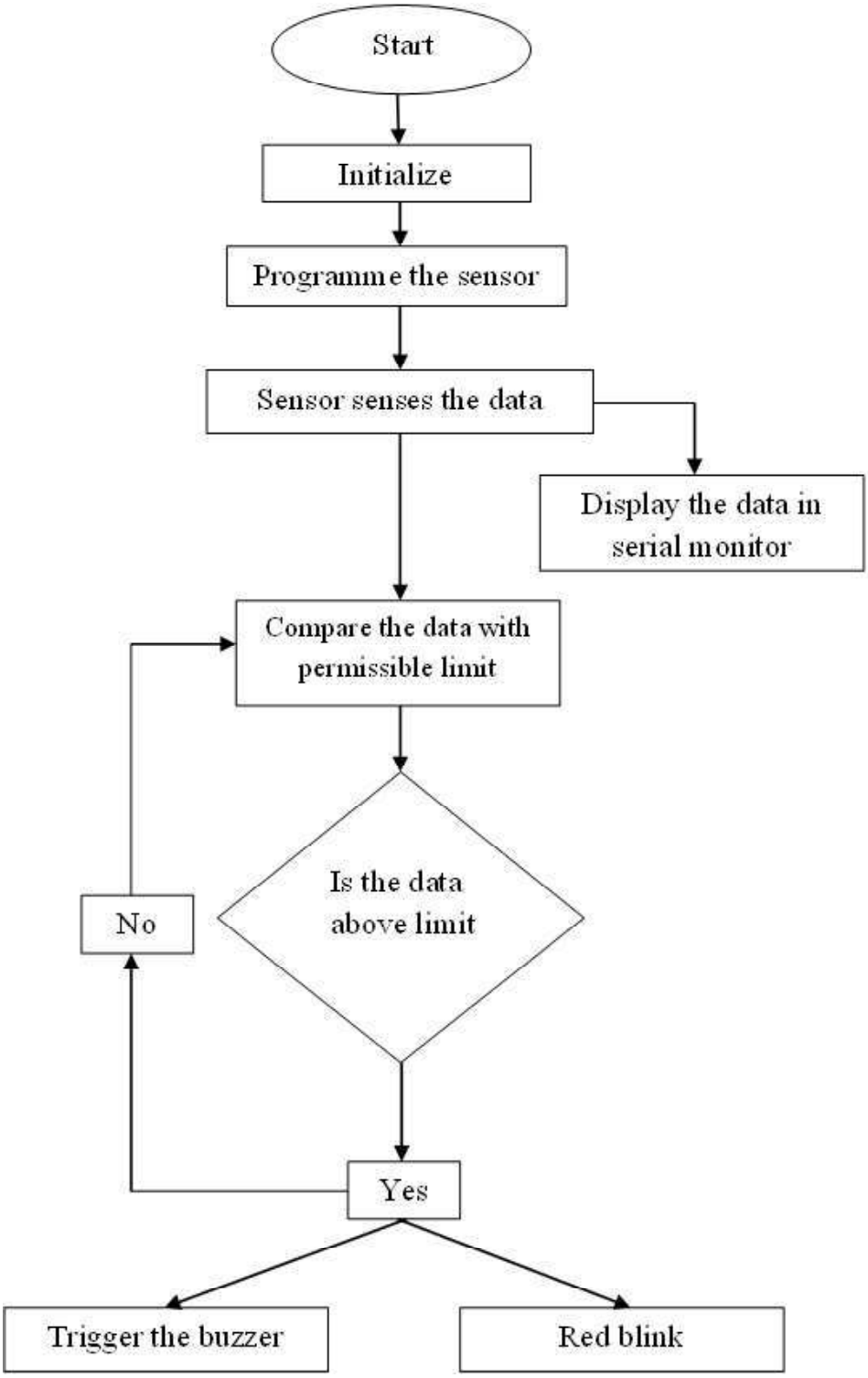


Figure 5: Flowchart of the monitoring system

The microcontroller receives data from the SW-420 vibration sensor, analyses it, and displays the results on a serial monitor. The prototype's physical indicator is provided via a buzzer and LED lights. Table 4 displays the data from the serial monitor.

The code specifies the vibration range so that the signalling devices operate accordingly. According to Table 4, the green LED blinks when the vibrations are minimal. When the vibrations are in the middle range, a yellow LED blinks, and when they are high, a red LED blinks and an audible tone alerting the user to the danger is activated. These physical cues are used to inform unskilled labourers about the site's safe and dangerous characteristics.

CONCLUSION

In this paper, an IoT-based prototype for tracking ground vibrations is built. The Arduino microcontroller transmits data to the program, and the SW-420 vibration sensor is used as the sensing device. Vibration readings are recorded by the sensor and sent to the Arduino IDE program, where they are seen on a serial monitor. When the vibrations reach the sensor's range, the LED lights flicker and the buzzer sounds. The paper's goals have been well defined, and a low-cost, dependable, and optimized prototype has been created. It makes sense to apply IoT and WSN in the mining sector as a replacement for traditional systems in order to maximize productivity, provide safety, and boost earnings.

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Flexible Pavement Design for Coal Mine Haul Roads - A Review

S R Mallick* Dr. A K Verma** Dr. K U M Rao**

ABSTRACT

In India major percentage of coal for generation of thermal power is supplied by open cast coal mines. Expansion of coal mines has led to deployment of large capacity haul trucks with carrying capacity varying from 10t to 300t in recent years. Haul road forms the lifeline of any open cast mine. Introduction of large capacity haul trucks require well-designed haul roads to minimize pavement failure, generation of dust, consumption of fuel, wear and tear of tire etc. Presently, design of haul roads is based on past experiences and empirical methods. Well-designed haul roads ensure low maintenance as well as low operating cost. The paper discusses the various design parameters and empirical design methods adopted for haul road construction.

INTRODUCTION

Major production of coal comes from opencast coal mines through deployment of sophisticated and high capacity dumpers (80t, 120t, and 300t), shovel, dragline, dozer etc. Capital investment on Heavy Earth Moving Machineries (HEMM) is around 70% of the total investment for any open cast project. Better health of these machineries ensures maximum availability and utilization leading to high production and profit. To ensure better health of these machineries well designed haul road with continuous improvement in their design parameters is required.

A typical surface coal mine has about 3 to 5 km of permanent haul road and various other lumpy roads that are constructed either with overburden material or from locally available material found near to the mine boundary. Some of those materials typically are mudstone, sandstone, gravel, clay etc. Often it is observed that the operating and maintenance cost of dumpers are significantly high in addition to haul road maintenance cost. It results in reduced production, frequent breakdown, accidents, death hazards, low worker motivation etc.

These days' opencast mines are planned for greater depths, often beyond industry's current experience, expertise and knowledge. In past 30 years the carrying capacity of hauling equipments e.g. dumpers/trucks has grown from 10t to 170t, 350t being envisioned at places, requiring better haul roads to carry heavy loads. Surface coal mine haul road undergoes more strain due to multiple reasons such as poor surface course, inadequate construction process, poor construction materials, varying load on the surface, improper drainage system, etc.

HAUL ROAD CLASSIFICATION

In an opencast coal mine, haul roads are basically required for transportation of coal from the various coal faces to the stock yard, overburden material to the dump yard and also for the movement of vehicles to the workshop (Fig. 1). Haul roads are of three types i.e. permanent, semi-permanent and temporary depending upon the traffic and the nature of its operations. Permanent haul roads are made outside mine boundary to connect approach road to the mine and extend up to the dump yard. These roads are thickest and made of high quality engineering materials and hence construction cost is high. Life of these roads is longer. Semi-permanent haul roads have medium life period, engineered to desired thickness, high quality construction materials, relatively expensive to build, used as main haul roads in mines and dumping yards. The type of roads having lifespan 3 ~ 5 years are often clubbed with permanent haul roads (Vittal and Mathur, 2010). Materials used are same as permanent haul roads but road thickness is less. Temporary haul road are of short life period, minimum pavement thickness, low quality construction materials, inexpensive to build and used mainly for shovel or dump yard access. They change

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considerably with the advancement of the mine working face. Typical construction materials are native material from vicinity of the mine.

Figure 1: Semi-permanent haul road of Basundhara opencast mine, MCL

DESIGN OF HAUL ROAD PAVEMENT

Pavement is a hard, high strength top finished road surface that separates the underlying well-compacted foundation (called sub grade) from the weight of vehicles. There are mainly two types of pavement, depending upon the strength and type of underlying foundation: (1) Rigid Pavement and (2) Flexible Pavement. In rigid pavement, most of the load is carried by slab itself and slight load goes to underlying layers. In flexible pavement, load distribution is primarily based on layered system. Structural capacity of rigid pavement depends only on characteristics of concrete slab. Structural capacity of flexible pavement depends on the characteristics of each single layer.

Pavement of a haul road is the actual surface on which the truck travels. Figure 2 shows a typical cross section of a mine haul road pavement consists of four distinct layers namely, surface course, base course and sub-base. Thus, pavement is a structure of superimposed layers of material that is placed on sub-grade. Main function of pavement is to provide friction to the truck and distribute the wheel load to the underlying layers. Pavement deteriorates with time due to interactive effects of traffic load, in-situ material strength, structural thickness and subgrade type. Ideally pavement should be stable, non-yieldable and enables the trucks to move faster with safely and comfortably.

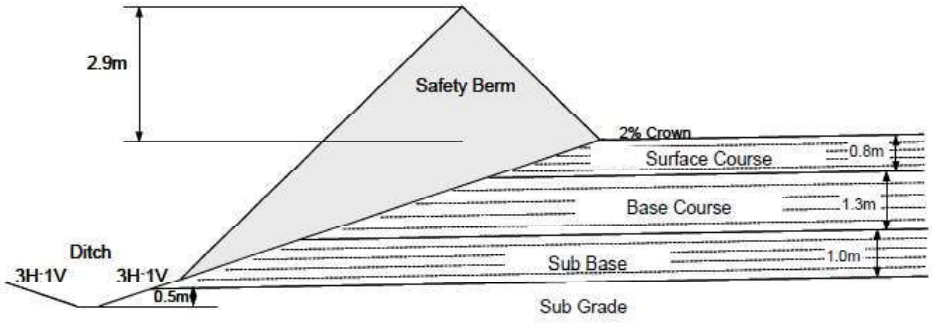

Figure 2: Typical Haul Road Cross-Section for 320t haul trucks (Tannant and Regensburg, 2001)

Stress transferred to the sub grade soil through pavement layers considerably lower than the contact pressure under the wheel load on the surface. The reduction in stress depends on thickness and characteristics of individual layers. So, design and construction of effective pavement ensures distribution of wheel load on larger area per unit layer depth.

Surface course is top most layer of pavement on which wheels of vehicles are in actual contact. It is generally made of compacted gravel to provide a smooth surface and to resist pressure exerted by the tires. Surface course should have high adhesion, low rolling resistance coefficient, no penetration under load. Earlier bituminous concrete were used as surface course material but now-a-days crushed stone or overburden material are used. Bituminous carpeting is not recommended because (1) at high temperature regions, tire temperature increases further increases due to high tire pressure. This leads to the reduction of tire life because of development of radial cracks in tire; (2) it is getting damaged due to acceleration and braking effect of high capacity dumpers results into formation of large pot holes and ditches; (3) spillage of coal, overburden material and water on damages the road surface.

Base course is the layer of material which lies immediately below the surface course. It consists of granular material like stone fragments or slag that can be stabilized with binding materials like cement, natural pozzolans etc. The base course is the main source of the structural strength of the road.

Sub-base is the layer lies between base course and sub-grade. Material used in sub-base are same as base course like laterite, crushed stone, gravel, moorum, natural sand either cemented or untreated. Apart from providing structural strength to the road, it prevents intrusion of sub-grade soil into the base course, water accumulation and provides working platform for construction equipment. The base course and sub-base courses are primarily used to improve load supporting capacity by distributing the load.

Various composite materials have been developed by researchers (Cetin *et al.* 2010, Behera 2012; Mallick et al. 2013) as sub-base and base course material as shown in Figure 3. Cetin *et al.* (2010) experimented with unpaved road surface material (URM), fly ash and lime kiln dust. The CBR value of the soil stabilized with fly ash (10% and 20%) and lime kiln dust (2.5% and 5%) is greater than 160% at 28 days curing. Behera *et al.* (2012) experimented with mine overburden material, fly ash and lime. The CBR value of the soil stabilized with fly ash (15% and 20%) and lime (3% and 6%) is greater than 160% at 28 days curing. Mallick *et al.* (2013) experimented with mine overburden, fly ash and clinker. The CBR value of the soil stabilized with fly ash (60% and 80%) and clinker (8%) are greater than 140% at 28 days curing.

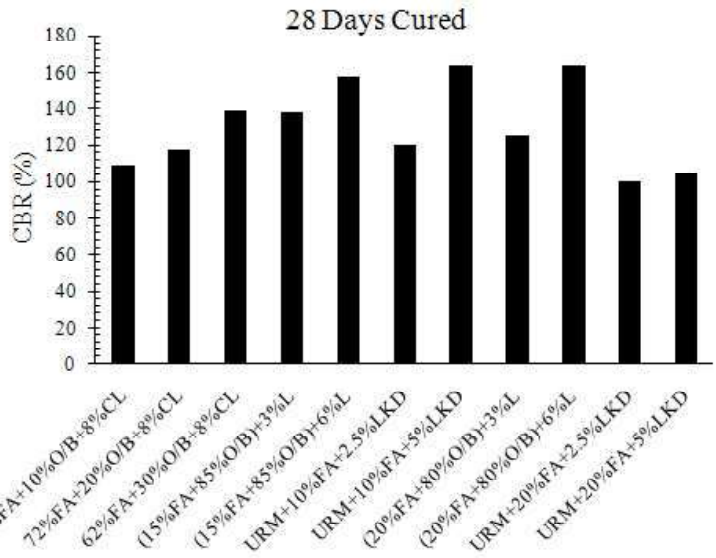

Figure 3: Comparison of CBR result of different developed composite materials

Sub-grade is the naturally occurring surface on which the haul road pavement is constructed. It may be leveled by excavation or back-filled to provide a suitable surface. The performance of the haul road is affected by the characteristics of the sub-grade. The loads on the pavement are ultimately received by the sub-grade to be transferred to the earth mass. It should not be overstresses at anytime i.e. Pressure on top of it should be within permissible limit.

PAVEMENT DESIGN APPROACH

From, 1920s pavement design based on "Rule-of-Thumb" approach came. This approach helped in constructing many roads satisfactorily, but it is uneconomical and difficult to construct pavements in unsuitable/worst conditions. Later on different approaches like Pre-road test, Group Index methods, Pedological methods and Strength based methods have been developed. Among them strength based method is popular and widely adopted.

Pre-road test approach is based on the principle of soil mechanics. The main objective of this approach was to protect the sub-grade by placing sufficient thickness of material over the sub-grade.

Group Index method uses the AASHO (American Association of State Highway Officials) method of soil classification to calculate a numerical indicator for the quality of roadbed soil based on traditional soil properties. The higher the group index, lower the quality of soil to carry traffic. The higher group index requires a thicker pavement to carry the design traffic. The group index is computed by combining the results of the Atterberg tests. Principle in Pedological or soil forming classification methods is based on the principle of geological formation of soil i.e. soil from same parent rock under similar climate, age, weather and topography possesses similar engineering properties. Number of highways agencies has developed design methods around the Pedological classification e.g. Michigan engineers have correlated pavement performance with soil types. It utilizes geographic, topographic, and agricultural soils maps to develop classification systems for predicting soil conditions encountered in their given areas. The design philosophy is similar to the group index method.

Strength-Based Method

Strength-based design method uses shear strength or load-deformation characteristics of the roadbed material. The strength tests indicate the relative quality of the roadbed materials. Some of the popular strength-based methods have been discussed below.

Burmister's method

The simplest layered approach in analyzing the pavement is the two layer method introduced by Burmister in year 1943 as shown in Figure 4. According to this theory, load-settlement characteristics of the two-layer system are influenced by two important ratios i.e. (1) The ratio of the radius of the bearing area to the thickness of the reinforcing or pavement layer and (2) The ratio of the modulus of the subgrade to that of the pavement, for practical design purposes.

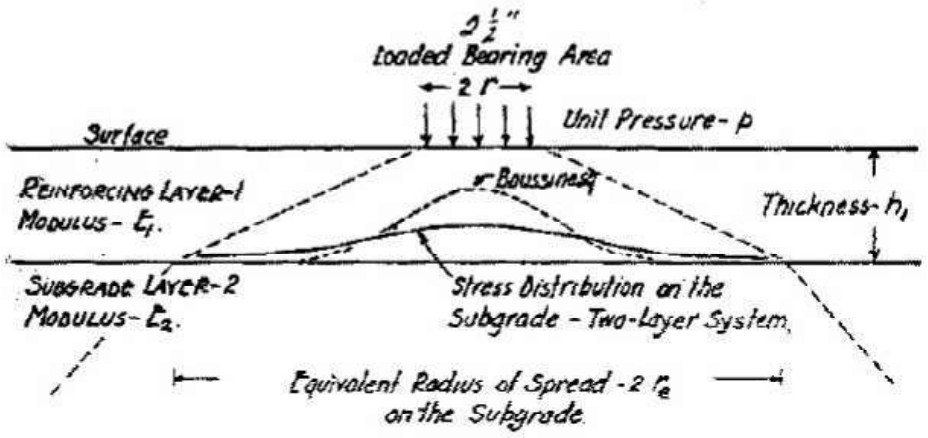

Figure 4: Burmister's Two Layer System (Burmister, 1943)

Burmister assumed that thickness of each layer is uniform and infinite dimensions in all horizontal directions. Each layer is weightless, homogeneous, isotropic, and linearly elastic. The pavement systems are free from stresses and deformations before application of external loads without any dynamic effects. Presently Burmister's Method is not in use for haul road design.

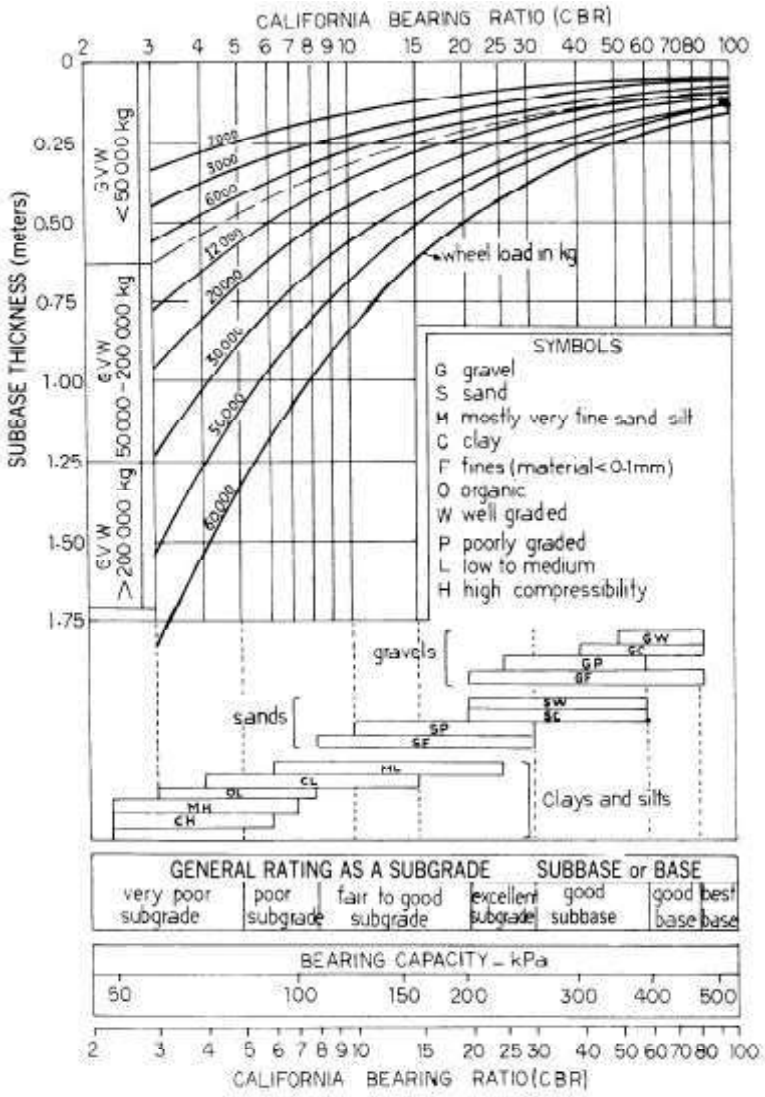

Figure 5: CBR curves (Kaufman and Ault, 1977)

CBR based design

California Bearing Ratio (CBR) based design determines the thickness of working surface, base and sub-base based on CBR value determined from laboratory investigation. The standard material for this test is crushed California limestone which has a value of 100. The harder the surface, the higher the CBR value. CBR is defined as follows

$$CBR = \frac{p}{p_s} \times 100$$

Where, p = measured pressure for material $[N/mm^2]$, and p_s = pressure to achieve equal penetration on standard material

There are two ways of pavement design based on CBR first approach was given by Kaufman and Ault (1977) and another by Atkinson (1992). Figure 5 shows CBR curve given by Kaufman and Ault (1977), in which sub-base thickness is determined by vehicle wheel loads as well as by soil type. Wheel loadings for any vehicle are obtained from manufacturers' specifications. Maximum loading on any wheel of vehicle can be determined by dividing the gross vehicular weight over each axle by the number of tires on that axle. To provide a clear indication of the wheel loading characteristics, CBR chart is divided into three categories. Each category represents a range of wheel loadings, under fully loaded conditions, that may be anticipated for vehicles in a given weight class. Wheel loading and CBR values are used to calculate sub-base thickness using CBR chart.

Figure 6, shows CBR curves given by Atkinson (1992) requires laboratory tests or the assumption of CBR values of sub-grade, and available base or sub-base materials. The CBR curves shows directly the total thickness needed over any sub-grade soil. The total sub-base and base thickness is created by putting down a series of relatively thin layers of correct moisture content. The combined sub-base, base and wearing surface thickness must be sufficiently large so that stresses occurring in the sub-grade will not cause excessive distortion or displacement of the subgrade soil layer. Any sub-grade that is less consolidated than soft rock will require additional material in order to establish a stable base. Finally, the most economic combination of wearing course, base course and sub-base is selected.

Mechanistic design

A mechanistic design is based on a theoretical linear-elastic multi-layer system model as shown in Figure 7. A limiting design criterion of vertical compressive strains in the sub-grade is used to assess the structural design adequacy of haul road under the specific loading condition. Vertical compressive strains induced in a road by wheel loads decrease with increasing depth, which permits the use of a gradation of materials. The road as a whole must limit the strains in the sub-grade to an acceptable level and the upper layers must protect the layers below. Applied load, sub-grade strength, pavement structural thickness and layer resilient modulus control the structural performance of a haul road. An upper limit of 2000 micro-strain is generally placed on layer strain values. Strain

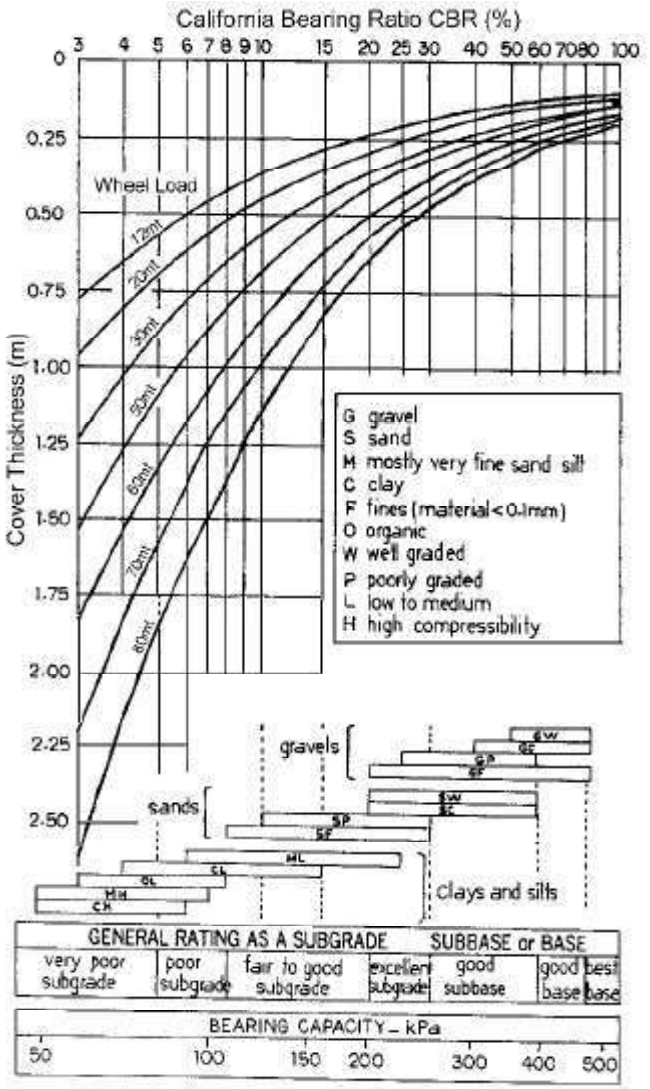

Figure 6: CBR curves (Atkinson, 1992)

values exceeding 2500 micro-strains are associated with unacceptable structural performance (Thompson et. al, 1997; Thompson, 2011).

Using a mechanistic design methodology, the specification of the layer thicknesses and compaction is based on limiting load-induced strains in the softer in-situ to below certain critical values. These values are associated with the category of roads designed, dumper size, performance requirements and road operating life. The higher the traffic wheel loads and volumes (kt/day) and the longer the operating life and associated performance requirements are of the road, the lower is the critical strain value (Table 1).

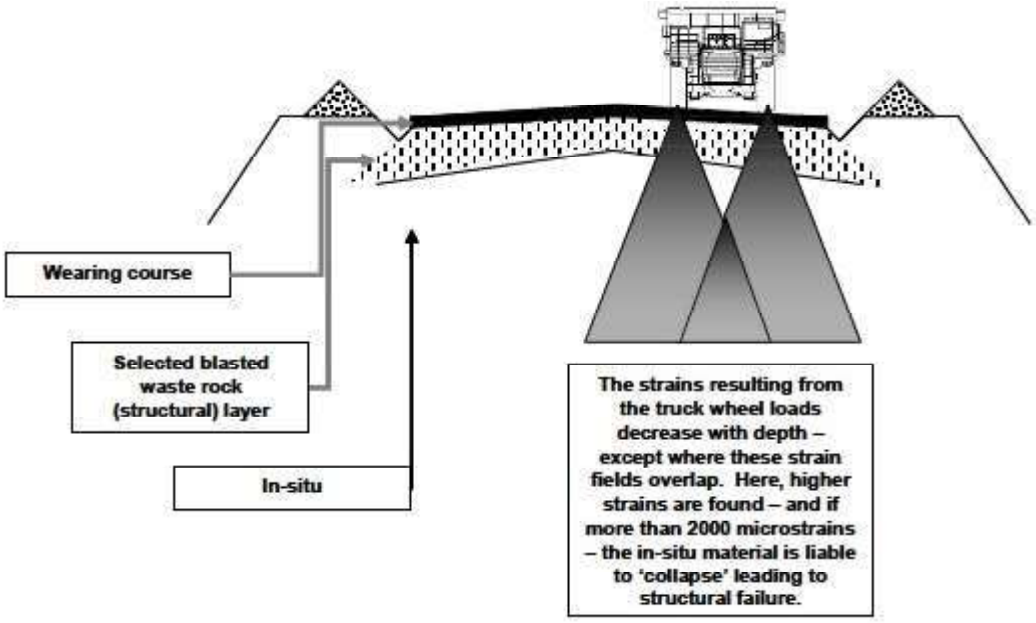

Figure 7: Mechanistic Structural Design (Thompson, 2011)

Table 1: Haul road classification and associated mechanistic structural design limiting strain criteria (Thompson, 2011)

Haul Road Category	Typical Description	Range of maximum permissible vertical elastic strains (Micro-strains)	
		Traffic volumes > 100kt/day	Traffic volumes < 100kt/day
Category-I	1. Permanent life-of-mine 2. High traffic volume 3. Main hauling roads and ramps in-and ex-pit 4. Operating life > 20 years	900	1500
Category-II	1. Semi-permanent 2. Medium-to-high traffic volume 3. Ramp roads in-and ex-pit 4. Operating life > 10 years	1500	2000
Category-III	1. Shorter-term 2. Medium-to-low traffic volume 3. Ramp roads in-and ex-pit • Operating life < 5 years (@ > 50kt/day • Operating life < 10 years (@ < 50kt/day)	2000	2500

INDIAN APPROACH OF HAUL ROAD DESIGN (CMPDI & CRRI RECOMMENDED)

CMPDI in 1980s designed some haul road cross-sections for various capacity (35t, 50t, 85t and 120t) dumpers. These designs were based on Gray's empirical formula. Gray's formula is an empirical relationship to design rigid pavements. It is a relationship between thickness of

pavement (d) in inch; bearing capacity (B) in lbs/sq. inch; radius of circular contact of tire in inch; and static wheel load (W) in lbs. This is only applicable for rigid pavement design:

$$d = 0.564\sqrt{\frac{W}{B}} - L$$ (Seelye *et al*., 1948)

In 2001 CMPDI and CRRI together developed CBR based design curves and determined designed thickness for various capacities of dumpers. The design recommended by CMPDI in 1980 differs subsequently from the design recommended in 2001. Table 2 given below illustrates the major changes.

Table 2: Design difference between Gray's formula and CBR method

Parameters	Design of 1980	Design of 2001	Remarks
Carriage way	13.25 m	17.50 m	Width of carriage way increased
Total thickness of pavement crust	825 mm	1150 mm	Increased pavement thickness for same CBR value of subgrade
Construction material	Graded stone aggregates, brick on edge, Bituminous concrete	Sand & crushed rock	Bituminous layer omitted

On comparing both the designs for same load and CBR value of subgrade, the latest design recommends:

1. Increased carriage way to avoid accident & provide smooth running of vehicles.
2. Increase overall thickness for same CBR value.
3. Emphasis on use of locally available overburden material.
4. Omission of bituminous layer from surface course.

CONCLUSIONS

Construction of mine haul roads differs in many aspects from highways. Wheel loads on haul roads are much higher compared to highways. The problems of design life, continuous change of layout requires a different approach. The haul road designer is required to use continuing ingenuity in layout by the use of cuts, spoil bridges, and ramps, to provide the shortest, least steep and most easily negotiable haul roads. High quality haul roads ensure:

1. Reduced operating costs due to reduced fuel consumption, reduced maintenance cost, and longer tire life.
2. A safer working environment that will improve efficiency.

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Environmental Assessment of the Impact of Mining in Keonjhar District

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ABSTRACT

Man has played an important role in shaping his environment. He is responsible for the degradation of the environment since his appearance on the surface of the Earth. He has the ability to utilise nature and natural resource for his conforts. Due to increase of population, the economic needs have increased at a rapid rate. He went on exploiting the Earth's resources. This has adverse impacts on global climate. Moreover, it has affected the diversity of living beings, tribes, forests and other resources.

The present study was undertaken to analyse the environmental impact of mineral extraction in Keonjhar District of Odisha using Geographic information system. Mining has a three-stage operation, involving regional exploration, detailed exploration and actual mining. Focusing on this exploration of mines in Keonjhar District, there is serious threat to environment, significant reduction in dense forest area along with negative impact on health. Hence, a suitable mining policy is inevitable for sustainable development for optimum utilisation of the mineral resource in Keonjhar District.

Minerals have played a significant role in history and in the development of present industrial economy of the world.For economic growth a country mineral resources plays an important role and continuation of human civilization. However mining,like any other industrial activity tends to leave a strong negative impact on the environment unless it is meticulously planned and carefully executed. It is a well- known fact that mining is an environmentally destructive activity. Man is responsible for the degradation of the environment since his appearance on the surface of the earth. For our comforts we are recklessly exploiting nature, natural forces and natural resources. Moreover, it has affected the diversity of living beings, Forests and other resources have been also get affected.

The growing global demand for metals and minerals has been continuously pushing up both domestic and international prices of minerals. Mining is a three-stage operation, involving regional exploration, detailed exploration and actual mining. Regional exploration is mainly a survey-activity to identify areas bearing mineral deposits. Detailed exploration is a little more invasive and can involve close spaced drilling (depending on the mineral) and substantial testing to establish commercially exploitable ore bodies. Mining project therefore, have a long gestation period requiring large investments in exploration and other development activities before commercial production can begin.

The state of Odisha is bestowed with abundant mineral resources which are found to be deposited under the large tract of forest mostly located in Keonjhar, Sundargarh, Mayurbhanj, Koraput and Kalahandi district. According to Directorate of Mines, Government of Odisha, there are more than 26 types of minerals available in the state. But the state Government has identified 13 minerals such as iron-ore, bauxite, chromite, coal, limestone, dolomite, fireclay, china clay, nickel ore, mineral sand, manganese, graphite, quartize / silica, as major minerals. In Odisha, there top 6 districts, where mining activities are being undertaken rampantly include, Keonjhar (31.28%), Sundargarh (20.03%), Angul (10.24%) followed by Jharsuguda (8.87%), Koraput (6.3%) and Mayurbhanj. Particularly the reserve of iron ore deposit approximated as more than 1000 million tonne and places of deposits are found at Joda, Thakurani hills, Bansapani hills, Sasangoda hills and Gandhamardan hill range of Keonjhar. According to Indian Bureau of mines, 2005, the Keonjhar district itself contains 75% of high-grade iron ore reserves of Odisha which contribute 21% of Indian total production.

OBJECTIVES

To assess the impact of mining operations resulting in serious depletion of the forest and disturb the surrounding

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natural environment. To analyse the process of human-induced deforestation that took place at iron ore mined area of Keonjhar district. The paper attempts towards analyse health impacts of mining on the local population. The paper also provide important insights on the mining policy to formulate legal measures for the regulation of mines. So that the policy will seek to develop a sustainable development framework for optimum utilization of the natural mineral resources.

CLASSIFICATION OF FOREST

The division wise classification of forest and coverage area by legal Status in Keonjhar district are as given below:

Table - 1
FOREST COVERAGE AND CLASSIFICATIONS

CLASSIFICATION	COVERAGE AREA IN SQ. KM. UPTO 1996	COVERAGE AREA IN SQ. KM. UPTO 2016
Reserved Forest	1833.02	1835.3563
Demarked protected Forest	648.41	272.3796
Undemarked Protected Forest	43.41	220.7857
Under Served Forest	0.24	-
Unclassified Forest (Non-Forest land may forest cover)	-	268.9819
Unclassified Forest	-	0.2645
TOTAL	2525.08	3366.1562

SOURCE: DIVISIONAL FOREST OFFICE, KEONJHAR

The above forest area is 30% of the total geographical area of the district. The reserved forests of the district consist mostly of steep hills and narrow winding valleys. Environmental assessment concerning sustainable development, Non- forest land diverted as forest land in 76 projects which is about 10319.8016hects. Apart from this 74 mine leases in Keonjhar District had produced Iron and Manganese without environment clearance during 2000-01 to 2010-11 violating environmental protect Act.

ENVIRONMENTAL ASSESSMENT AND IMPACT OF MINING

Mining as an industrial activity, disturb the surrounding natural environment and resulting serious pollution, destruction of soil, old and new subsidence, Noise pollution, energy cause to acid rain and global warming, biological disturbance, aquatic problems, etc. The state government leased out a large part of its mineral resources, whose exploration is found to directly affect the forest. The environmental impact of open cast mining is many and diverse in Keonjhar district. Increase in mining activities is damaging to vegetation. Mining in forest zones, is a major factor of degradation. The problem of waste rock dumps during mining become devastating to the landscape. As a result, natural plant communities get disturbed thus, making the environment unsuitable for growth of plants. Location of the mines at inaccessible location is a major challenge to assess the impact.

A comparison of forest land category mask of mine area within 10 kms. Radius (in ha) was superimposed on the basis of Land Use (LU) and Land Cover (LC) in Keonjhar district as given in Table- 2. The table shows area and percent of forest land cover and change during the periods 1990, 2000 and 2012. Percentage of change occurred was computed by the following formulae:

$$\text{Percent Forest Land Change} = \frac{\text{Present forest land area - Previous forest land area}}{\text{PreviousForest Land Area}} \times 100$$

Forest was classified into three categories on the basis of crown density i.e. dense, open and degraded. As per the percent change analysis, it was found that maximum deforestation occurred in the vicinity of iron ore mining areas in Keonjhar district.

Table-2 revealed that most of the iron ore mining activities are taking place in the vicinity of dense forests because most of the iron resources are located with the hilly terrain covered with forest in Keonjhar district. Therefore decrease in the dense forests is attributed to the removal of trees to initiate iron mining activities and development of mining infrastructure. It has been find out that forest land located near to the mining lease area such as upper

Jagar, Kumundi, Lower Jagar village has been largely converted to open forest and land with shrub. It may be occurred due to increase in anthropogenic activity like mining, road, development of settlement, setting and expansion of villages, dumping of overburdens on forest land and increase demand for fuel wood. This also indicates that the mining authority has failed to check the falling of trees in and around the lease area at. Rapid conversion of dense forest into open category is quite alarming from ecological and economical point of view. It will create problem for habitation of wild animal resulting in more human-wild life conflict.

TABLE-2

THE PERCENTAGE OF CHANGES OCCURRED IN FOREST LAND AT VARIOUS YEAR

CATEGORY OF LAND	STATUS OF LU/LC IN(HA) 1990	STATUS OF LU/LC IN (HA) 2000	STATUS OF LU/LC IN(HA) 2012
Dense Forest	5255.10(16.70%)	3123.67(9.93%)	1527.51(4.85%)
Open Forest	3567.89(11.34%)	5673.44(18.03%)	7430.88(23.62%)
Forest Plantation	256.24(0.81%)	202.54(0.64%)	179.17(0.56%)
Land with Shrub	2707.24(8.60%)	3808.63(12.10%)	5810.32(18.47%)
Total land area in the 10 km. radius in Ha	31456.08	31456.08	31456.08

Apart from this the important environmental impact of hazardious mining activities in the district highlights on the following points:

(I) Mining activity can cause a considerable loss of land because of chemical contamination, destruction of productive layers of soil. Large mining operations disturbs the land by directly removing material in some areas and by dumping waste in others. There can be a considerable loss of wild life habitat.

(II) Physical changes in the land, soil, water and air associated with mining directly and indirectly affect the biological environment. Direct impact includes death of plants or animals caused by mining activity or contact with toxic soil or water from mines. Indirect impact includes changes in nutrient cycling, total biomass species diversity and ecosystem instability due to alteration in ground water or surface water availability.

(III) Blasting and transport cause noise disturbance to local residence and wild life.

(IV) The presence of old and deep mines in Keonjhar district cause the ground surface to subside in a vertical or horizontal direction. This may severly damage buildings, roads and farm lands as well as alter the surface damage pattern.

(V) In surrounding of mines the adjacent villagers suffering from common diseases like, malaria, water born diseases, cholera, diarrhea and families having persons' suffering from severe diseases like T.B., Blood pressure also.

POLICY MEASURES

It is inevitable that, every ongoing and future development project contain the following aspects of environmental protection:

(I) Mining plan to incorporate reclamation scheme to provide cropland, grassland and/or wood-land as appropriate.

(II) Scheme of storage of top soil, subsoil and overburden and their replacement after mining.

(III) Arrangement to leave patches of original vegetation as reference points.

(IV) Creation of nursery for original species in advance of mining and planting of original and/or other species.

(V) Abatement measures to restore air quality, more particularly in respect of Sulphur-dioxide, suspended particulate matter and oxides of nitrogen.

(VI) Lying down of precautions for storage, transport, usage and disposal of hazardous substances.

(VII) Plans to prevent degradation in aesthetics and quality of life.

(VIII) Environmental impacts, causal factors and mitigating measures.

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Estimation of Reduction in Carbon Footprint on account of Deployment of Surface Miners in Mahanadi Coalfields Limited

Dr. Satya Prakash Sahu*

ABSTRACT

Among others, mining is one of the fundamental activities which caters to the supply of raw materials to other basic industries and fulfils most of the energy needs of the human race and is believed to be a major contributor to the anthropogenic emissions. Mining itself utilizes enormous amount of energy in form of electricity and fuels for machineries. Moreover, it adds to concentration of greenhouse gases in the atmosphere in form of CH_4 emissions, gases due to blasting, from mineral processing plants and many more. Thus emissions from mining cannot be neglected, since it contributes significantly to the bludgeoning global warming. This paper highlights the importance of calculating carbon footprint of mines in order to determine its contribution to the present climate change and also encourage development of cleaner technologies to mitigate such emissions. In this paper the authors have also presented an estimation of reduction in carbon footprint by deploying surface miners in coal mines of Mahanadi Coalfields Limited. The results indicated that there is reduction of carbon foot-print due to elimination of multiple unit operations as well as consumption of less energy due to reduced ash transportation. Total CO_2 reduction during 2023-24 by deploying surface miners has been estimated as 238465581 kg

Key words: Coal mining, Surface miner, Carbon foot-print, Greenhouse gas emissions, Carbon dioxide equivalent

INTRODUCTION

Coal is considered as the most polluting source of energy, which creates environmental problems at various stages of its procurement from mining, transportation, stock piling, coal preparation, and utilization (Pandey et al., 2014). From mining to coal cleaning, from transportation to electricity generation and finally to its disposal as end product, it releases numerous toxic pollutants into the environment. Mining operations have the potentiality to demolish flora and fauna and contaminate soil, air, and water in the surrounding areas. Deterioration of air quality due to coal mining, land degradation, water pollution and siltation, loss of vegetation and driving out fauna, noise and vibration, reduction in aesthetics, and rehabilitation of people are some of the major issues associated with coalmining activities (Maiti, 2013). Coal mining starts with land cleaning for the removal of vegetation and topsoil by using dozers and scrapers, which may create damages to soil quality and plant community as well as releases a large amount of dust, which is a serious concern of coal mining areas (Ghose, 2007). After removal of vegetation and top soil, drilling and blasting actions are performed to reach to the coal seam. Drilling and blasting are the most predominant method being followed for breaking hard rocks and over burden material in coal mines (Dhekne et al., 2016). Blasting is associated with risk of misfire, fly rock, ground vibrations, air over-pressure, noise, blasting fumes, formation of boulders. Therefore, it is not preferable used in mines where habitats are in close vicinity. The mechanical cutting technology has evolved overtime and now is being applied for cutting soft to medium hard rocks as an alternative to drilling and blasting in both underground and surface mines. India's commitment for self-reliance in coal has urged the coal companies for adoption of mass production and environment friendly technologies like surface miners in open cast coal mines. Because of their ability to perform continuous and versatile selective mining, bulk production, reliability, and cost-effectiveness, surface miners are being used in mining projects at a rate that is continuously growing (Prakash et al., 2020).

This paper highlights the importance of calculating carbon footprint of mines in order to determine its contribution to the present climate change and also encourage development of cleaner technologies to mitigate such emissions. Deployment of surface miners eliminates various unit operations such as drilling, blasting, crushing, loading and unloading at coal handling plants which results

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into reduction of carbon footprint. In this paper the authors have also presented an estimation of reduction in carbon footprint on account of deployment of surface miners in coal mines of Mahanadi Coalfields Limited.

COAL PRODUCTION, DESPATCH AND ENERGY GENERATION SCENARIO IN INDIA

Coal Production and Despatch in FY 2023-24

Coal mining sector is one of the most fundamental sectors. It involves extraction of coal which cater to the need of thermal power plants and a key resource in the process of development. India, having abundant reserves of coal, has an enormous potential to develop through mining sector. The judicious and planned exploitation of these reserves can make the country self-sufficient in meeting its energy demands, raw material requirements for industrial development and foreign trade in form of mineral exports. Thus, coal mining is a very crucial industry for a developing nation like India. Coal production, despatch and power sector supply scenario in India during last 4 years is depicted in Fig. 1a. The share of Coal India Limited (CIL) and Mahanadi Coalfields Limited (MCL) to India's coal production, despatch and power sector supply in the FY 2023-24 is depicted in Fig. 1b. In FY 2023-24, CIL's contribution (%) to India's coal production, despatch and power sector supply was 78, 78 and 77 respectively. MCL' contribution to CIL's 1 BT production aspiration for the financial years 2024-25 and 2025-26 are 225 MT and 290 MT respectively.

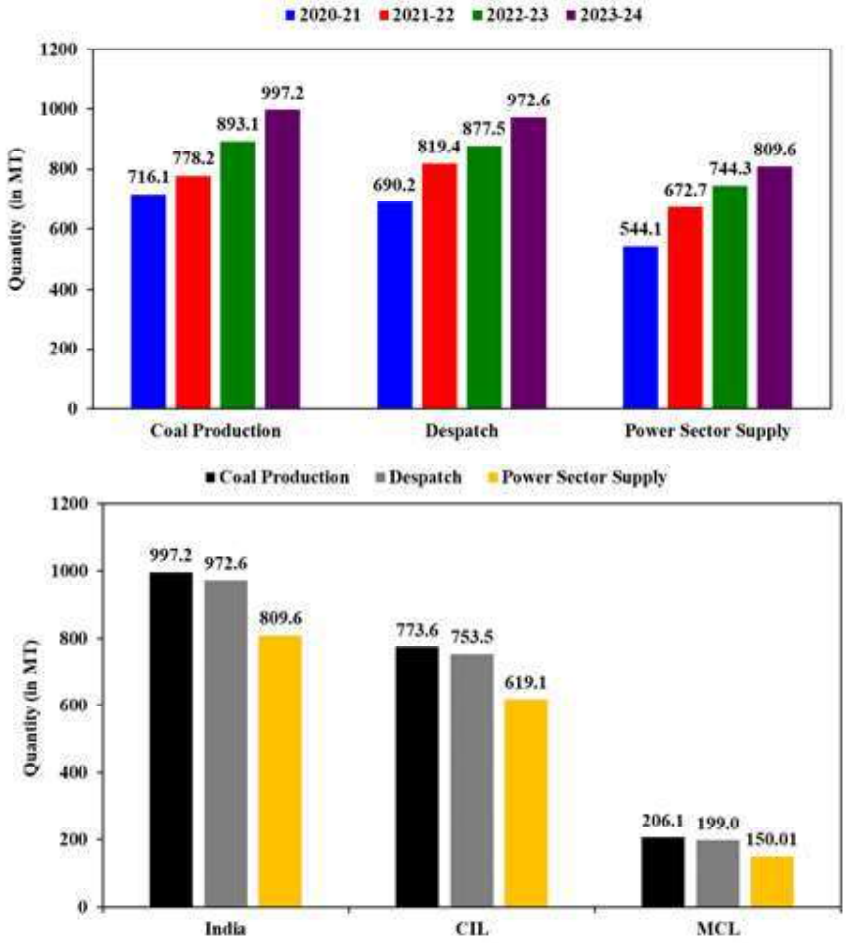

Figure 1. (a) Coal production, despatch and power sector supply scenario in India in last 4 years, (b) Contribution of CIL and MCL to India's coal production, despatch and power sector supply in FY 2023-24

Energy Statistics

One of the major uses of mining is the extraction of coal and other conventional fuels to meet the energy requirements of the country. Energy is referred to as a 'strategic commodity' and any uncertainty in its supply can be detrimental for the growth of developing economies such as India. As the energy requirement is increasing at a very rapid rate, maintaining a balanced and continuous supply is of prime importance. The energy generation statistics for the last 02 years is shown in Table 1. The share of installed capacity of coal (including lignite) accounted for nearly ~51% of the total installed capacity and its share in the total generation was over ~73% in FY 2022-23 with a growth of 10% in over FY 2021-22. In case of renewable sources the installed capacity was 30.1%. However, its share in the power generation was 12.5% only in FY 2022-23 with a growth of 19% over last FY (Table 1).

GREEN HOUSE GAS (GHG) EMISSIONS FROM COAL MINING

With very significant CO_2, CH4, and N_2O emissions from different mining activities as fugitive emissions, coal mining is a major contributor to the build-up of GHGs in the atmosphere. These gases allow solar energy to reach the earth's surface but delay that energy's escape into space, and thus effectively trapping heat in the lower atmosphere. Global net anthropogenic GHG emissions have been estimated to be 59 ± 6.6 $GtCO_2$-eq in 2019, about 12% (6.5 $GtCO_2$-eq) higher than in 2010 and 54% (21 $GtCO_2$-eq) higher than in 1990, with the largest share and growth in gross GHG emissions occurring in CO_2 from fossil fuel combustion and industrial processes (IPCC, 2023). Average annual GHG emissions during 2010–2019 were higher than in any previous decade on record, while the rate of growth between 2010 and 2019 (1.3% yr^{-1}) was lower than that between 2000 and 2009 (2.1% yr^{-1}). In 2019, approximately 79% of global GHG emissions came from the sectors of energy, industry, transport, and buildings together and 22% from agriculture, forestry and other land use (AFOLU) (IPCC, 2023). Globally, India ranks third in GHG emissions with global share of 7.3%. The per capita emission however, still remains low for India with 1.9 metric tonnes in 2019. With a meagre emission of 0.395 million tonnes of CO_2e in 1858, its emissions in 2019 went upto 2616.45 million tonnes of CO_2e. Our country relies largely on mining industry for its energy requirements. Mining, as helpful as it may be, but comes with a cost. The cost of our environment. Mining involves use of heavy machineries, blasting equipment, mineral processing plants, coal handling plants etc. which are a huge source of GHGs. Therefore, mining is a significant contributor to the present global warming menace due to release CO_2 and other GHGs. And the scale at which it is happening in our country, it cannot be neglected. Thus, Carbon Footprint is very essential to track and check the emissions caused by mining.

Carbon Footprint

It is now quite evident that the trending global warming menace is a consequence of the reckless anthropogenic CO_2 emissions. Therefore, in order to curb it we need to keep a track of these emissions. So, the countries worldwide are now preparing "Greenhouse Gas Inventory" to delineate a detailed account of total CO_2 and other major greenhouse gases emitted by them as a result of various anthropogenic activities. This estimation of approximate values of CO_2 emissions along with few major greenhouse gases is referred to as Carbon Footprint.

Carbon dioxide equivalent (CO_2e)

Carbon dioxide equivalent (CO_2e) is the standard unit used to compare and account for emissions from various GHGs based on their global warming potential. For instance, Figure 2. illustrates that CO_2 has a GWP of 1 and CH_4 (methane) has a GWP of approximately 28 (on a 100-year time horizon). Therefore, for every tonne of CH4 emitted, an equivalent of 28 tonnes of CO_2 would be emitted. Since one tonne of a particular GHG is not the same GWP as one tonne of another, this standard unit is a simple way to normalize and express GHGs as an equivalent of CO_2.

STUDY AREA

MCL, a Mini Ratna Company, is amongst the highest coal producing companies of Coal India. MCL has improved its coal production capacity from 23 MT in FY 1992-93 to 206.10 MT in FY 2023-24. As CIL is the largest coal producer of the nation, MCL caters to about 27% of the coal production of CIL and has been given a target of 290 MT in FY 25-26 in its 1 BT Program. MCL is situated in 4 districts of Odisha State namely Angul, Jharsuguda,

Table 1: Energy Statistics

Energy Generation in India (Source: Ministry of Power)	2021-22				2022-23			
	Installed Capacity (in GW)	% of Total Installed Capacity	Generation (in Billion Units)	% of Total Generation	Installed Capacity (in GW)	% of Total Installed Capacity	Generation (in Billion Units)	% of Total Generation
Coal	204.1	51.1%	1041.5	69.8%	205.24	49.3%	1145.91	**70.5%**
Lignite	6.6	1.7%	37.1	2.5%	6.62	1.6%	36.19	2.2%
Sub- Total of Coal and Lignite	210.7	52.7%	1078.6	72.3%	**211.9**	50.9%	1182.1	**72.8%**
Gas	24.9	6.2%	36.0	2.4%	24.82	6%	23.89	1.5%
Diesel	0.5	0.1%	0.1	0.0%	0.59	0.1%	0.23	0.0%
Total Thermal/Fossil Fuel	236.1	59.1%	1114.7	74.7%	237.3	57%	1206.21	**74.3%**
Hydro	46.7	11.7%	151.6	10.2%	46.85	11.3%	162.1	**10.0%**
Nuclear	6.8	1.7%	47.1	3.2%	6.78	1.6%	45.86	**2.8%**
Wind	40.4	10.1%	68.6	4.6%	42.63	10.2%	71.81	4.4%
Solar	54.0	13.5%	73.5	4.9%	**66.78**	16.1%	102.01	6.3%
Biomass/Bagasse	10.2	2.6%	16.1	1.1%	10.25	2.5%	16.02	1.0%
Small Hydro	4.8	1.2%	10.5	0.7%	4.94	1.2%	11.17	0.7%
Others (Waste to Energy)	0.5	0.1%	2.3	0.2%	0.55	0.1%	2.53	0.2%
Total Renewable	109.9	27.5%	170.9	11.5%	**125.2**	30.1%	**203.55**	**12.5%**
Total India	399.5	100.0%	**1491.9**	100%	416.1	100%	**1624.47**	100%

[Bhutan Imports: 6.74]

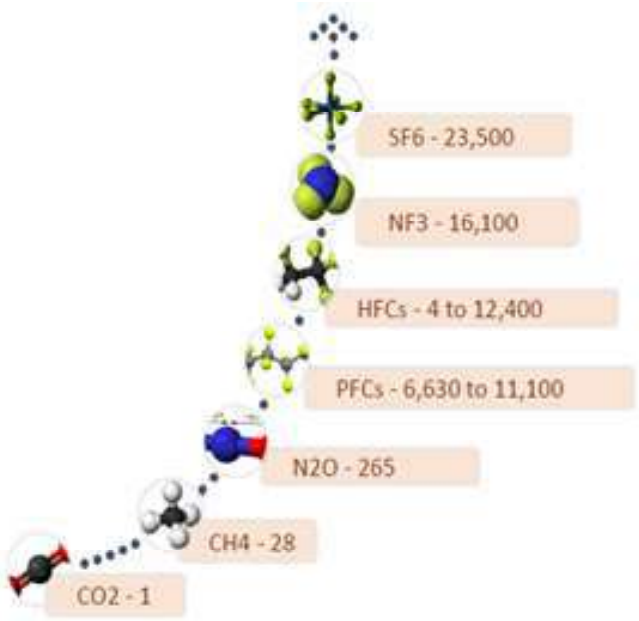

Fig. 2: Global Warming Potential of IPCC Recognized GHGs

Sundergarh and Sambalpur with two major Coalfields of the Country viz. Talcher Coalfield in Angul district and Ib-Valley Coalfield in Jharsuguda & Sundergarh districts, with Headquarters at Sambalpur. These coalfields comprise of 12 Mining Areas with 16 operating OC mines and 03 operating UG. The prevailing geo-mining conditions are suitable for opencast mining. Both the coalfields comprise about 24 % of the country's reserves. As per the latest estimate made by Geological Survey of India, Talcher Coalfield has the largest and that of Ib Valley Coalfield has the 3rd largest coal resources amongst all the coalfields in India. The total resources of coal in both the coalfields of Odisha have been estimated at around 88.10 BT, out of which, around 54.12 BT is in Talcher Coalfield and 33.98 BT is in Ib-Valley Coalfield. This is out of the total 361.41 BT national coal resources as on 01.04.2022.

SURFACE MINER

The strategy in MCL is to maximize coal production through Surface Miners whereby the conventional method of drilling, blasting, crushing and other CHP operations are totally eliminated, and we get directly dispatchable sized coal at the face. MCL is the trendsetter in introducing Blast-free technology in opencast mine by Surface Miner (Wirtgen Make-2100 SM) in 1999 at Lakhanpur OCP, MCL

(Pradhan et al., 2014; Singh et al., 2023). Last FY, out of total 206.10 MT, MCL has produced 202.20 MT through surface miners which was about 98% (Figure 3). There are many environmental benefits of adopting this technology on a large scale and are summarized below:

- Significant reduction in dust generation due to total elimination of drilling, blasting, crushing and other coal handling plant (CHP) operations. Inter-locking of the water spray system with movement of the cutting drums and mounting of the water spray nozzles on the cutting drums itself ensures very less dust generation during the cutting operation. As the cutting drums and picks mounted on the drums are covered by the body of the surface miners and rubber flaps have been provided to ensure cutting operation in closed environment, dust generation and its dissemination is significantly reduced.
- Reduction of carbon foot-print due to elimination of multiple unit operations as well as consumption of less energy due to reduced ash transportation.
- Fire and spontaneous heating are reduced as blast induced fissures and cracks are not developed and this has significant environmental benefits. Deterioration of the coal quality in the stock is also reduced due to this effect.
- Smooth high-wall, no requirements of dressing, smooth floor and good road condition in the coal face.
- Very economical operation due to elimination of cost of drilling, blasting, crushing, loading & unloading, CHP operations etc. and significant saving with respect to conventional mining.
- Conventional mining which involves drilling, shovel-dumper combination results in increase in noise level (both at active working zone and areas which are far from the work site). Surface miner being a hydraulically controlled machine contributes to reduction of noise level (Dey and Bhattacharya, 2012).

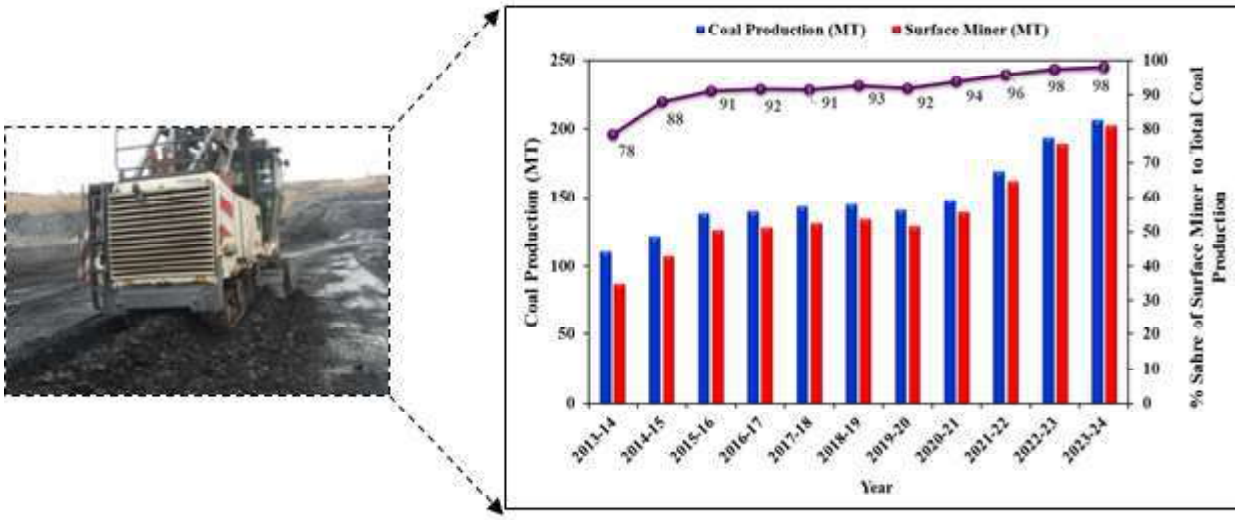

Fig. 3: % Share of surface miner to total coal production in MCL

Operating modes of Surface Miners

(A) Empty travel back method

In this method, the surface miner cuts the material from one end of the pit then it moves back to the starting end. During the backward movement there will be no cutting of material, i.e., it travels back. During the backward movement there will be no cutting of material, i.e., it travels back empty. After coming back to the starting point, the machine is adjusted for a new cut in adjacent strip as shown in the Figure 4. This method is generally adopted in the mines having a less pit length, where the turning time is more than the empty travel back time. It is also applicable in case of bad pit-end condition where the machine is not able to turn there or when the pit width is not sufficient to allow the turning of machine at the end of a cut.

(B) Turn back method

In this method, the surface miner cuts from one end of the area and after completing the cut, the cutting drum is

raised and the machine turns back, and set itself at the adjacent strip as shown in Figure 5. This method is generally adopted in the mines having a field length of more than 200 m, so that the time consumption in turning is lesser than empty travel back time. This method is widely used in limestone mines as it gives more production.

(C) Continuous mining method

In this method, the Surface miner operates on an even field and continuously cuts the material. The machine moves with cutting the material and near the pit end, it turns with a gentle angle without raising the cutting drum, so that there is no discontinuity in cutting operation. The cut area gets an oval shape, as shown in the Figure 6.

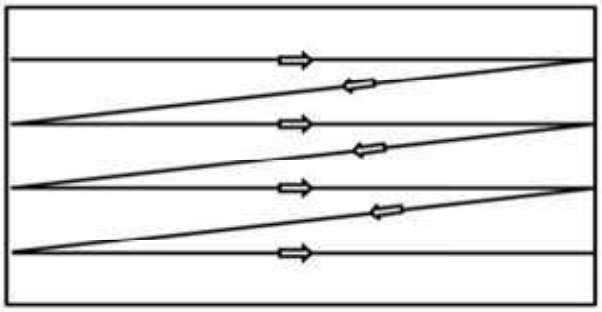

Fig. 4: Empty travel back method

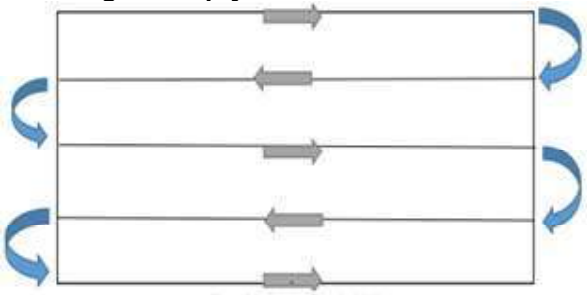

Fig. 5: Turn back method

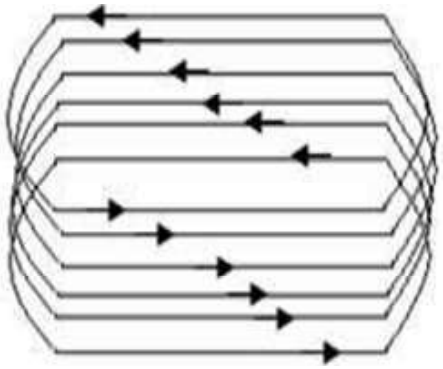

Fig. 6: Continuous mining method

RESULTS AND DISCUSSION

Estimation of Reduction in Carbon Footprint from Surface Miners

(A) Drilling

Diesel consumption in drilling (ltr/hr) = 45
Number of drill holes/hr (nos./hr) = 3
Meterage drilled/hole (m/hole) = 7
Meterage drilled in one hr (m/hr) =21
Explosive used in one hole (kg) = 50
Powder factor of explosive (Te/kg) = 4
Coal produced per hole = 200 Te
Coal produced per hour of drilling = 600 Te
Diesel consumption for producing 1 Te of Coal = 45/600 = 0.075 (ltr/Te)
Diesel consumption for producing 202.20 MT of Coal by conventional mining (ltr) = 15165000 [= 202.20×1000000×0.075]
Diesel consumption per hr in surface miner = 80 ltr/hr
Coal produced per hr (te/hr) = 1500
Diesel consumption for producing 1 Te of coal by SM = 80/1500 = 0.05
Diesel Consumption for Producing 202.20 MT Coal by SM = 10110000 [0.05×202.20×1000000]
Saving in Diesel consumption in 2023-24 = 15165000 - 10110000 = 5055000 lt
CO_2 produced per ltr of diesel (kg/ltr) = 2.68
CO_2 reduction due to use of surface miner (Diesel saving from drilling only) = 13547400 kg [5055000×2.68].....(1)

(B) Blasting:

CO_2 produced due to blasting (kg/Te) = 432
Explosive required for production of one Te of Coal (kg/Te) = 0.25
Explosive required for 202.20 MT Coal Production (Te) = (0.25×202.20×1000000)/1000 = 50550
CO_2 reduction due to use of Surface Miner (kg) (No blasting required) = 51525×432 = 21837600.....(2)

(C) Crushing

Electricity Consumption/FB Unit/Day (kWh/day) = 140
Avg. Crushing achieved/FB /Day (Te/day) = 2500
Electricity Consumption for one Te coal crushing (kWh/Te) = 0.056 (=140/2500)
Electricity consumption for 202.20 MT coal (kWh) = 202.20×1000000×0.056 = 11323200

CO_2 generated per kWh of consumption (kg/kWh) = 0.82 (Weighted avg. sp. emission rate of fossil fuel -fired stations - 0.82 **t** CO_2/MWh as per norms of BEE)
CO_2 reduction due to use of SM (No crushing required) (kg) = 11323200×0.82 =9285024……(3a)

(D) Loading/unloading and movement near feeder barker
No of trips required for 202.20 MT @ 16 te/trip (Nos.) = 202.20×1000000/16 = 12637500
Diesel consumption for 500 m extra movement/trip [@2.5 ltr/km] (ltr/trip) = 1.25 (2.5 ltr/km×0.5 km = 1.25)
Total diesel saved (ltr) = 12637500×1.25 = 15796875
CO_2 produced per ltr of Diesel (kg/ltr) = 2.68
CO_2 reduction due to use of SM (CHP feeding avoided) (kg) = 15796875×2.68 = 42335625……..(3b)
Total saving due to crushing (kg) = 3a+3b = 51620649……..(4)

(E) Total Coal Production through SM in the year 2023-24 (MT) = 202.20
Average Ash reduction due to SM @ 5% (Te) = 10,110,000 (= 202.20 MT×0.05)
45% Coal average transportation [20 km] = 4549500 (=10,110,000 ×0.45)
55% Coal average transportation [1000 km] = 5560500 (=10,110,000 ×0.55)
Two Diesel Engine, each will consume 800 ltr/hr and considering speed 40 km/hr-Consumption/km = [1600 lt/hr/40 km/hr] = 40 ltr/km/hr
One rake will carry 3800 te. Hence consumption/km/te = 40/3800 = 0.01
CO_2 generated per te per km = 0.0268 (2.68 kg of CO_2/ltr of diesel burning)
CO_2 reduction due to use of SM (Ash reduced 5%) = [(4549500×0.0268×20) + (5560500×0.0268×1000)] = 2438532+ 149021400 = 151459932……..(5)
Grand total CO_2 reduction during 2023-24 = (1)+(2)+(4)+(5) = 13547400+21837600+51620649+151459932 = 238465581 kg

CONCLUSIONS

The authors have made an estimation of reduction in carbon footprint on account of deployment of surface miners in coal mines of Mahanadi Coalfields Limited. The results indicated that there is reduction of carbon foot-print due to elimination of multiple unit operations as well as consumption of less energy due to reduced ash transportation. Total CO_2 reduction during 2023-24 by deploying surface miners is 238465581 kg.

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