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Acknowledgement:

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.

Editorial

This volume contains papers authored by some of our young faculty members of Mining. They have accepted research and teaching vas a career and most of them left their mining assignments. This shows their love towards this noble profession.

The authors have their accessibility to mines in andc around their Institutions. By regular interaction with the mines they have understood the problems of any mine. This has helped them to teach practical aspects and also attracted them to write technical papers.

The papers published shows the interest of the authors and as has been the tradition this journal had groomed several scientists, managers, researchers and faculty members to become experts in their respective fields.

Some of the papers were devoted to mining activities of Keonjhar district of Odisha, one of the richest iron ore mining districts of India. Keonjhar has a rich tradition of Mining by opencast means and it had been major iron ore supplier of SAIL, Tata Steel, JSPL, JSW, and many others.

I am confident that the authors of this volume will be the leading researchers of tomorrow.

Prof G.K.Pradhan
Technical Editor (Hony)

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An Approach to Uplift the Blasting Performance Through the Integration of Drone Surveying and Real-Time Measurement

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

ABSTRACT

Designing of blasts with proper blast hole pattern has been an essential feature of any blast. In case of opencast mines, this not only influencing the productivity but also create several unsafe conditions. Thus a precise Drill Plan design and execution are essential for achieving the best possible safer blast results. Utilizing an accurate GPS hole navigation system in conjunction with Measure While Drilling (MWD) data from bench surveys can drastically alter blast configuration and drilling patterns. By customizing each blast hole segment to its unique conditions, blasters may maximize fragmentation and avoid fly rock by incorporating these new data types into the blast design process. In order to obtain extremely accurate drilling hole placement based on the drill pattern, this research intends to investigate the advantages of combining drone photogrammetry with a Post Processed Kinematics (PPK) surveying methodology. Concurrently, blast hole charging with MWD optimization can yield fresh insights into the properties of rock mass. By doing so, the laborious procedure of manually assessing each hole is eliminated, and the intended blast outcomes such as fragmentation, muck pile shape, ground vibration, etc. are more easily attained.

Keywords: Measure While Drilling (MDW), fragmentation, drone photogrammetry, Post Processed Kinematics, Muck pile

INTRODUCTION

Blasting performance is influenced by a number of fixed and variable parameters. One of the major parameters has been 'Drill Hole Pattern'. Planning and executing proper drill hole pattern help in maintaining proper performance as well as least damage to the host rock as well as ensuring better safety. In Indian opencast coal mines over 10 to 15 percent of holes are drilled by not following proper drill hole pattern (including depth). This alone has been one of the main cause of excessive fly rock as well as other unsafe features.

Fly rock is prevented and fragmentation is improved via digital drill pattern design (Sereshki et al 2016). Nevertheless, it is frequently impractical to perform this for each photo due to standard survey methods. Establishing a precisely calculated blast pattern is essential for drilling and blasting operations in order to achieve the required fragmentation as well as downstream benefits like loading, hauling, transportation, etc. (Elbeblawi et al. 2022). Drill planning can be a challenging undertaking in the absence of drill plan survey and guidance technologies. Physically marking the locations of the holes according to the drill plan is unreliable since wind and rain can cause the marks to be removed or moved, or cars can drive over them. When matching the drill bit with the collar location using this method, there may be more positional errors made. Pit construction and mine planning have made extensive use of the tried-and-true method of GPS rover and base station surveying (Leick, A. 2015). Because the surveying process is time-consuming, expensive, and complex, it is not commonly used in drilling and blasting operations for the preparation of daily drill plans. To do this and attain the intended explosion effects, a drone-based survey is needed for every blast.

MATERIALS AND METHODS

The majority of commercial Unmanned Aerial Vehicles (UAVs), also referred to as drones, navigate using an inbuilt Inertial Measurement Unit (IMU) and the Global Positioning System (GPS). As seen in Figure 1, there are three ways to fix GPS problems in drones-

The role of GPS in drones and different surveying methods
a) Ground Control Point (GCPs) method: For data to come out precise, it's important to use ground control points

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when drone surveying operations are underway. Ground control points (GCPs) are points on the surface of the earth of a known location (Greenspan et al. 1996). Instead of resorting to GCPs, GPS correctional technology can be used to get the same or even better accuracy (Hoftmann-Wellenhof et al. 2001). It enhances the quality of location data by using global position system receivers to produce precise, accurate data. This GPS correctional technology can reduce data gathering by 75%. Additionally, it creates smoother workflows because of the time that is shed (Kaplan et al 2017). RTK and PPK methods are two methods to achieve greater accuracy.

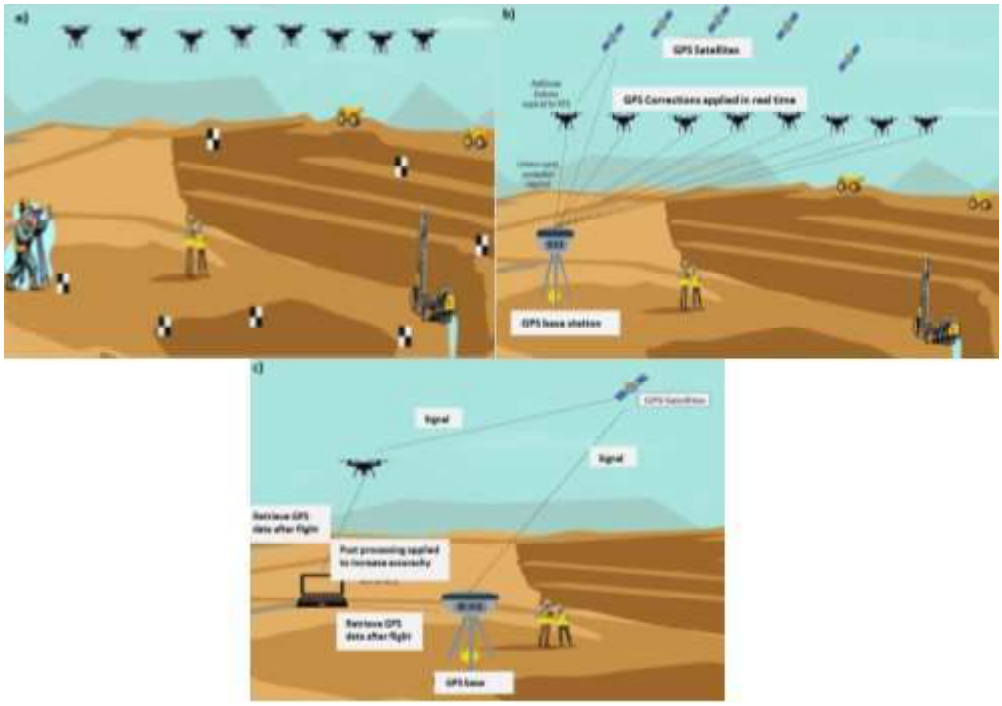

Figure 1: a) Workflow with drones, base station, and ground control points GPS correctional technology b) Workflow with drones, base station, and RTK, c) Workflow with drones, base station, and PPK

b) RTK (Real-time Kinematics): In this method of survey, the measured positions of the base station must be transmitted to the drone (Souza et al 2009). This requires a stable connection between the base station and the drone during the measurement. For the drone, this requires an extra antenna and receiver, increasing the payload complexity and size, weight, and power (SWAP) (Feng & wang 2008).

c) PPK (Post Process Kinematics): PPK applies the same offset correction as RTK, but this is followed by several additional post-processing steps to further increase the measurement accuracy (Xi et al. 2020). Thus, PPK will result in more accurate GPS/IMU measurements than RTK (Pirinen et al. 2014). PPK does not require a connection between the base station and the drone (Pýrtý 2021). This simplifies data collection as shown in Figure 2.

Increased accuracy in drilling

With the precise matching of drill pattern design and using GPS guided hole navigation system, the drill operator can detect the drill hole locations with centimetre level accuracy (Kendoff et al 2007). Driller knew where the holes were to be drilled and to the desired elevation even when the terrain was uneven (Schunnesson 1990). The hole was separated accurately as per the planned burden and spacing. The back row was straight and planned with survey-grade accuracy. Below is the comparison table of some holes that were manually surveyed with a GPS rover and then compared with automated PPK workflow (Table 1) and it shows that inch level of accuracy.

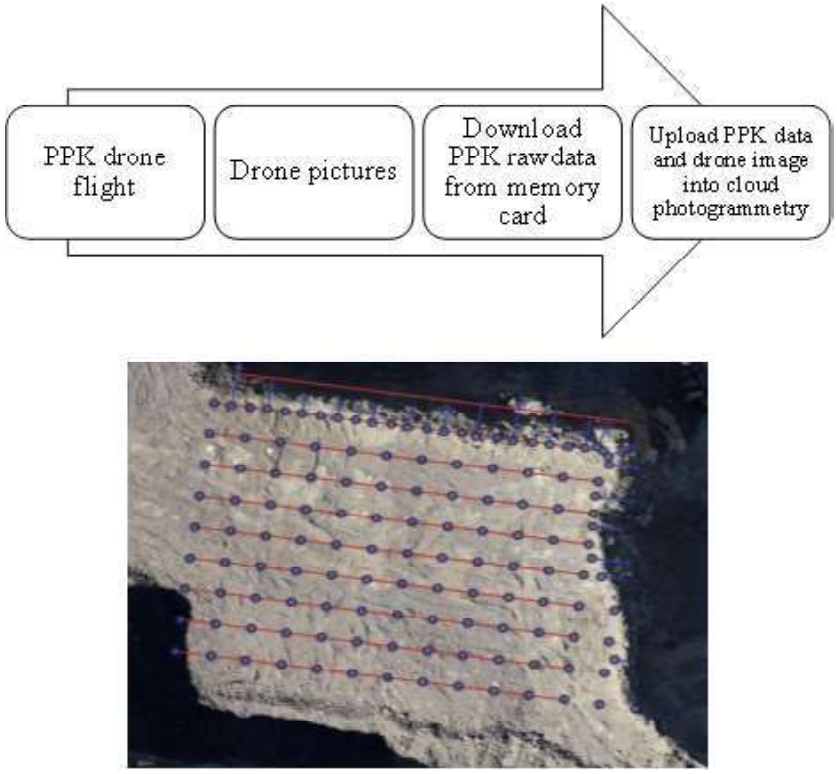

Figure 2: PPK data capture workflow with no base station to plan drill pattern design layout using Strayos software

Table 1 : Comparison between manual surveying using GPS rover and automated PPK

Label	Actual value			Strayos elevation Z (ft)	Delta elevation, Z (ft)
	Longitude	Latitude	Elevation Z (ft)		
0	-122.81643917	43.61888286	3234.114	3233.824	0.291
1	-122.81643917	43.61888276	3233.986	3233.822	0.164
45	-122.81643917	43.61888306	3233.835	3233.816	0.019
46	-122.81643917	43.61888292	3234.734	3233.818	0.084
47	-122.81643917	43.6191016	3223.766	3233.062	0.705
48	-122.81643917	43.6191017	3223.589	3233.059	0.530

INDUCTION OF MEASUREMENT WHILE DRILLING (MWD) INTO BLAST DESIGN

A new practical and robust process for incorporating Measurement While Drilling (MWD) data into everyday blast design processes (Li et al. 2014). In particular, the team focused on evaluating a method for identifying seams by combining MWD data from multiple holes with 3D contextual data (Rai et al, 2015). This research lays the groundwork for enabling custom hole loading by seam as well as AI-powered seam detection. The data refers to the sensor data collected from production drill rigs during operation. This is generally comprised of geospatial data (e.g. penetration rate), pressure data (e.g. feed pressure), and calculation data (e.g. rock hardness). It is logged at regular intervals (~every 1" or 2 cm) down the hole as the drill operates. A summary of the most common output data fields is shown in Table 2.

Table 2 : Most Common Data Fields for MWD Data

Sl. No.	Data field	Data type	Description
1	Hole depth	Geospatial	The vector distance from the hole collar position to the current drill bit position is measured in ft or m. Note: This is not just the elevation component
2	Penetration rate	Geospatial	The velocity of the drill bit as it moves through the rock during drilling is measured in ft/s or m/s.
3	Percussion pressure	Pressure	The piston pressure is used to power the hammer in Top Hammer or DTH drills.
4	Field pressure	Pressure	The hydraulic pressure is exerted on the drill stem to move the bit in the direction of drilling
5	Flush pressure	Pressure	The compressed air pressure is exerted to push the crushed rock from the drill hole up the outer annulus of the drill pipe and out of the hole.
6	Rotation pressure	Pressure	The hydraulic pressure is applied to create torque on the drill stem and rotate it as it moves through the rock.
7	Rock hardness	Calculation	An estimate of the rock hardness is calculated through a proprietary algorithm based on the other data types recorded. This may not have units.

MEASUREMENT WHILE DRILLING SEAM ANALYSIS

The MWD data was pulled wirelessly from the drill back into the cloud-based blast design platform for analysis, The platform processed the MWD data and automatically combined it with the 3D photo model using the HNS information (Scoble et al 1889). Figure 3 shows the penetration rate extracted from MWD data visualized in the context of the 3D photo model. Rock seam detection was also supported by quantitative analysis of the metrics at each depth interval. The driller/blast engineer can easily identify the percussion rate and pressure, feed pressure, flush pressure, and rotation pressure (Zhang et al 2021). Averages were taken across all holes in the blast to identify the trends in the bench geology. These results would help in the selection of blast input parameters and explosive charging so that maximum utilization of explosive energy can be achieved into fragmentation and minimum into blast nuisances (Leung & Scheding 2015).

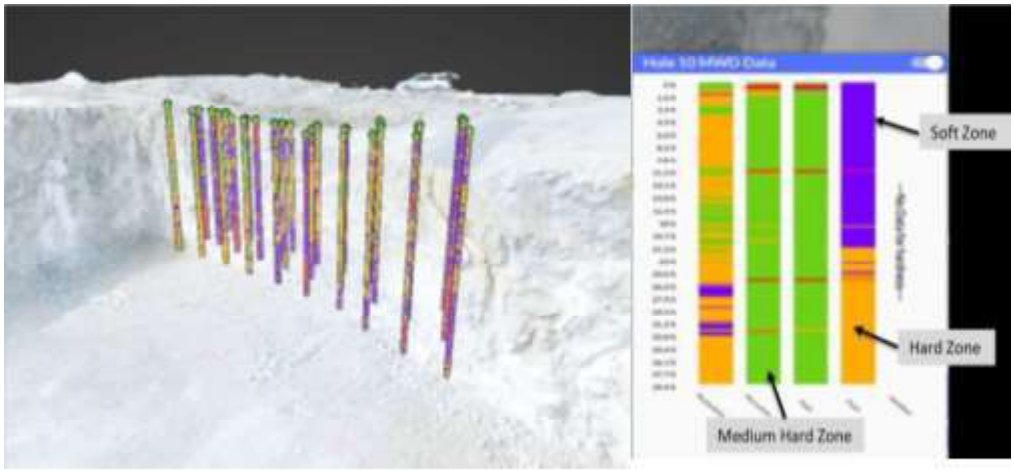

Figure 3 : MWD Data (Penetration Rate) in the context of a 3D model to identify the soft to hard rock zones

CONTEXTUAL BLAST LOADING DESIGN

The final step of the process was to integrate the MWD data and 3D survey model insights into the blast loading design process. This was achieved by visualizing the MWD parameters as colour-coded bars beside the burden profile in the loading design module of the cloud-based blast design platform. For each hole, the explosive products were adjusted based on the data collected as shown in Figure 4. In Figure 4, based on the obtained drilling data, the quantity/quality of explosives has been modified (bulk and cartridge). In this way, the cost of explosives w.r.t quantity of explosives can be easily saved. Moreover, the blast engineer can modify the blast input designs to minimize any nuisances.

Figure 4 : Blast loading design performed in the context of 3D burdens and MWD data

POST BLAST ANALYSIS USING ARTIFICIAL INTELLIGENCE

After the blast was fired, the muckpile images were captured using a drone for post-blast performance analysis.

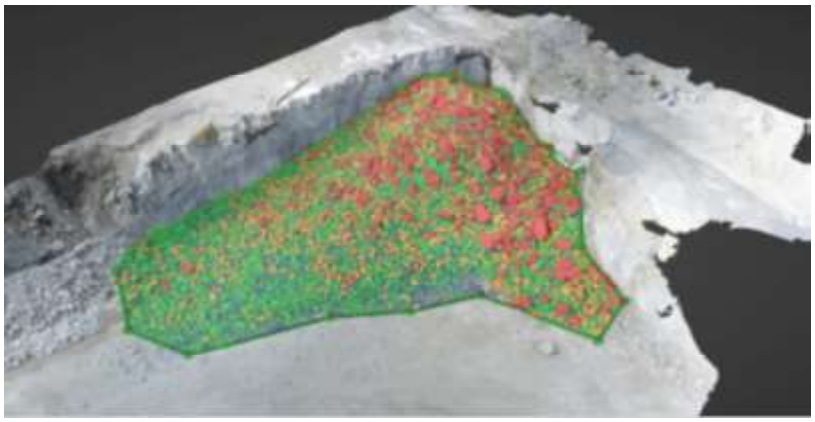

Figure 5 : 3D Photogrammetric Model of Muck pile

These images were uploaded into the same cloud-based blast design platform to create a post-blast photogrammetric 3D model with automatically generated fragmentation and muckpile movement analyses (Choudhary & Agrawal 2019). In this case, ground control points were not required, and the 3D model was created using the drone's onboard GPS. To enable accurate muckpile movement analysis, the elevation of the post-blast model was calibrated to the pre-blast model using a common visible marker. Tailoring the blast loading to the

MWD data and 3D burden data resulted in high quality blast outcomes. The obtained muckpile movement analysis results are shown in Figure 5.

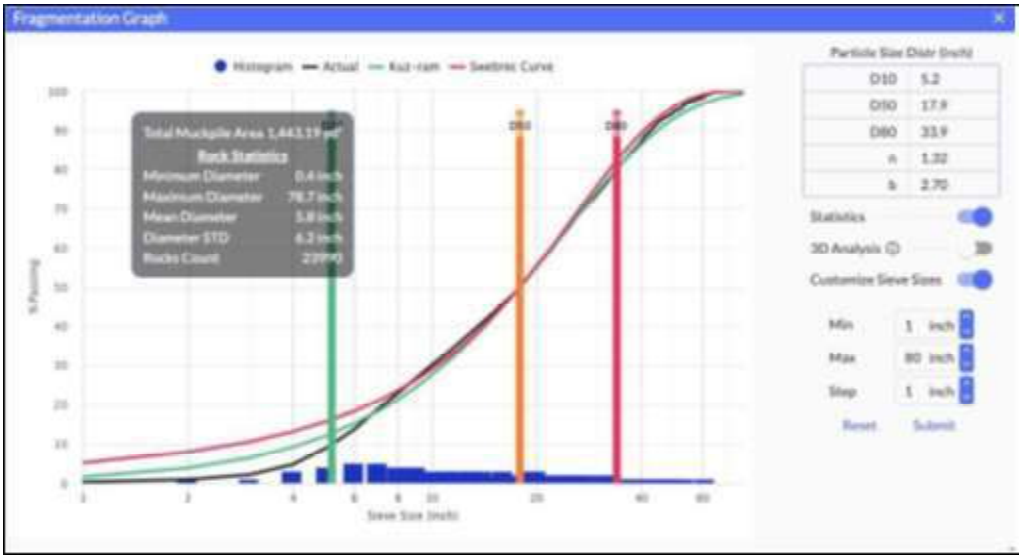

Figure 6 : Results of Automated Fragmentation Analysis

With the obtained blast fragmentation results from drone images, the comparison between predicted and actual fragmentation image analysis is shown in Figure 6. The obtained results are a combination of drone images and artificial intelligence. Furthermore, complete pre- and post-blast (in-situ and blasted muckpile) analysis data is given in Table 3.

Table 3 Results of automated muckpile movement analysis

Sl. No.	In-situ and blasted muck pile analysis	Data
1	Pre-blast volume	3.782 yd^3
2	Post-blast volume	4,749 yd^3
3	Swell factor	1.26
4	Average centre of mass movement	37.8 ft
5	Maximum throw	51.2 ft
6	Average throw	164.4 ft
7	Average trough drops	19.8 ft

RESULTS AND DISCUSSIONS

Blast results had improved with the use of GPS-guided drill navigation and PPK surveying procedure. The primary enhancement was attained in the fragmentation sizes subsequent to utilizing identical explosive items and hole diameters. The following advantages were also realized:

1. Time saved in pattern design and layout.
2. No need to go out on the bench with tapes and paint.
3. Quick setup and flight (no Base, Rover, GCPs), automated data processing, and design tools.

After incorporating MWD for seam identification and blast loading optimization can be done in a practical way for everyday in drilling and blasting operations. This workflow produced improvements in blast outcomes and increased efficiency in drilling operations by eliminating the requirement to measure manually and lay out the holes. Interestingly, tailoring the blast loading with the visualization of MWD and 3D burden data highlighted several situations where a loading decision made purely based on burden would not have been optimal. There were parts of holes where the minimum burden threshold should have been increased due to soft ground or voids and parts where it could be decreased because of hard ground. This concept of a 'variable minimum burden' at different depths within a hole, based on rock properties and explosives options, has the potential to bring significant safety benefits to the blasting industry.

CONCLUSIONS AND FUTURE WORK

By utilizing data from rock mass drilling and drone surveys, blast designing was able to build a reliable and workable mining method. The bench blasting system can be

implemented by mine management without fear of negative consequences. Artificial intelligence has the potential to revolutionize mining by enabling the analysis of uncontrollable parameters for the purpose of selecting blast input parameters.

1. After introducing a new and fully integrated workflow of PPK method surveying and transferring to GPS drills, the size of the impact seen in the drilling quality improvement and hole accuracy at the mine site.
2. The average difference in elevation between manual surveying and drone surveying is less than 10 cm which shows the higher accuracy at the minimal time.
3. Measure while drilling detected soft zones in the depth of 3.6-6 m and 8-9.5 m which helped the blasting engineer to modify the quantity/strength of explosives or plan for solid/air decking.
4. Using Measure While Drilling data, blast designing and desired fragmentation planning can be achieved easily without predicting the unusual impact.

New research should build on this by investigating the impact that a 'variable minimum burden' based on rock properties has on fly rock and fragmentation. Future research would show AI algorithms for automatic seam detection from MWD data. Additionally, the AI will suggest desired blast design input parameters based on the rock mass and survey data.

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Whole-Body Vibration Risks in Heavy Earth Moving Vehicle Operators – Case Study of an Open-Cast Coal Mine

Amit Kumar*

ABSTRACT

The exposure of Heavy Earth Moving Machinery (HEMM) operators in Indian open-cast coal mine to whole-body vibration (WBV) and associated health risks has been an area of concern. It highlights the link between WBV and musculoskeletal disorders (MSDs), particularly low back pain, hand pain, shoulder pain, neck pain, knee pain, etc. An attempt has been made to undertake this study at one mechanized coal mine, to evaluate WBV exposure levels during various HEMM operations and assess health risks using ISO 2631-1:1997 standards. Measurements were taken using a tri-axial accelerometer which was placed over the seat surface during different operational cycles. In addition to actual field data as recorded in an approved type of instrument, age was positively correlated with experience. These findings underscore the potential health risks associated with prolonged exposure to vibration in heavy machinery operators, particularly in relation to body composition and its effects on vibration absorption. In Indian mines, a number of studies have been undertaken and DGMS is closely monitoring the progress made in data collection on regular basis using approved type of instruments. DGMS also issues Guidelines from time to time laying emphasis on this aspect through Technical Circulars, holding interactive sessions in mines also.

Keywords: Ergonomics; Machine Vibration; Mine Hazards; Mine Safety; Mine Machinery; Whole-Body Vibration; Musculoskeletal Disorders.

INTRODUCTION

Risk management is crucial in environments where workers are exposed to various occupational hazards, particularly for operators of Heavy Earth Moving Machinery (HEMM). These operators encounter numerous ergonomic risk factors that can significantly impact their health. Research indicates that HEMM and agricultural machinery are major contributors to prolonged exposure to whole-body vibration (WBV), which poses serious health risks (Griffin, 1990).

Whole-body vibration (WBV) occurs when vibrations of any frequency are transferred to the human body through contact surfaces, such as the seat, floor, and handles of vehicles in a mechanical vibrating state. This exposure is prevalent in off-road work environments like mining, farming, and construction. WBV affects not only seated operators but also those standing on machinery such as concrete crushing machines, buses, and trains. In the mining industry, numerous studies have analyzed WBV exposure among HEMM operators, highlighting various factors that influence vibration levels during operations. Epidemiological studies have consistently reported heightened risks for musculoskeletal disorders (MSDs) among HEMM operators, particularly in the neck, lower back, and shoulders.

The impact of WBV on spinal health is influenced by several factors, including vibration magnitude, exposure duration, and body posture. Established standards from the International Organization for Standardization (ISO) and the American National Standards Institute (ANSI) link WBV exposure to various health issues, including negative effects on the digestive and reproductive systems (ISO, 1997; ANSI, 2002). Significant health risks associated with prolonged WBV exposure have been identified in large populations, indicating a higher incidence of spinal and peripheral nervous system issues (Seidel and Heidel, 1986).

The role of posture in developing lower back disorders (like back pain) has been emphasized, with awkward and static postures identified as major contributors to pain. Field studies have documented WBV exposure across various domains, including agriculture, trucking, and mining (Mayton, 2008; and Kim et al., 2016). Prolonged vibration exposure is believed to cause degenerative changes in intervertebral discs, leading to pain and suffering among operators (Bovenzi and Hulshof, 1998).

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However, the mechanisms of damage and the specific types of injuries remain inadequately understood (Griffin, 1998).

FACTORS INFLUENCING VIBRATION EXPOSURES

Numerous factors include –

- speed,
- haul road or surface conditions (at loading and unloading points,
- vehicle maintenance,
- driving experience,
- age of the operators,
- driver sitting posture,
- total vehicle weight,
- vehicle type,
- engine size (HP) and life of the engine,
- duration of operation,
- body weight
- type of fuel Diesel-powered and electric-powered engines
- length of the chassis (ex-crane length),
- cab position
- Illumination level at the place of movement/operation of the HEMM in the mine, and
- Climatic conditions and temperature level (in summer and winter season)

Several countries have developed standards to ensure minimum injuries to the operators of HEMM or Motorised vehicles.

While the primary concern with WBV exposure is back injury, several other health risks have been reported, including:

- Motion sickness
- Headaches
- Increased heart rate
- Abdominal and chest pain
- Blurred vision
- Impotence
- Hyperventilation
- High blood pressure
- Sleep induced by low-frequency vibration
- Kidney problems
- Changes in task performance, either improved or lessened
- Elevated muscle tension and muscle fatigue

INDIAN MINING SCENARIO

According to reports from the mining regulatory authority (like DGMS and Indian Bureau of Mines), the number of workers employed in the Indian mining sector has now surpassed seven lakh. The National Institute of Miners' Health (NIMH) in Nagpur conducted vibration surveys across various mines in the country. The findings revealed that workers in surface mines, particularly operators of heavy earth-moving machinery (HEMM), face a higher risk of health issues due to occupational vibration exposure. Mandal & Srivastav (2006) have undertaken several studies mines and according to them approximately 18% of workers are frequently exposed to vibration at work.

Furthermore, it was observed that older machinery tends to vibrate more. While timely maintenance can reduce these vibrations temporarily, replacement of machinery is necessary after a certain period. If the equipment is not ergonomically designed to mitigate harmful vibrations, it poses a significant safety risk. The mining and transportation industries heavily rely on outdated machinery, and the replacement process is notably slow

PROBLEM IDENTIFICATION

Machinery-induced vibration is widely recognized as a health hazard, particularly in the mining industry, where many workers are exposed to this physical stressor. Despite extensive research in developed countries, there is limited data available on the extent of this problem in India. As mining jobs become increasingly mechanized, workers are spending more time operating machinery and driving heavy earth-moving machinery (HEMM) (McPhee, 2004). While this shift toward mechanization has boosted production, it has also introduced new occupational hazards and safety concerns. The lack of ergonomic considerations in the workplace has significantly contributed to the prevalence of musculoskeletal disorders (MSDs).

In 1975, the Directorate General of Mines Safety (DGMS) issued a circular under the Metalliferous Mines Regulations of 1961, recommending safety measures against whole-body vibration (WBV) for workers. However, no specific vibration limits were prescribed for miners. During its 10th Conference on Mine Safety in November 2007, DGMS strongly recommended that vibration studies

of HEMM, based on ISO standards, be conducted before the machinery is put to use (DGMS, 2008). Despite this, no specific vibration threshold limits or guidelines for evaluating health risks were included (Kaku, 2004). The 11th Conference on Mine Safety, emphasized the importance of ergonomic assessments of working postures, recognizing the link between MSDs and mining jobs. Since MSDs have multi-factorial causes, ergonomists must apply various methods depending on the nature of the work performed by the machinery.

The Coal Mines Regulation of 2017 introduced ergonomic provisions for HEMM operators, stating that the operator's cabin or seat must be designed to ensure a clear line of sight both in front and behind the machine, without causing strain or constraint. This has made ergonomic assessments of coal miners in India increasingly necessary.

Previous studies have shown a positive association between whole-body vibration (WBV) and low back pain. Research on WBV among HEMM operators has so far been limited in India. Additionally, there is no data available on the quantification of WBV among HEMM operators based on job cycle. Limited research has been conducted on health outcomes in accordance with the ISO 2631-1:1997 Standard and the EU Directive 2002, specifically for HEMM operators in Indian surface coal mines.

Given these facts, there is a pressing need to address whole-body vibration among HEMM operators in Indian surface coal mines, which forms the basis for this study. After reading various research papers and examining the current mine condition it comes to light that HEMM operators have to do numerous tasks in mines in which they are highly prone to WBV exposure. Hence it is required to access the WBV exposure of HEMM operator in Indian Opencast Mining operation.

STANDARDS RELATED TO WBV

Since human body have adverse effect due WBV, so it is necessary to evaluate the health effects from exposure time and vibration dose during operations. One of the most popular Standards for measurement & evaluation of human responses to WBV is ISO 2631-1 which came into play in the 1997. In order to assess the health effects of vibration, it is proposed that the frequency- weighted R.M.S of ISO 2631-1 can be used on the basis of the translational motion of each axis on the seat surface where the crest factor is less than 9. The Table 1, represents the list of standards available related to WBV.

Table 1 : Standards and regulations for Whole-body vibration (*Source*: Sharma 2021)

ISO 2631-1:1997	Mechanical vibration and shock: Evaluation of human exposure to WBV: General requirements
BS 6841:1987	Guide to measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock
European Directive 2002/44/EC	Occupational vibrations
ANSI S3.18:2002	Adoption of ISO 2631
AS 2670.1: 2001	Evaluation of human exposure to whole-body vibration (ISO 2631) Part 1: General requirements
EN 14253: 2003	Mechanical vibration - Measurement and calculation of occupational exposure to whole-body vibration with reference to health - Practical guidance
GB/T 18368: 2001	Comfort evaluation of human exposure to whole-body vibration in recumbent position
VDI 2057-2: 2017	Human exposure to mechanical vibrations Part 1: Whole-body vibration
IS 13276 (Part 1): 2000	Adoption of ISO 2631

ISO 2631-5 (2004), provides additional guidance on assessment of vibration containing multiples shocks which is mainly used for evaluation of WBV which enters human body through hand held equipment. ISO 2631-5(2004) mainly focused on lumber responses in human body whenever exposed to WBV. This standard offered a criterion as the daily equivalent static compression dose S_{ed}, which is then used for calculating another risk factor called R. When this R factor values are less than 0.8, then they show the "low possibility of undesirable health effects" for lumbar spinal area and whenever R factor values exceed 1.2, which usually indicates the "higher possibility of undesirable health effects".

Another directive for evaluation of WBV such as European Directive 2002/44/EC (2002), which is similar to ISO 2631-

1, gives slightly higher values for action level and exposure level in both cases of r.m.s and VDV which ranges from 0.5-1.15 m/s^2 and 9.1-21 m/s$^{1.75}$, respectively.

For this particular study, ISO 2631-1 has been considered as evaluating standard. In order to evaluate the vibration using ISO 2631-1, various evaluation methods have been provided such as Weighted Root Mean Square (RMS) and the fourth power Vibration Dose Method (VDV). Certain parameters such as Crest Factor, RMS, VDV, peak value, MTVV, Exposure Limit Value (ELV), Exposure Action Value (EAV), Daily dose and Daily exposure, that needs to be calculated for the proper analysis of level of exposure.

MEASURING PARAMETERS OF WBV
(a) Weighted Root Mean Square (RMS)

This method of evaluation of whole-body vibration as mentioned in section 6.1 in ISO 2631-1 measures vibration in terms of acceleration. The weighted R.M.S is expressed in meters per second squared (m/s^2) for translational vibration and radian per second squared (rad/s^2) for rotational vibration. The weighted R.M.S acceleration shall be calculated in accordance with the following equation.

$$a_w = (\sqrt{(1}/T) \int_0^1 a_w^2(t)dt) \qquad (2.2)$$

Where,

- $a_w(t)$ is the acceleration (translational & rotational) as function of time, in meter per second squared (m/s^2) or radian per second squared (rad/s^2), respectively.
- T is the duration of measurement, in seconds.

The above equation (2.2) gives the R.M.S value for respective axes i.e. x, y, and z axes which is represented by a_{wx}, a_{wy}, a_{wz} respectively. As there is more risk of damage spinal cord in x and y axis, therefore ISO 2631-1 suggested that the acceleration value should be multiplied by factor 1.4. whereas, the vertical axis should be multiplied by factor 1.0 to get the weighted mean of all the values of acceleration. In order to evaluate vibration taking place in multiple directions following formula can be used for this purpose which is the vector sum of frequency-weighted RMS in three orthogonal axes.

$$a_{wv} = \sqrt{(1.4a_{wx})^2 + (1.4a_{wy})^2 + (1.0a_{wz})^2} \qquad (2.3)$$

VDV is the parameter that combines the magnitude of vibration and the time for which it occurs. Whenever assessing continuous vibration, it has been recommended to use Vibration Dose Value (VDV) which is a cumulative measurement of vibration level received in an 8-hour or in 16-hour period. VDV is determined whenever the Crest Factor exceeds 9. Considering factors like magnitude, frequency, and exposure duration, the VDV gives a measure of the total exposure to vibration:

$$VDV = \{\int_0^T [a_w(t)]^4 dt\}^{1/4} \qquad (2.4)$$

where,

- $a_w(t)$ is the instantaneous frequency-weighted acceleration;
- T is the duration of measurement

The Standard also suggests that, for some exposures such as continuous vibration and low crest factor, the dose value may be approximated by the estimated vibration dose value in the equation

$$eVDV = 1.4a_{wt}T^{1/4} \qquad (2.5)$$

Where,

- a_{wt} is the frequency weighted R.M.S acceleration and the exposure duration is T seconds.

(c) Crest Factor

According to ISO 2631-1, crest factor is defined as the modulus of the ratio of the maximum instantaneous peak value of the frequency weighted acceleration signal to the R.M.S value. The peak value can be determined over the duration of measurement i.e., the time period used for the integration of the R.M.S value.

$$CF = \frac{Max\,(a_w(t)}{\max\,(a_w)} \qquad (2.6)$$

To a certain limit, the crest factor is used to measure the severity of shock i.e., lower or equal to 9. If the Crest factor is greater than 9 then there is transient shock present and, in that case, an additional method such as VDV is used to evaluate the level of exposure.

(d) Daily dose & Daily Exposure

The 8-hour energy equivalent vibration total value for a worker in meter per second squared (m/s^2), including all whole-body vibration during the day is known as Daily

exposure. It is the average of root mean square acceleration signal in 8- hour duration. The following can be used to calculate the daily exposure:

$$A_{x,y}(8) = 1.4a_{wx,wy}\sqrt{\frac{T_{EXP}}{T_0}}$$

$$\text{OR, } A_z = a_{wz}\sqrt{\frac{T_{exp}}{T_0}} \qquad (2.7)$$

where,

- T_{exp} is the daily duration of exposure to the vibration;
- T_0 is the reference duration of 8-hour.

Similarly, the 8-hour energy equivalent vibration total value for a worker in vibration dose value, including all whole-body vibration during day is known as Daily dose.

EXPOSURE ACTION VALUE (EAV) & EXPOSURE LIMIT VALUE (ELV)

A value for either a worker's daily vibration exposure, A (8) of 0.45 m/s^2, or a worker daily VDV of 9.1m/s$^{1.75}$, above which the risks from vibration must be controlled is known as Exposure Action Value (EAV). That mean above which some action is required to reduce the effect of whole-body vibration.

Whereas, A value for either a worker's daily exposure, A (8) of 1.15m/s^2, or a worker daily VDV of 21m/s$^{1.75}$, above which workers should not be exposed is known as Exposure Limit Value.

Table 2 : RMS and VDV threshold values w.r.t ISO 2631 1:1997 Vibration Exposure Standards

Parameter	Threshold vibration value	HGCZ*
RMS (m/s^2)	< 0.45	Below HGCZ (moderate)
	0.45-0.9	Within HGCZ (caution)
	> 0.9	Above HGCZ (severe)
VDV (m/s$^{1.75}$)	< 8.5	Below HGCZ (moderate)
	8.5-17	Within HGCZ (caution)
	>17	Above HGCZ (severe)

Note: HGCZ refers to Health Guidance Caution Zone*

WBV ASSESSMENT

In the first stage, a suitable instrument & site is selected for this study. The questionary had prepared to analyze the present health status of operator and machine condition. In 2nd stage, HEMM vehicles like Dumper, Tipper & Shovel is chosen. In 3rd stage, placing of instrument on driver's seat is done and most importantly collection of data is also done. The collected data has analyzed by the SVAN PC++ software and thereafter the statistical analysis has been carried out.

INSTRUMENT USED

The instrument used for the measurement of whole-body vibration is the Svantek SV 106A which is six-channel human vibration meter and analyzer. This instrument meets the requirements of ISO 841-1:2017, ISO 5349, ISO 2631-5 and directive 2022/44/EC of the European parliament and it is an ideal choice for measurements according to ISO 2631-1.

It simultaneously works with a triaxial accelerometer which measures the vibration in three mutually perpendicular directions (x-longitudinal, y- y-transverse, z-vertical). This instrument consisted of a triaxial accelerometer accommodated in a semi-rigid nitrile rubber disk which was placed over the seat, on a vibrating surface with the driver sitting on top of it. It detects the vibration in three directions i.e., direction along the body, back-to-front and side-to-side.

The data is stored in data acquisition instrument which is easily downloaded in PC using USB interface via its specific software i.e., SVANPC++. This instrument can measure the data in two band either in 1/1 or 1/3 octave.

Fig 1: Triaxial Seat pad accelerometer (Left) & Human vibration meter& analyzer (Right)

CASE STUDY

This study was conducted on HEMM operators working in Rajapur mines (Figure 2, Shows location of the Mine) situated at Dhanbad in Jharkhand which is an open-cast mine Mines.

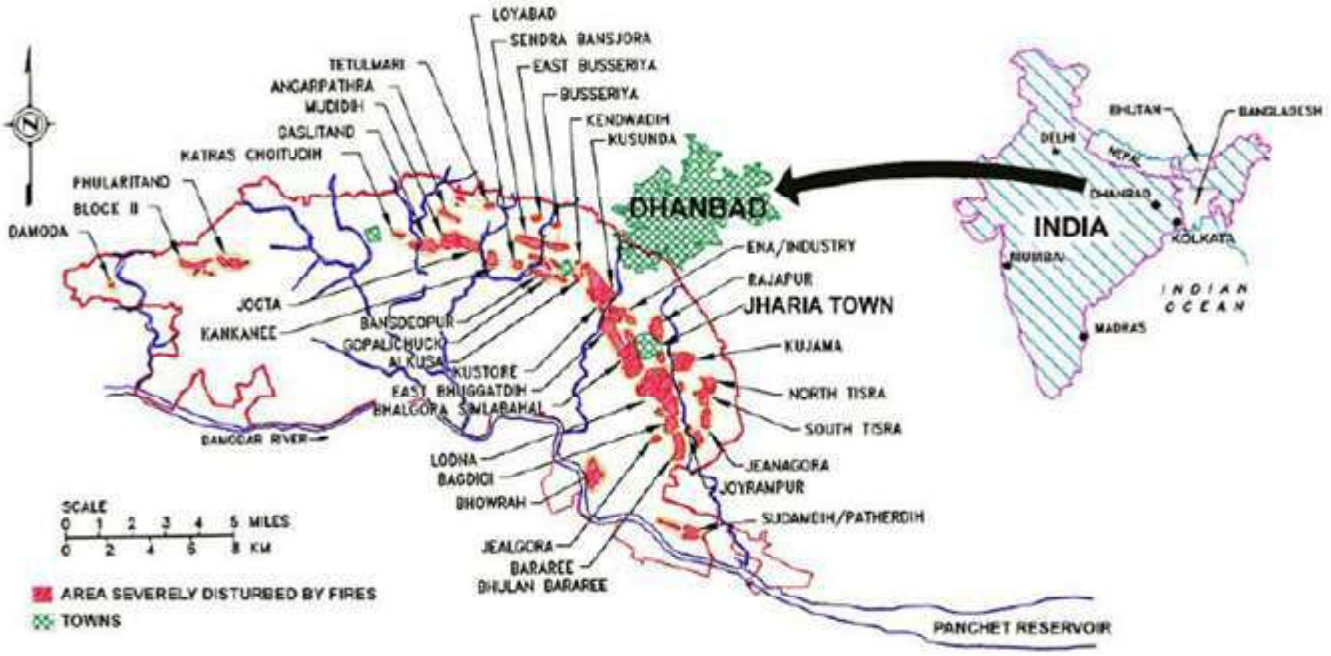

Figure 2 : Shows the Location of Mines of Jharia Coalfields and Rajapur OCP of BCCL

This is one of the fire-mines which lies in the famous Jharia region. It is a mechanized mine, where the method of coal extraction is mainly deep hole drilling and blasting with a combination of shovel & dumper. The gradient of haul roads varied from 1 in 12 to 1 in 16 which is used for carrying coal as well as overburden through the dumpers and tippers. The height of the bench was 10 m for coal as well as overburden and the width of the bench was more than equal to the height of the bench or more than twice the width of the largest dampers. Mine operation was going on 2nd last strata of coal and it was around 80 feet deep.

PARTICIPANTS & HEMM DEPLOYED

Operators of Heavy Earth Moving Machinery (HEMM) performing routine tasks in surface mines are highly vulnerable to whole-body vibration (WBV) due to prolonged exposure.

This study examined 30 operators utilizing 30 different HEMMs (17 tippers, 5 dumpers, 5 shovels, 2 wheel dozers, and 1 rock breaker) at the Rajapur opencast coal mine of BCCL (Figure 3). The Mine was operated using a shovel-dumper combination. Table 3, provides a summary of demographic and occupational characteristics (age, height, body weight, BMI, and experience) of operators working with different types of Heavy Earth Moving Machinery (HEMM). Tipper operators (n = 17) had a mean age of 34 years (SD = 4), mean height of 169.25 cm (SD = 8.07), and a mean body weight of 57 kg (SD = 11), with a corresponding BMI of 19.89 (SD = 2.77) and an average experience of 11 years. Dumper operators (n = 5) had a slightly lower mean age of 33 years (SD = 6), with an average height of 165.20 cm (SD = 10.65) and a higher mean body weight of 65 kg (SD = 21), resulting in a mean BMI of 23.29 (SD = 4.43). Shovel operators (n = 5) had a mean age of 34 years (SD = 7), mean height of 161.54 cm (SD = 14.78), mean body weight of 62 kg (SD = 9), and a BMI of 23.90 (SD = 4.51). Dozer operators (n = 2) showed a mean age of 31 years (SD = 8), height of 160.02 cm (SD = 2.16), weight of 50 kg, and a BMI of 19.53 (SD = 0.53), with an average experience of 15 years. The lone rock breaker operator (n = 1) was 43 years old, with a height of 167.64 cm, weight of 70 kg, and a BMI of 24.91, having 15 years of experience.

Table 3 : Demographic and Occupational Characteristics of Operators

			Age (years)	Height (cm)	Weight (kg)	BMI (kg/m^2)	Experience (years)
Machine name	**Tipper**	**Mean**	34	169.25	57	19.89	11
		Maximum	40	182.88	81	25.92	18
		Minimum	25	152.40	38	14.91	3
		Standard Deviation	4	8.07	11	2.77	4
		Count	17	17	17	17	17
	Dumper	**Mean**	33	165.20	65	23.29	10
		Maximum	42	182.88	100	29.90	16
		Minimum	28	158.50	49	19.51	6
		Standard Deviation	6	10.65	21	4.43	4
		Count	5	5	5	5	5
	Shovel	**Mean**	34	161.54	62	23.90	11
		Maximum	41	176.78	72	30.83	15
		Minimum	25	137.16	52	19.19	5
		Standard Deviation	7	14.78	9	4.51	4
		Count	5	5	5	5	5
	Dozer	**Mean**	31	160.02	50	19.53	15
		Maximum	36	161.54	50	19.90	15
		Minimum	25	158.50	50	19.16	15
		Standard Deviation	8	2.16	0	.53	0
		Count	2	2	2	2	2
	Rock Breaker	**Mean**	43	167.64	70	24.91	15
		Maximum	43	167.64	70	24.91	15
		Minimum	43	167.64	70	24.91	15
		Standard Deviation	.	.	.	.	.
		Count	1	1	1	1	1

Fig. 3 : Photograph showing HEMMs deployed at the mine Pictures of HEMM

The tippers, primarily from Bharat Benz and Volvo, have payload capacities ranging from 13.5 to 35 tonnes, with engine capacities of 7200cc or 460hp. The dumpers, all from CAT, have a uniform payload capacity of 90.7 tonnes and 699 kW engines. The shovels, from Volvo, feature bucket capacities between 0.52 to 3.8 m^3 and engine outputs of 170kW to 360hp. Additionally, wheel dozers from CAT and Komatsu have bucket capacities of 2.21 to 3.7 m^3 and engine powers of 105 to 200 HP. The rock breaker, manufactured by Hyundai, is powered by a 139 HP engine. Table 4, provides detailed specifications of HEMMs.

DATA COLLECTION

In order to get a representative sample for whole-body vibration, the piezoelectric triaxial seat pad accelerometer (Instrument No- 84744 & 84743) was mounted over the driver seat with the help of adhesive tapes (Figure 5). The seat pad accelerometer was connected to the control panel which recorded the vibration exposure in the form of signals called vibration analyzer which were saved in .wav file format in the data acquisition machine (Instrument No.-81064 & 81065). The seat pad accelerometer measured vibration in three translational axes with reference to the human i.e., the fore-and-aft direction in the x-axis, lateral direction in the y-axis, and vertical direction in the z-axis as shown in the mounting pad. Whole body vibration data was collected for different cycles such as:

- During the loading of the vehicle.
- During the running of the vehicle in a loaded condition.
- During the unloading of vehicle.
- During running of vehicle in empty condition.

For every cycle of operation, vibration measurements were taken from the start of the activity till its end which eliminates the measurement errors caused due to the idle time between two consecutive cycles. There may be slight possibility of displacement of the seat pad accelerometer from its position and for that adhesive tapes were used to fix it so that error is minimized.

A questionnaire was prepared for the operators such as their name, height, weight, driving experience, no of trip per day, no of trip per day, etc., and noted down. The questionnaire also included any kind of musculoskeletal symptoms such as pain in the neck, knee, shoulder, wrist, fore-arm, elbow, hand & finger, upper back, lower back, legs, and feet which they were going through due to continuous working in mines. Most of the operators belong to poor socio-economic backgrounds and were less educated. During the process of data collection, every activity of the operators/drivers such as their sitting posture, bending of their body, etc. was closely observed.

Table 4 : Specification of HEMM Vehicles

Machine name	Payload Capacity (tonnes/m^3)	Engine capacity	Make	Model
Tipper (T1)	17 tonnes	460 HP	Bharat Benz	3128(8*4)
Tipper (T2)	17 tonnes	460 HP	Bharat Benz	3128(8*4)
Tipper (T3)	13.5 tonnes	460 HP	Volvo	440 fmx
Tipper (T4)	13.5 tonnes	460 HP	Volvo	440 fmx
Tipper (T5)	13.5 tonnes	460 HP	Volvo	440 fmx
Tipper (T6)	13.5 tonnes	460 HP	Volvo	440 fmx
Tipper (T7)	13.5 tonnes	460 HP	Volvo	440 fmx
Tipper (T8)	13.5 tonne	460 HP	Volvo	440 fmx
Tipper (T9)	13.5 tonnes	460 HP	Volvo	440 fmx
Tipper (T10)	35 tonnes	460 HP	Volvo	440 fmx
Tipper (T11)	17 tonnes	460 HP	Bharat Benz	3128
Tipper (T12)	17 tonnes	460 HP	Bharat Benz	3128
Tipper (T13)	13.5 tonnes	460 HP	Volvo	440 fmx
Tipper (T14)	13.5 tonnes	460 HP	Volvo	440 fmx
Tipper (T15)	13.5 tonnes	460 HP	Volvo	440 fmx
Tipper (T16)	17 tonnes	460 HP	Bharat Benz	3128(8*4)
Tipper (T17)	17 tonnes	460 HP	Bharat Benz	3128(8*4)
Shovel (S1)	0.52 - 2.02 m^3	170kW	Volvo	300
Shovel (S2)	1.77 - 3.8 m^3	148kW	Volvo	360
Shovel (S3)	1.77 - 3.8 m^3	360 HP	Volvo	480
Shovel (S4)	0.52-2.02 m^3	170 kW	Volvo	300
Shovel (S5)	0.52-2.02 m^3	170 kW	Volvo	480
Dumper (D1)	90.7 tonnes	699 kW	CAT	777D
Dumper (D2)	90.7 tonnes	699 kW	CAT	777D
Dumper (D3)	90.7 tonnes	699 kW	CAT	777D
Dumper (D4)	90.7 tonnes	699 kW	CAT	777D
Dumper (D5)	90.7 tonnes	699kW	CAT	777D
Wheel Dozer (WD1)	3.7 m^3	200 HP	CAT	814
Wheel Dozer (WD2)	2.21 m^3	105 HP	Komatsu	WD600
Rock Breaker (RB1)	none	139 HP	Hyundai	215

Fig 5: Instrument setup during collection of WBV data

DATA ANALYSIS PROCESS

The demographic data and WBV exposure data were entered into Microsoft Excel for analysis. Descriptive statistics, such as frequencies, means, and percentages, were used to summarize the demographic characteristics of the operators. Whereas, acceleration data was converted into daily vibration exposure i.e. A (8) for the analysis. The data were further analyzed to identify patterns or relationships between demographic variables and WBV parameters.

RESULT & DISCUSSION

Operators of Heavy Earth Moving Machinery (HEMM) performing routine tasks in surface mines are highly vulnerable to whole-body vibration (WBV) due to their continuous exposure to vibration (Table 5 & 6). For evaluation of WBV exposure the collected dominant axis data i.e. z-axis was considered. Based on the dominant axis vibration the daily vibration exposure value i.e. A (8) was estimated. To evaluate the risk of WBV the Exposure Level Value (ALV) and Exposure Action Value (EAV) suggested by 2631-1:1997 was used. The SPSS output table provides descriptive statistics for two variables, daily vibration exposure value i.e. A (8) and vibration Dose across different machine types: Tipper, Dumper, Shovel, Dozer, and Rock Breaker. For A(8), the Dozer showed the highest mean value (M = 0.51, SD = 0.07), while the Shovel had the lowest mean value (M = 0.40, SD = 0.07). The Rock Breaker had a constant value for aw across all observations (M = 0.45). Regarding vibration dose, the Dozer also had the highest mean (M = 4.70, SD = 2.13), with the Shovel showing the lowest mean (M = 3.47, SD = 1.35). The Rock Breaker had no variation in VDVw (M = 3.20, SD = 0.0). Overall, the Dozer consistently had higher values for both **A (8)** and **Vibration dose**, indicating greater vibration exposure compared to other machines.

Table 5 : Machine-wise vibration characteristics

		A (8)				Daily Dose			
		Mean	Maximum	Minimum	Standard Deviation	Mean	Maximum	Minimum	Standard Deviation
Machine name	Tipper	.48	.62	.35	.08	4.36	6.83	3.19	.91
	Dumper	.43	.48	.32	.07	4.61	5.66	3.20	1.11
	Shovel	.40	.46	.28	.07	3.47	4.80	1.58	1.35
	Dozer	.51	.56	.46	.07	4.70	6.20	3.19	2.13
	Rock Breaker	.45	.45	.45	.	3.20	3.20	3.20	.

Table 6 : Details of risk level based on Daily vibration exposure value i.e. A (8) and Daily dose

Vehicle name	A (8)	Risk Level	Daily Dose	Risk Level
T1	0.62	Moderate	6.83	Low
T2	0.60	Moderate	4.09	Low
T3	0.58	Moderate	5.60	Low
T4	0.50	Moderate	5.36	Low
T5	0.52	Moderate	4.42	Low
T6	0.54	Moderate	4.09	Low
T7	0.52	Moderate	5.04	Low
T8	0.56	Moderate	6.20	Low
T9	0.45	Moderate	4.23	Low
T10	0.46	Moderate	4.68	Low
T11	0.48	Moderate	5.66	Low
T12	0.50	Moderate	3.90	Low
T13	0.46	Moderate	3.19	Low
T14	0.52	Moderate	4.90	Low
T15	0.41	Low	4.19	Low
T16	0.43	Low	4.10	Low
T17	0.42	Low	4.09	Low
S1	0.47	Moderate	4.58	Low
S2	0.46	Moderate	4.80	Low
S3	0.46	Moderate	4.73	Low
S4	0.42	Low	4.20	Low
S5	0.48	Moderate	3.29	Low
D1	0.38	Low	4.10	Low
D2	0.42	Low	3.80	Low
D3	0.45	Moderate	3.20	Low
D4	0.42	Low	3.20	Low
D5	0.38	Low	2.53	Low
WD1	0.35	Low	3.53	Low
WD2	0.32	Low	3.78	Low
RB1	0.28	Low	1.58	Low

Table 6, presents the daily vibration exposure value i.e. A (8) (m/s²), Daily Vibration Dose (m/s¹.w u), and associated risk levels for various vehicles, including Tippers (T), Shovels (S), Dumpers (D), Dozers (WD), and a Rock Breaker (RB). The RMS values indicate the intensity of vibrations, while VDV values measure cumulative vibration exposure over time. Each vehicle is assigned a risk level (Low or Moderate) based on these measurements.

For instance, Tipper T1 has an RMS of 0.62 m/s², classified as a Moderate risk level, and a VDV of 6.83 m/s¹.w u , classified as Low risk. Across the vehicles, RMS values range from 0.28 to 0.62 m/s², with most falling within the Moderate risk category. VDV values are consistently categorized as Low risk, ranging from 1.58 to 6.83 m/s¹.w u .

This data is critical for assessing vibration exposure and determining the necessary interventions to manage health risks for operators, particularly in vehicles with higher vibration exposure.

Evaluations Of Whole-Body Vibration Exposure Of Heavy Earthmoving Machinery Operators Based On Job Cycle

Table 7.1, 7.2 & 7.3 presents a set of measurements for various machines (T1–T17, D1–D5) in relation to their Root Mean Square (RMS) acceleration values (m/s²) and Vibration Dose Value (VDV) levels (m/s¹.w u) under four different operating conditions: Loading, Running, Unloading, and Empty. RMS values are used to assess the overall vibration levels experienced during these states, while VDV values measure the cumulative effects of vibration over time.

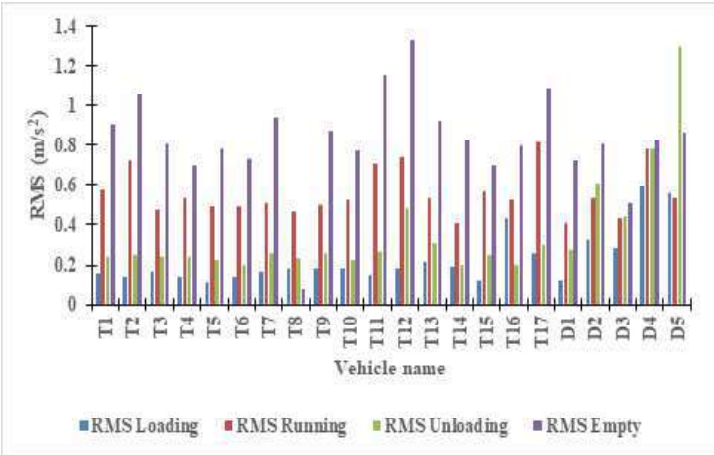

Fig. 7.2: Machine wise and task wise weighted acceleration values

Table 7.1: Task-based vibration exposure values

Machine name	RMS Loading (m/s^2)	RMS Running (m/s^2)	RMS Unloading (m/s^2)	RMS Empty (m/s^2)	VDV Loading ($m/s^{1.75}$)	VDV Running ($m/s^{1.75}$)	VDV Unloading ($m/s^{1.75}$)	VDV Empty ($m/s^{1.75}$)
T1	0.158	0.573	0.243	0.903	0.989	4.581	1.78	6.879
T2	0.141	0.723	0.251	1.06	1.152	7.834	1.496	7.186
T3	0.167	0.476	0.239	0.807	1.23	3.922	1.642	5.553
T4	0.146	0.536	0.239	0.702	1.724	4.335	1.789	4.898
T5	0.109	0.488	0.228	0.781	0.977	4.241	1.957	5.984
T6	0.139	0.495	0.202	0.736	1.479	4.261	1.249	5.754
T7	0.164	0.512	0.256	0.944	1.923	4.524	1.772	6.095
T8	0.18	0.47	0.23	0.079	1.229	4.422	0.167	0.565
T9	0.187	0.498	0.258	0.875	1.654	4.315	1.963	6.479
T10	0.18	0.524	0.229	0.778	1.551	4.055	1.526	5.254
T11	0.154	0.71	0.265	1.153	1.051	5.346	1.667	8.289
T12	0.182	0.744	0.479	1.33	2.106	6.302	2.466	9.29
T13	0.218	0.534	0.305	0.92	2.355	4.36	1.507	5.888
T14	0.19	0.406	0.198	0.82	2.173	4.462	1.382	6.317
T15	0.121	0.57	0.252	0.697	0.923	4.651	0.902	3.346
T16	0.435	0.528	0.204	0.801	4.597	4.046	1.212	6.509
T17	0.256	0.813	0.3	1.088	2.413	8.482	2.092	9.226
D1	0.119	0.41	0.273	0.722	1.563	3.184	1.293	4.966
D2	0.321	0.53	0.607	0.804	6.31	4.825	2.218	5.553
D3	0.284	0.43	0.438	0.508	4.566	3.479	2.205	4.881
D4	0.589	0.78	0.78	0.824	3.408	3.841	3.841	5.828
D5	0.56	0.534	1.3	0.869	4.194	4.032	6.053	1.341

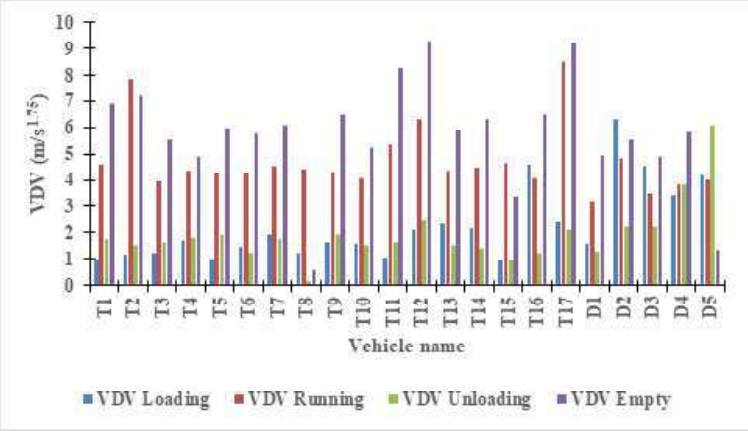

Fig. 7.3 Machine-wise and task-wise vibration dose values

This detailed data can be utilized for evaluating machine compliance with vibration safety standards and for identifying areas where performance improvements may be needed to mitigate vibration exposure.

MUSCULOSKELETAL RISK ASSESSMENT OF OPERATORS

Figure 6, provides a frequency distribution of reported MSD symptoms among 30 participants. The majority of participants (46.7%) reported experiencing no symptoms. A smaller proportion reported various individual symptoms, including hand or shoulder pain (3.3%), neck pain (3.3%), back pain (6.7%), and numbness in the hand (3.3%). Knee pain was reported by 16.7% of participants. Additionally, 20.0% of participants experienced two or more symptoms. The cumulative percentage indicates that by the time two or more symptoms are accounted for, 100.0% of the participants have been represented. These results suggest a range of symptom experiences, with a significant portion of the population reporting multiple symptoms.

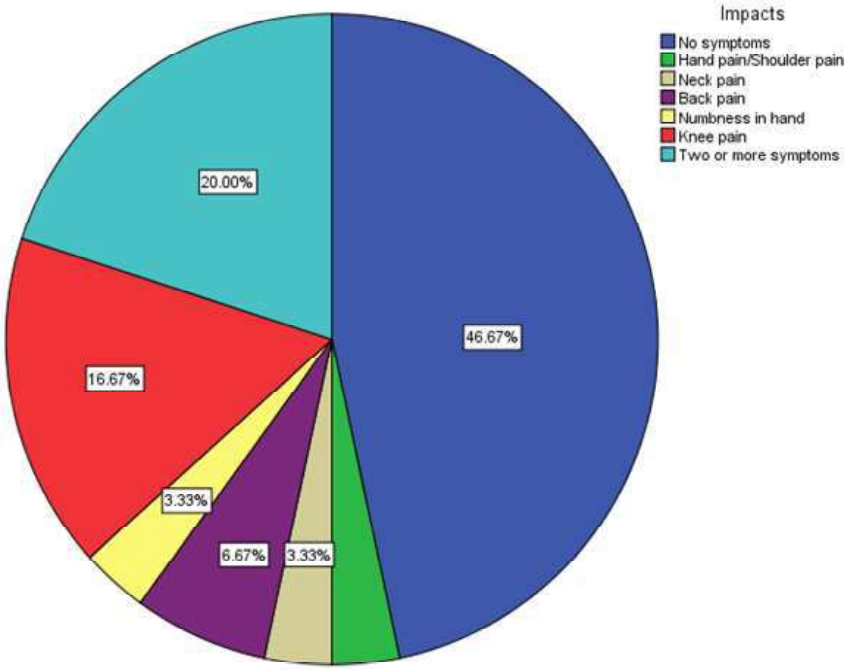

Fig 6 : Overall distribution of MSD symptoms

Table 8, summarizes the occurrence of musculoskeletal disorder (MSD) symptoms among operators of different machinery, including Tippers, Dumpers, Shovels, Dozers, and Rock Breaker. The table presents the percentage of individuals reporting no symptoms and those reporting specific MSD symptoms such as hand/shoulder pain, neck pain, back pain, numbness in the hand, knee pain, and having two or more symptoms.

For Tipper operators, 41.2% reported no symptoms, while 35.3% experienced two or more symptoms. Specific symptoms included back pain (5.9%) and knee pain (11.8%). Among Dumper operators, 40% reported no symptoms, and 40% experienced knee pain, with 20% reporting back pain. Shovel operators showed similar results, with 40% reporting no symptoms, and 20% experiencing hand/shoulder pain, neck pain, and knee pain. Dozer and Rock Breaker operators reported no symptoms, with 100% of them symptom-free.

This data highlights the prevalence of MSD symptoms among operators, with Tipper operators showing the highest percentage of multiple symptoms, indicating the potential need for ergonomic interventions or further health assessments.

Table 8 : Machine-wise distribution of MSD symptoms

Machine name	Tipper	MSD symptoms	No symptoms	Count (%)	7 (41.2)
			Hand pain/Shoulder pain	Count (%)	0 (0.0)
			Neck pain	Count (%)	0 (0.0)
			Back pain	Count (%)	1 (5.9)
			Numbness in hand	Count (%)	1 (5.9)
			Knee pain	Count (%)	2 (11.8)
			Two or more symptoms	Count (%)	6 (35.3)
	Dumper	MSD symptoms	No symptoms	Count (%)	2 (40)
			Hand pain/Shoulder pain	Count (%)	0 (0.0)
			Neck pain	Count (%)	0 (0.0)
			Back pain	Count (%)	1 (20)
			Numbness in hand	Count (%)	0 (0.0)
			Knee pain	Count (%)	2 (40)
			Two or more symptoms	Count (%)	0 (0.0)
	Shovel	MSD symptoms	No symptoms	Count (%)	2 (40)
			Hand pain/Shoulder pain	Count (%)	1 (20)
			Neck pain	Count (%)	1 (20)
			Back pain	Count (%)	0 (0.0)
			Numbness in hand	Count (%)	0 (0.0)
			Knee pain	Count (%)	1 (20)
			Two or more symptoms	Count (%)	0 (0.0)
	Dozer	MSD symptoms	No symptoms	Count (%)	2 (100)
			Hand pain/Shoulder pain	Count (%)	0 (0.0)
			Neck pain	Count (%)	0 (0.0)
			Back pain	Count (%)	0 (0.0)
			Numbness in hand	Count (%)	0 (0.0)
			Knee pain	Count (%)	0 (0.0)
			Two or more symptoms	Count (%)	0 (0.0)
	Rock Breaker	MSD symptoms	No symptoms	Count (%)	1 (100)
			Hand pain/Shoulder pain	Count (%)	0 (0.0)
			Neck pain	Count (%)	0 (0.0)
			Back pain	Count (%)	0 (0.0)
			Numbness in hand	Count (%)	0 (0.0)
			Knee pain	Count (%)	0 (0.0)
			Two or more symptoms	Count (%)	0 (0.0)

Establishment Of Relationship Between Operator Characteristics And Whole-Body Vibration Parameters (Table 9)

The efforts were made to establish a relationship between operator characteristics (such as age, experience, height, weight, and body mass index [BMI]) and whole-body vibration (WBV) parameters, including Root Mean Square (RMS) acceleration and Vibration Dose Value (VDV).

Table 9 : Correlation matrix between demographic characteristics and vibration parameters

		Experience (years)	Age (years)	Height (cm)	Weight (kg)	BMI	RMS	VDV
Experience	Pearson Correlation	1	.477**	.048	.127	.160	-.074	.044
	Sig. (2-tailed)		.008	.802	.502	.398	.696	.819
	N	30	30	30	30	30	30	30
Age	Pearson Correlation	.477**	1	.266	.376*	.307	-.218	-.298
	Sig. (2-tailed)	.008		.156	.040	.099	.247	.110
	N	30	30	30	30	30	30	30
Height (cm)	Pearson Correlation	.048	.266	1	.556**	-.091	.095	.225
	Sig. (2-tailed)	.802	.156		.001	.633	.619	.232
	N	30	30	30	30	30	30	30
body weight (kg)	Pearson Correlation	.127	.376*	.556**	1	.768**	-.677**	-.437*
	Sig. (2-tailed)	.502	.040	.001		.000	.000	.016
	N	30	30	30	30	30	30	30
BMI	Pearson Correlation	.160	.307	-.091	.768**	1	-.896**	-.710**
	Sig. (2-tailed)	.398	.099	.633	.000		.000	.000
	N	30	30	30	30	30	30	30
Aw	Pearson Correlation	-.074	-.218	.095	-.677**	-.896**	1	.694**
	Sig. (2-tailed)	.696	.247	.619	.000	.000		.000
	N	30	30	30	30	30	30	30
VDVw	Pearson Correlation	.044	-.298	.225	-.437*	-.710**	.694**	1
	Sig. (2-tailed)	.819	.110	.232	.016	.000	.000	
	N	30	30	30	30	30	30	30

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 9, presents Pearson correlation coefficients and significance levels between several variables: Experience (years), Age (years), Height (cm), Weight (kg), BMI, RMS, and VDV. The correlation values indicate the strength and direction of linear relationships between these variables, with significance levels indicating whether these correlations are statistically meaningful. Significant correlations at the 0.01 level include:

- A positive correlation between body weight and BMI ($r = .768$, $p < .001$).
- A strong negative correlation between BMI and RMS ($r = -.896$, $p < .001$) and BMI and VDV ($r = -.710$, $p < .001$).
- A positive correlation between RMS and VDV ($r = .694$, $p < .001$).
- A negative correlation between body weight and RMS ($r = -.677$, $p < .001$).

Additionally, age is significantly correlated with experience ($r = .477$, $p = .008$) and body weight is significantly correlated with VDV ($r = -.437$, $p = .016$) at the 0.05 level. No significant correlations were found between height and other variables.

These findings suggest notable relationships between body weight, BMI, and vibration exposure (RMS and VDV), and also indicate the influence of experience and age on other physical characteristics.

Based on the correlation the linear regression model was prepared. The relationship between BMI and the weighted root mean square acceleration in the z-axis (awz) is described by the following regression equation:

a_{wz} = “0.0191 × BMI + 0.8679 (4.1)

In this equation, a_{wz} represents the predicted weighted acceleration along the vertical axis, and BMI stands for the operator’s body mass index. The coefficient of -0.0191 indicates that as BMI increases, the weighted acceleration (a_{wz}) decreases slightly. The intercept of 0.8679 reflects the baseline level of a_{wz} when BMI is zero, serving as a statistical constant for the model.

The R^2 value of 0.80 suggests that 80% of the variability in awz can be explained by BMI, indicating a strong relationship between BMI and vertical vibration exposure. This high R^2 value demonstrates that BMI is a significant predictor of whole-body vibration exposure in the vertical axis. However, the remaining 20% of the variability is attributed to other factors not accounted for in the model (Figure 7).

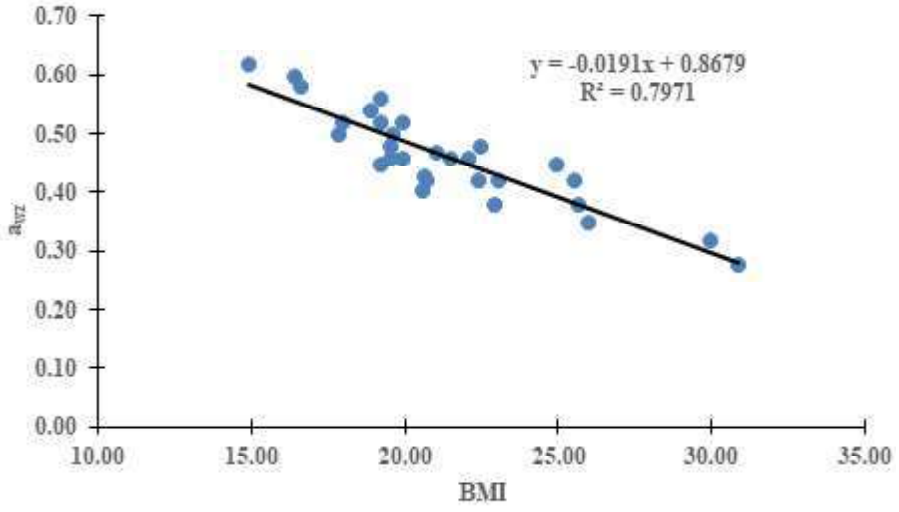

Fig. 7 : Regression plot between weighted acceleration and BMI

Similarly, the relationship between BMI and vertical vibration dose value (VDVwz) can be represented by the following regression equation:

VDVwz = “0.2158 × BMI + 8.8519 (4.2)

Where, VDVwz is the predicted vibration dose value in the vertical axis, and BMI is the body mass index of the operator. The negative coefficient (-0.2158) indicates that

as BMI increases, the VDVwz decreases. The intercept of 8.8519 suggests the baseline VDVwz when BMI is zero, although this is not a realistic scenario in practical terms, it serves as a statistical constant in the model.

The R^2 value of 0.55 implies that 55% of the variance in VDVwz can be explained by BMI, indicating a moderate strength of the relationship between these variables. This suggests that BMI is a significant predictor of vertical whole-body vibration exposure, though other factors may also contribute to the remaining unexplained variance (Figure 8).

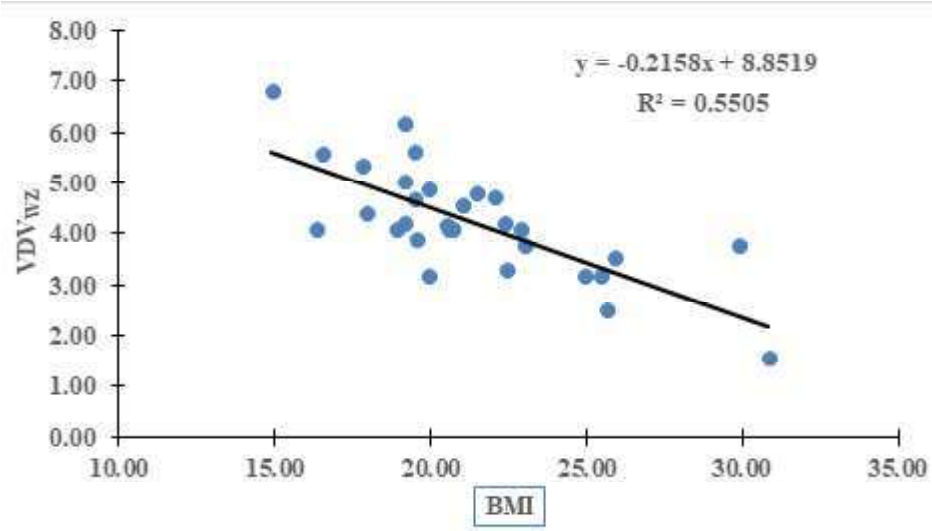

Fig. 8 : Regression plot between VDV and BMI

CONCLUSION AND SUGGESTION

CONCLUSION

This study aimed to evaluate whole-body vibration (WBV) exposure among heavy earthmoving machinery operators, identify the musculoskeletal risks associated with prolonged exposure, and examine the relationship between operator characteristics and vibration parameters. The findings highlight significant differences in WBV exposure across various machinery types and operational conditions, with the **Dozer** showing the highest average daily vibration exposure value (A(8)) and vibration dose. Among operators, the **Tipper** and **Shovel** were also identified as vehicles with moderate vibration risks. Despite the moderate risk of WBV exposure, musculoskeletal disorder (MSD) symptoms varied, with **Tipper** operators showing the highest occurrence of two or more MSD symptoms (35.3%). Furthermore, significant correlations were found between **BMI** and vibration exposure, with higher BMI being associated with lower WBV exposure values (RMS and VDV). The relationship between operator characteristics, such as **body weight** and **BMI**, and vibration exposure was evident, with heavier individuals experiencing lower vibration intensities.

Overall, the results underscore the importance of addressing WBV exposure, particularly for operators using high-exposure vehicles like the **Dozer** and **Tipper**, and emphasize the need for ergonomic interventions to reduce MSD risks.

SUGGESTIONS

1. **Improving Vehicle Design:** Manufacturers should focus on optimizing the design of high-exposure vehicles, such as the **Dozer**, to minimize vibration exposure. This could include improving suspension systems, seat ergonomics, and vibration-dampening technologies.

2. **Regular Monitoring of WBV:** It is recommended that mining companies implement continuous WBV monitoring systems across all machinery types to ensure that vibration exposure remains within safe limits. This will allow for real-time detection and adjustment of potentially hazardous conditions.

3. **Operator Training and Awareness:** Operators should be trained to identify symptoms of WBV exposure and MSDs. Providing awareness programs on the potential health risks and techniques to reduce exposure (e.g., using proper posture, taking regular breaks) can significantly mitigate health impacts.

4. **Ergonomic Interventions:** Since operators with higher **BMI** appear to experience lower vibration exposure, ergonomic interventions such as customized seats and workstations based on operator characteristics can further reduce risks. Targeted health assessments and ergonomic evaluations should be conducted regularly.

5. **Preventive Health Measures:** Regular health assessments for early detection of musculoskeletal disorders are critical. Providing operators with access to physiotherapy, fitness programs, and medical checkups can aid in reducing the long-term health impact of WBV exposure.

6. **Illumination Survey :** Conducting this on regular basis will help significantly in reducing discomforts of the operators.

7. **Policy Review and Compliance:** Mining companies should ensure compliance with international standards such as ISO 2631-1:1997 for vibration exposure limits. Revising policies to include more stringent monitoring and control measures for high-risk machinery will enhance operator safety.

By addressing these areas, the risks associated with WBV and MSD among machinery operators can be significantly reduced, leading to improved operator health and well-being in surface mining environments.

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Mining and Economic Sustainability-Evidence from Emerging Economies

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ABSTRACT

Mining and mineral processing have the potential to be important sources of income and driving forces behind broader economic development. But this potential is not always realized. In fact, the mineral-dependent nations include some of the poorest and worst performing economies in the world. Mining does not always contribute to sustainable economic development. The purpose of this study is to answer two questions: What are the economic effects of mining and mineral processing? Can we manage mineral wealth so that the economic benefits are enhanced in the short term and sustained over the long term. This study, concentrates on the economic aspects of mining and the sustainability of mining's benefits.

Keywords: Mining, Economic Development, Sustainable, Markets, Wealth

INTRODUCTION

The terms sustainability and sustainable development are both illuminating and confounding. They are illuminating because they remind us that unfettered markets, for all their advantages in organizing economic affairs, do not always bring us the outcomes we desire. Specifically, it is possible that some economic or commercial activities today may be unsustainable—in that they come at the cost of such significant environmental damage or social disruption that future generations are worse off than the present generation. How do mining and minerals fit into this picture of sustainability and sustainable development? At first glance, mining and minerals would seem to be quintessential unsustainable activities. Individual mines have finite reserves that once mined are gone. The earth's crust contains only a limited quantity of any mineral. Yet for several reasons, this view of mining and minerals is misleading. First, mining is more sustainable than it appears. Through mineral exploration and development, mining companies replace reserves that mining depletes. Through technological innovation, mining companies are able to discover or mine resources that otherwise would be technically or commercially unfeasible to mine. Second, recycling sustains the benefits of the materials made possible by mining, even if a mine itself is not sustainable. Third, and most important, even if a mine itself is not sustainable, in principle the economic benefits created by mining can be sustained indefinitely through appropriate investment in education, health care, infrastructure, and other activities that can create well being long after mining ceases. In other words, a depleting mineral resource can, in effect, be converted into a sustainable, renewable source of human well being through appropriate investment.

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ANALYSIS

Historically, there has been a lot of focus on how mining impacts at the national level, and especially its contribution of income to government. At the same time, mining has often been conducted with little regard to those affected nearby. Today, "stakeholders" are a key issue of concern. Stakeholder theory has been developed from management and organisational literature, and stakeholder management refers to how organisations deal with "any group or individual who can affect or is affected by the achievement of the organization's objectives." (Freeman 1984: 46) Following this broad defintion, the list of potential stakeholders can be almost inexhaustible.4 Government is still an important actor, as are owners and investors. Even people abroad are affected, as mining contributes to global warming as well as to the provision of minerals. Increasingly though, focus has moved to local and regional stakeholders. They include inter alia employees and their families, subcontractors, local authorities, indigenous populations, all those who wish to enjoy the local environment for leisure or business, or the natural environment itself. And finally, stakeholders can include both current and future generations. The effects of mining vary not just according to who the stakeholders are, but also according to factors such as geological conditions, mining technology, economic and political context (see e.g. Bridge 2004). What kind of ore

is being mined and how? For example, acid drainage is a large environmental threat when extracting sulphide-containing ores and gold mining is associated with a risk of cyanide-leakage.

ECONOMIC EFFECTS OF MINING

There is an extensive literature on the economic effects of mining. A more detailed review can be found in a parallel report by Söderholm & Svahn (2014), who focus on the relationship between mining and regional development, and in particular employment. As they note however, a lot of the research has focused on effects on the national level, and often in developing countries. Experience shows that while natural resource wealth can be a source for economic growth and welfare, it has often not translated into development for the broader society. This is also known as the "resource curse". Causes include weak governance, corruption and irresponsible company behaviour (see e.g. Sachs & Warner 2001). The demand and price of mined resources are generally determined on global markets, which tend to be volatile and cyclical. The result is boom and bust economies and fragile communities (Radetzki 2008). Mining companies, whose investments and technologies have long life-cycles, in turn have difficulties adjusting to changes in the economy and society (see Bartos 2007). Also, due to the inflow of new revenues, the exploitation of natural resource wealth can lead to higher real prices and exchange rate appreciation, thereby deteriorating competitiveness in other sectors of the economy. This phenomenon is known as the "Dutch disease" (Radetzki 2008: 206-211). Mining has become more capital-intensive, technical and automated. As a result, there are fewer direct jobs within the mining industry at the same time as the rate of extraction has increased (SGU 2013; Ejdemo& Söderholm 2011; Bartos 2007; McMahon & Remy 2001: 2; Warhurst & Mitchell 2000). Studies of the total employment effect of mining give widely different estimates of the multiplier, from less than one up to several jobs supported for each direct job in mining (see Söderholm & Svahn 2014; Ejdemo & Söderholm 2011). Studies rely on different methodologies for estimating the job creation effects & Söderholm 2011; Bartos 2007; McMahon & Remy 2001: 2; Warhurst & Mitchell 2000). Studies of the total employment effect of mining give widely different estimates of the multiplier, from less than one up to several jobs supported for each direct job in mining (see Söderholm & Svahn 2014; Ejdemo & Söderholm 2011). Studies rely on different methodologies for estimating the job creation effects.

In light of this conceptual background, consider more closely the economic effects of mining on communities and regions. Mining contributes directly to a local or regional economy by employing workers and generating income at the mine. Mining also contributes more broadly through its links with other economic activities. The mine itself may purchase supplies, equipment, electricity, food, and other inputs from local or regional businesses. Miners and their families stimulate local production of household goods and services through their spending of income earned at the mine. On the other hand, mining like any other activity—involves costs, which may be both commercial and more broadly social and environmental in nature. Therefore, the extent to which a region benefits overall from mining depends on the balance between benefits and costs, broadly defined to include the full social effects of mining. Not surprisingly, the extent to which a particular community or region benefits from mining varies considerably from case to case.

INITIATIVES

Initiatives that target the public sector and public governance focus on reforms and policies which can help maximise the benefits emanating from the mining sector. They are guided by that awareness that good governance is important for translating mineral wealth into development for society. On a regional level, the European Union (EU) has addressed the mining and minerals sector, notably through the Raw Materials Initiative. The group states that the following elements need to be included to attain a sustainable mineral policy: Facilitation of the transformation of natural mineral capital into built physical, economic, environmental or social capital of equal or greater value;

- ensuring that environmental and negative social impacts of mining are minimised and their costs incorporated into production functions;
- requiring transparency and information sharing;
- reconsidering the allocation of rights and the availability of resources across generations;
- addressing benefit risk trade-offs from the perspective of multiple stakeholders and create contingency plans that will ameliorate the effects of mineral market booms and busts; and

- correlation and consistency with other governmental policies.

Several initiatives target companies and their management, with varying focus such as proposals for principles and policies for sustainable practice; management standards; accountability, reporting and assurance. The most influential and well-known initiatives of the first kind include the UN Global Compact and its Ten Principles, which cover human rights, labour, the environment and anti-corruption; the UN Guiding Principles on Business and Human Rights; and the OECD Guidelines for Multinational Enterprises. One of the broadest and most cited initiatives focused on the mining sector is the International Council on Mining and Metals (ICMM). Its predecessor, the International Council on Metals and the Environment (ICME), was established in 1991. The MMSD final report was released in 2002. It focused on nine key challenges for the sector:

1. Viability of the minerals industry.
2. The control, use, and management of land.
3. Minerals and economic development.
4. Local communities and mines.
5. Mining, minerals, and the environment.
6. An integrated approach to using minerals.
7. Access to information.
8. Artisanal and small-scale mining.
9. Sector governance: roles, responsibilities, and instruments for change.

CONCLUSION

Mineral wealth can provide countries with a tremendous opportunity for economic development by providing the funding for investment and growth. Many countries, however, have squandered this gift from nature and end up no better off than countries without an abundance of natural capital. Using minerals to build a sustainable economy requires:

- policies that maximise resource rent generated by mining;
- recovery of resource rent by an agency able and willing to reinvest rent;
- reinvestment of rent in other assets that are capable of generating income and employment once resources are exhausted, such as human capital, public infrastructure and manufactured capital The critical factor for sustainable economic development is the third criteria, reinvestment of the rent. Most resource-rich countries recover a substantial portion of the rent through taxes. However, the rent is then used for current consumption rather than to build the wealth that guarantees the livelihoods of future generations as well. Countries that have been successful in reinvesting rent usually have explicit policies to guide them. Botswana's Sustainable Budget Index is one example, but by no means the only one

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Challenges to Mining and Mineral Industries in Kendujhar

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INTRODUCTION

The district of Kendujhar in north Orissa, is divinely bestowed with the best and the largest deposit of quality iron ore in 3 regions, at Daitari, Gandhamardan, and Joda-Barbil; nation's only known deposit of the strategic mineral Chromites in Baula Sukinda belt; quality deposit of Manganese ore in the famous Joda-Koida-Meghatiburu triangle; Nickel ore in chromites over burden, and Vanadium in adjoining Mayurbhanj. Thus, this district is supremely positioned for the best quality steel making, supported by coal and other process materials available in neighbouring districts.

CHALLENGES

In addition to nearness to these vital raw materials, Kendujhar provides cheap land, salubrious climate, abundant soft water, surplus electricity, peaceful labour, reasonably good roads and rails (both existing and under construction), and airports, and finally nearness to markets and ports. And yet, we have not been able to attract quality investment. Some have come to meet these challenges with big promises only to withdraw with flimsy excuses, or delaying decisions, possibly because captive mines and minerals export continue remain as their ultimate aim.

In mid-seventies, the citizens had resorted to public agitation when the location of a public sector steel unit was unprofessionally rejected by steel ministry, in spite of the fact that Govt judged Nayagarh in our district as the best location in India among the 28 sites examined by a consultant. Now after years of waiting, it is heartening to know that India's two 'Navaratna' public sectors, namely, NMDC and SAIL are now expected to choose Kendujhar for a most modern 'Ultra Mega Steel Plant'. Lately, the hopes of the Citizens had receded when the three steel majors left Kendujhar, ostensibly, in the absence of help/support from Govt. The departure of Arcellor-mittal, Sterlite Industries, and Uttam Galva left a bitter taste.

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Possibilities Elaborated

Our district has already short listed two most suitable locations among many others with:-

a. Adequate land available now scaled down to only 3600-4000 acres, at both Patna and at Barbil.
b. Possible participation of OMC, with Raw Material linkage of quality ore from nearby Gandhamardan, by even conveyor belt, for competitive steel making.
c. Dispersed Mineral processing to enrich Ore quality while restoring the solid wastes back to enrich the depleted forests while returning the used water to enrich ground water, mountain streams.
d. Adequacy of water from proposed Baitarani Barrage at Rajnagar
e. Sufficient power, now available from the 400MVA grid station of Power Grid Corporation at nearby Naranpur, avoiding captive generation, and consequent reduced pollution.
f. An electrified double line Rail linkage to Ports in the East Coast, to be ready by Mar 2016.
g. A proposed Rail link from Kendujhar to Badampahar (already surveyed and estimated by SE Rly) connects us to Steel City of Jamshedpur and coal belt of Jamshedpur through this proposed new rail line.
h. Two 4/6 laned National Highways with good linkages to ports and markets is fast progressing and nearing completion in about one year.
i. A highly motivated, technically qualified and skilled youth from our own technical institutions.
j. A peaceful labour force to be ready with 'Skill Development' programme launched by Govt of Odisha.
k. Nearness to existing secondary and tertiary industrial hubs at Kalinga Nagar, Angul, Rourkela, Jamshedpur/ Ranchi, and finally Kolkata/Kharagpur for much needed mutual support.

OPPORTUNITIES EXPLAINED

While seeking support for such a major investment in Mines, Mineral processing, and steel making, let us air some of our expectations and apprehensions, in the line of CSR for inclusive growth, as against the current practice

of PR. Firstly, they should more than meet the environmental laws of the nation by bringing the most modern technology, and best engineering practices with minimum pollution from effluents, mainly to reduce damage to our forests, air, water and soil. Secondly, in resettlement and rehabilitation, an adequate package as per current policy and transparent discussion are the need for such a task of exacting and difficult complexity. Thirdly, they could show appropriate bias towards the people of our and our neighbouring backward districts of Mayurbhanj, Sundargarh, Debgarh and even Singbhum (Jharkhand State) for employment and business relationships. Fourthly, they could extend adequate support to creating centers of excellence in the area of science, technology, education, and medicine in our area. And, finally, they would develop and encourage ancillaries all over these districts to bring some quality employment/ self employment to our youth and entrepreneurs, in the neighbourhood of their production unit.

LOOKING BACK AT THE RESOURCE BASE

Unlike many other mineral bearing areas of the world, in India they iron ore appears under the hills of thick rain forests inhabited by our tribals and where most of the rivers originate. Therefore, taking out minerals from underneath such areas on mother earth, calls for very special challenges for both mining and mineral processing engineers, within the bounds of law, legislated to meet our own needs. Kendujhar is no different Mining industry in the Forests of Kendujhar. The recent records show that the mining lease (ML) area granted to 109 mines for Iron ore, Manganese ore, and Chromites, are over a total leased area 33560 Ha. Within the same ML area, 24112 Ha are forest land. The rest 9448 Ha are revenue and private land together. At the same time, the area of forest land diverted for 'non-forest use', technically called Compensatory Afforestation, adds up to only 6102 Ha, for the 24112 Ha of forestland occupied by the Lease Holders. This works out to be only 25.3 % of Forest Land under their occupation. Thus, the area of forest land of over 18000 Ha, remains within the Mining Lease area, but outside the care of both the forest deptt and the Lessee, the known place of illegal / erratic mining and secondary and tertiary source of mineral for many operators.

Violations have helped None As the data above indicate, the mining industry does not even compensate for the loss of forest cover caused by them. They appear to take shelter under a lot of confusing guidelines on 'broken land', Virgin land', 'Renewal of Lease', 'Non compliance of EMP prior to end of lease period' with the excuse of continued operation etc. They lobby hard with many Committees through their strong and organized associations, and legal luminaries, purely in their commercial interest. There are, however, a few exceptions. Thanks to most unscrupulous ones among them, in just one generation, we are handed down a near nude forest, in the name of "Growth" elsewhere, in complete contrast to the objective of the law we framed for ourselves. Some of the satellite pictures of NRSA shown to Citizens on forest cover in Kendujhar were revealing. To an ordinary observer, the hills of Kendujhar appear far worse than even the coastal districts, where there are little or no natural forests. There lies the Challenges for the Mining fraternity, Engineers included.

STATUS OF LAND WITHIN ML AREA

During mining operation, the status of the land, or 'Kissam' remains unchanged as "Forest". It is because at closure of the mine, the land is to be restored as per 'Environment Management Plan', the most important part of any 'Mining Plan". EMP is a continuous process which the mine managers have deliberately neglect to meet the exponential growth targets. Abandoned mines are left devoid of forests for years. Indian Bureau of Mines are to enforce the provision of MCDR-88, on measures of protection of environment. These measures cost money, which should rightfully be set aside from the mineral wealth taken from under the forestland. In anticipation of renewal, the leaseholders do absolutely nothing even at the end of the lease period, leaving a lot of gap between the promises on paper and action on ground. Our fervent plea lies buried under the language of market place, of competition, and globalization. The Citizens strongly feel that the nexus, if any, must be broken for the sake of our forests. If needed, the effected civil society must be allowed some say in this. Unlike their counter parts in Western Ghat, here in the East, they are only 'Voice less' Spectators to the wanton damage to valuable hard wood forests.

UNREASONABLE DEFICIENCY IN PLANTATION OF FORESTS

The compensation amount collected by Forest Department (Rs 20.97 Crores, collected in 23 years since 1984 in Kendujhar forest division alone) for 'Compensatory Afforestation', namely, for Plantation,

maintenance, and protection, has gone in to Government treasury, and very little of that (15% in case of Kendujhar forest division, for example) returns to the district for the actual ground work. It is as if the present generations Government sustain their establishment by felling trees. No wonder, the sensitive tribal residents of this border district who depend on the Non Timber Forest Products(NTFP) for sustenance, feel being constantly robbed by people from 'Else Where'.

Supreme Court intervention comes as Saviour

The continuous regressive activities on forests, mainly in mining sector, was brought to the door of Hon'ble Supreme court by the alarmed environmentalists who pleaded that the value of trees in the forests are not just their 'Log Values'. Their leaves produce 'Oxygen' for the animal life. They provide shades to moderate ground temperature, and thus reduce loss of moisture. Their roots not only hold a lot of water by capillary action, but also hold the soil tight against erosion. The forests are a home to life from ants to elephants, from birds to carnivores, to sustain a biodiversity. Ecology becomes 'Deep Ecology' where life is redefined. Hon'ble Supreme Court, after proper hearing, ordered steep hikes in the compensation amount from 6-9 Lakhs per Ha, hoping that the use of forest land for 'Non-Forest' purpose will decline and simultaneously, adequate funds would be available for creation of new forests and/or effective regeneration of lost forests. But this did not happen on ground.

As a result of this order, in Kendujhar alone, the Rs 21crs collected in 23 years shot up to Rs 1548 crs in just 8 years (till Nov 13). Indirectly, it exposed the ignorance of the forest officials as to the 'True Value' of forests, and the nexus of the vested interests to plunder the natural resources for a bigger share of profit. But kendujhar's pain did not end here. It was only beginning. Kendujhar district's two forest divisions have raised Rs 1548 crs ,which is more than 50% of whole of Odisha, into this fund created by Supreme Court, called "CAMPA" fund. This simply indicates that about 50% of the forests lost to miners in the whole of Odisha, is here in Kendujhar. But when it comes to utilizing the same for the cause of creation and regeneration of forests and wild life here, only less than 1% is returned to Kendujhar. In spite of SC guidelines, a 'Pro rata' allocation of CAMPA fund is denied.

STATE CAMPA BRINGS INJUSTICE TO KENDUJHAR

Citizens of kendujhar had occasion to examine the proceedings of all 11 steering committee meetings of State CAMPA, including the last one held on 28 July 2015 and are totally disappointed with the arbitrary way the fund is managed, allocated and utilized. Surprisingly, the committee is kept in darkness about District wise collection of CAMPA deposits where the forests are actually lost. Besides, the ability to handle the massive task of regeneration of forests is negated by sere lack of skilled manpower at district level. When the task in Kendujhar alone is that of two circles, there is none here. Over 24000 ha of 'Hardwood' forests handed out to the miners. Now creation of same area of forests is indeed a massive task beyond the scope and capability of district forest administration.

Citizens see a 'National Environmental Disaster' in making in Kendujhar. Extensive 'Deforestation', untreated oversized mine waste dumps, excessive silting from the loosened earth, severe air and water pollution with consequences of spread disease to human beings, plants and animals, dangerous lowering of ground water levels, drying up of streams and rivers due to illogical allocation of water to Mining industries, all leading to Climate Change.

CONCLUSION

These are only some of the points, most serious in nature. In Kendujhar, we are very disturbed about the sudden and appreciable climate change, deeper descent of ground water level, vanishing wild life, silting of reservoirs, adverse effect on our agriculture and domestic animals, clogging of water points by eroded top soil, loss of sacred relationship of our rural and tribal folks with forests. These are some of the impacts which can be objectively assessed by professional scientists and environmentalists from reputed institutions like TERI or NEERI, unlike the embedded consultants making EIA reports for commercial interest. We in Kendujhar are disillusioned by the present state of 'Governance', which is quite weak in delivery, never a 'Bottoms up' approach, always imposed from above. Now on we will increasingly depend on the 'New age' professionals to address the civilizational needs of 'sustainability', 'Environment'and 'Well ness' in pursuit of their carrier.

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Laboratory and Field Investigation on Coal Mine Overburden- A Case Study

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ABSTRACT

Performance of haul road pavement depends majorly on the bearing capacity of in-situ material. The paper presents the results of an extensive field and laboratory investigation of in-situ material and coal mine overburden material of Bhubaneswari Coal Mine Limited. California Bearing Ratio tests, Dynamic Plate Load tests, Shear tests, Field Density tests, Proctor Compaction tests are carried out to evaluate the strength properties as well as compaction characteristics of the in-situ material and collected mine overburden material. The paper also discusses the importance of various tests required for evaluation and assessment of mine haul road condition.

Keywords: Pavement, Haul Road, CBR, CBR_d, E_{vd}, Opencast Coal Mine

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 well stabilized haul road plays a vital role to maintain high productivity of a surface mine, because failure of such road leads to increase in air borne dust, reduced traffic mobility, increase in cycle time, increase in frequency of vehicle maintenance and fuel consumption. Stabilized haul road base is one of the most important components of mine haul road design. Based on the size of a surface coal mine, length of permanent haul road varies from 2 to 5 km. Apart from that, temporary haul roads or lumpy roads are also constructed from locally available material. The locally available material includes the overburden materials like sand stone, crushed gravel, morrum, top soil, sub soil and others based on their regional geological formation. Ulusay et al. [1] categorized the overburden material as heterogeneous with equal percentage of fine and coarse grains. The finer grains of sand, gravel, clay etc. are used as a filling material which does not contribute to the haul road stability whereas coarse grained is used as base and sub-base material. Tannant and Regensburg [2] mentioned that pot holes, sinking, rutting and settlement are major failure modes observed in mine haul roads. In a surface mine, cost of truck/dumper haulage contribute up to 50% of total mining cost [3].

Large capacity dumpers are used in surface mine to haul coal and overburden from mine to the stock yard and waste dump site respectively. Gross vehicular weight of large capacity dumpers can go up to 4000 kN and tire pressure to support the dumpers are typically in the range of 600 to 690 kPa [4]. Critical strain limit of mine haul road varies between 1500 and 2000 micro-strains [3]. Hence, mine haul roads should have sufficient bearing capacity and stiffness. Cost norm for 35 t dumper for a fixed thickness decreases from Rs. 602/m to Rs. 442/m when CBR value increases from 3 to 7% [5]. In this investigation, geotechnical properties of mine overburden materials are evaluated to check their suitability as haul road construction material. It is found that only untreated morrum is suitable as a sub-base material. Hence, commercial additive is required to improve the CBR of mine overburden materials for its use in sub-base and base course.

CASE STUDY

Coal mine A located in central part of India is considered in this study having annual production of about 15 Mt of

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coal and 7 Mm^3 of overburden. These material are transported by 80 t dumpers (make: Caterpillar) and 10 t dumpers (make: Tata) and uses bias and radial tyres respectively. The wear rate of bias and radial tyre is around 160 and 190 h/mm respectively, whereas the average life is around 6500 and 11,500 h respectively. The length of mine haul road in this mine is around 8 and 2 km respectively and sub-base is constructed by mixture of sand and morrum in the ratio 2:3; and 45–63 mm size stone metal is laid over as a Water Bound Macadam (WBM). Finally, the freshly constructed mine haul road are compacted using 100 kN power roller. The haul roads in this mine is flexible type and are designed based on California Bearing Ratio (CBR) method. Figure 1 shows the haul road section. For dust suppression, mine management is using water sprinkling method due to frequent movement of dumpers as well as service vehicles.

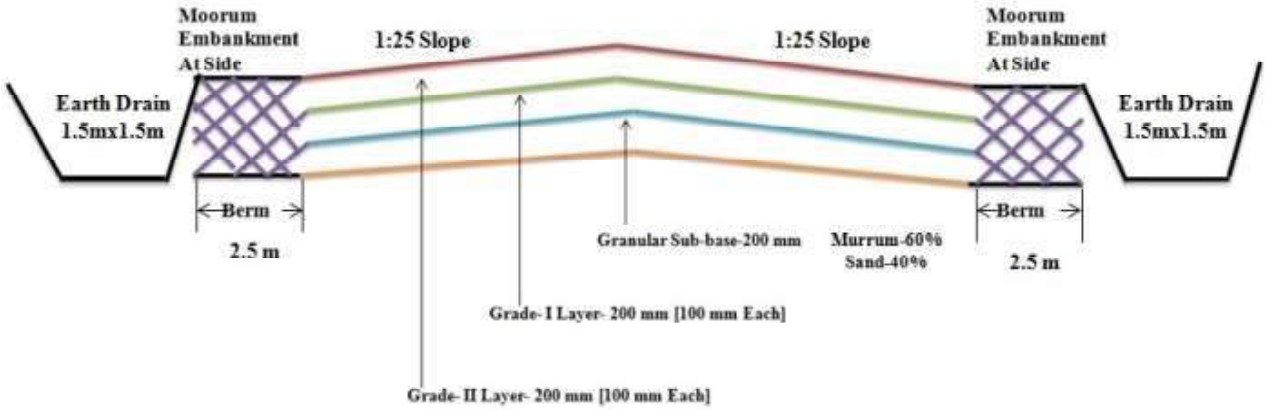


Fig. 1. Haul Road Pavement of Study Mine

Figure 2 shows the haul road condition of the mine with the problems like (a) pot holes and rutting, (b) material spillage from moving dumpers and dust generation, (c) excess sprinkling of water and deterioration of surface course. All the materials used for the construction of the haul road are the mine overburden material.

Fig. 2. Mine Site Observations

MATERIALS AND METHODS

To access the suitability of the mine overburden material of this mine as a pavement material field tests (dynamic CBR test and dynamic plate load tests) were carried out on morrum and sub soil. For laboratory investigation morrum, sub soil and top soil from the overburden are carefully sampled from different areas of waste dump for representative samples (Fig. 3). The samples are then placed in air tight packets in controlled environment and transported to the laboratory. For all collected samples, specific gravity, particle size distribution, liquid limit, plastic limit, shrinkage limit, chemical compositions, optimum moisture content, maximum dry density, static and dynamic CBR and deformation modulus are determined.

MATERIAL CHARACTERIZATION

Laboratory Investigation

The physical properties like specific gravity, Atterberg limits as liquid limit (LL), plastic limit (PL), plasticity index (PI) of overburden materials are shown in Table 1. Table 2 shows the chemical properties of murrum, sub soil and top soil. The specific gravity of top soil is found to be less than that of sub soil and murrum because of less iron content. Table 2 shows that the iron content in murrum, sub soil and top soil are 26.11, 9.83, and 5.89% respectively. Pandian [6] mentioned that the materials with high iron content have relatively high specific gravity. Table 2 shows that the compositions of CaO in murrum, sub soil and top soil are 0.65, 0.62 and 1.21% respectively which is low. Hence, natural binding cannot be expected and so some additive is required to enhance the pozzolanic reaction to increase the material strength. The LL, PL, PI and SL reflect important geotechnical characteristics of volume change with addition of water.

Table 1. Physical Properties of different Mine Overburden Materials

Property	Murrum	Sub Soil	Top Soil
Specific Gravity	2.74	2.61	2.5
Gravel (> 4.75 mm)	37.4	---	---
Sand (4.75 mm-0.075mm)	35.23	73.37	43.12
Silt and clay (< 0.075 mm)	27.37	26.63	56.88
Liquid Limit, LL (%)	46.1	24.6	32.78
Plastic Limit, PL (%)	19.1	Non-Plastic	16.15
Plasticity Index, PI (%)	27	---	16.63
Shrinkage Limit, SL (%)	15.13	20.83	19.61

Particle size distribution reflects whether the material is poorly, medium or well graded and has strong influence on density. Murrum contained 37.4% gravel, sub soil contained 73.37% sand while top soil contained 56.88% silt and clay as shown in Fig. 3. As murrum contained higher percentage of gravel, its maximum dry density is highest while it is lowest for top soil as it contained higher percentage of silt and clay. The engineering properties of a material such as CBR, cohesion, angle of internal friction are dependent on the moisture content and density (Table 3). Typically the higher the compaction the better is its geotechnical characteristics. Hence, it is necessary to achieve the desired degree of compaction which is necessary to meet the expected properties [7].

Table 2. Chemical Properties of different Overburden Material

Constituents	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	MgO	TiO_2	Na_2O	MnO	LOI
Murrum	33.82	33.70	26.11	0.65	2.49	0.54	2.09	0.15	0.45	…
Sub Soil	54.80	25.87	9.83	0.62	2.69	0.67	1.88	…	…	3.64
Top Soil	51.48	26.96	5.89	1.21	1.71	0.59	2.37	…	…	9.79

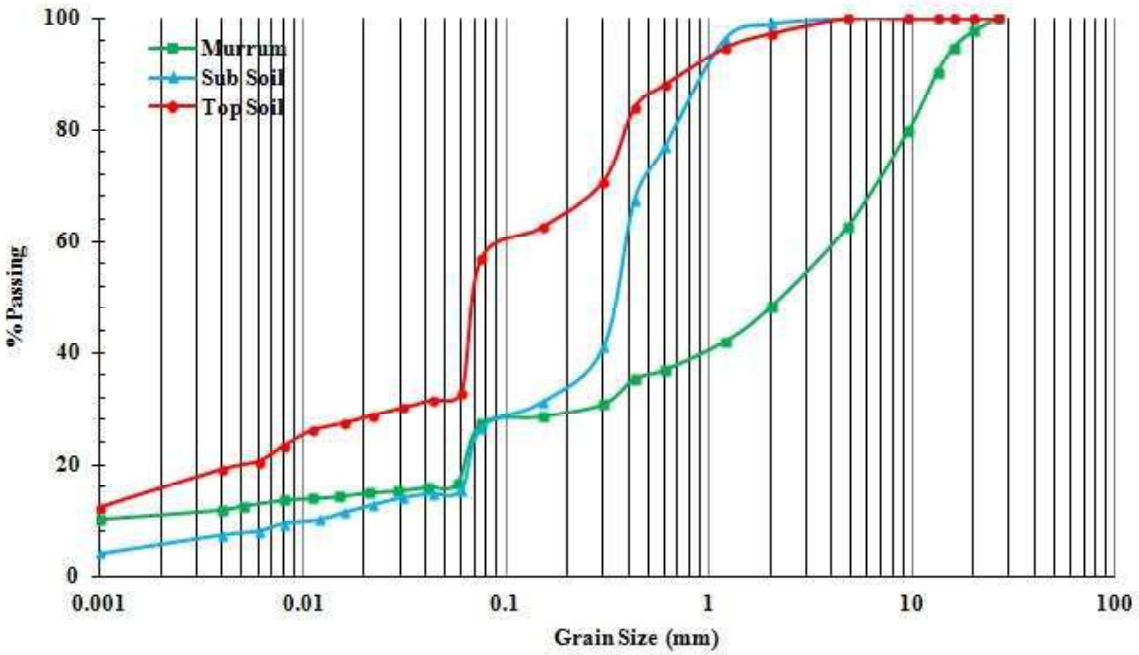


Fig. 3. Grain size distribution curve of mine overburden

Table 3. Engineering Properties of different Mine Overburden Materials

Property	Murrum	Sub Soil	Top Soil
OMC (%)	10.63	6.7	10.4
MDD (kg/m^3)	2055	1990	1974
CBR [Un-soaked] (%)	39.3	8.5	4.7
CBR [Soaked] (%)	18	2.1	1.7
Cohesion (kPa)	38.9	22.2	20.6
Angle of Internal Friction (^{0})	37.1	36.7	36.2

COMPACTION CHARACTERISTICS

During compaction the density of soil is increased by application of mechanical energy such as tamping, rolling and vibration. In this process particles are forced to be closer and closer by reducing inter-particle air voids. The overall moisture content of all overburden samples varies between 6 and 11% and the highest OMC is 10.63% for murrum. The maximum dry density (MDD) of top soil is highest and equal to 2055 kg/m3; whereas it is least for top soil with a value 1974 kg/m3. The reason of less cohesion of top soil is due to its non-cohesive nature. Compaction curves obtained from modified proctor compaction test of various samples are shown in Fig. 4.

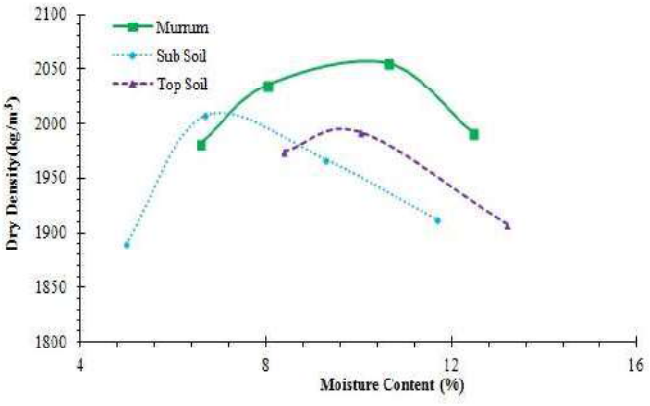
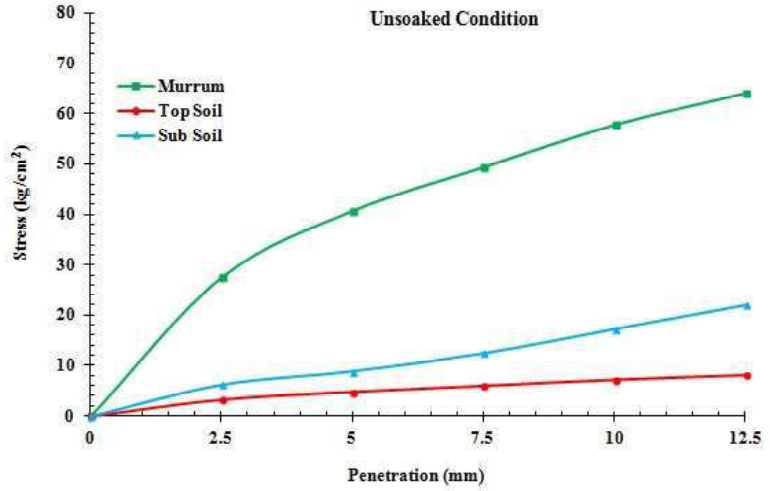


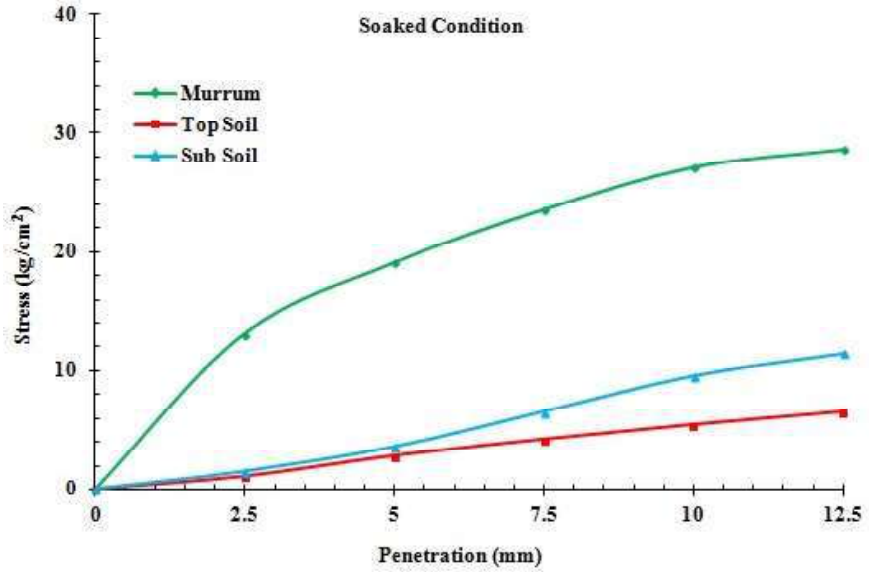
Fig. 4. Variation of dry density with moisture content

CALIFORNIA BEARING RATIO

Mine haul road design based on CBR is well established and popular method for design of base and sub-base course of road pavement. CBR tests are carried out to characterize the untreated overburden materials. In un-soaked condition CBR values without additive varied between 4 and 39% as shown in Fig. 5a. In un-soaked condition CBR value is more than the soaked condition and it is due to the capillary forces created at optimum moisture content and MDD condition in addition to the friction resisting the penetration of the plunger [8]. However, when the samples are tested after 4 days of soaking, CBR values obtained are very low due to the destruction of the capillary forces as well as reduced frictional resistance as shown in Fig. 5b. Soaked condition is a conservative estimate, yet considered for worst scenario. The untreated mine overburden samples did not show any appreciable strength values which classify the material unsuitable for sub-grade [9]. The general relationship between CBR and quality of sub-grade soil used in pavement construction is given in Table 4.



(a)



(b)

Fig. 5(a) and (b) Stress and penetration relationship in un-soaked and soaked condition

Table 4. Sub-grade categorization based on CBR [9]

Quality of Sub-grade	CBR (%)
Very poor Sub-grade	0-3
Poor to Fair Sub-grade	3-7
Fair Sub-grade	7-20
Good Sub-grade	20-50
Excellent Sub-grade	75

FIELD INVESTIGATION

The light weight deflectometer (Make-ZORN) is a hand portable device that was developed in Germany to measure the soil in-situ dynamic properties (dynamic CBR and dynamic deformation modulus). Typically, these values are used to evaluate the degree of compaction. Thus it is suitable for compaction quality control of soil-surfaced roads, embankments and replacement fill.

CBR, CBR_d, test can be performed both in laboratory and in-situ. The test can be conducted as an alternative to the static CBR test, especially due to the short period of time required. The CBR_d test is carried out with the use of Light Weight Deflectometer**,** where a falling weight is used to generate a defined load pulse on the CBR piston. CBR_d is calculated on the basis empirical formula [10] as:

$$CBR = \frac{87.3}{s^{0.59}}(\%) \qquad (1)$$

Where, 87.3 is the number standing as a value of dynamic loading including empirical coefficient, and s is the settlement in millimetres.

The LWD modulus is evaluated using the static plate load test [11]

$$E_{LWD} = 1.5R\frac{\sigma}{s}(\mathrm{MN/m^2} \qquad (2)$$

Where, E_{LWD} = dynamic deformation modulus, R = radius of the loaded plate, σ = stress under the loaded plate, s= mean settlement of the loaded plate.

The above equation does not consider the speed related factors and inertial forces in the test evaluation. The stress under the plate is generally constant and equal to 0.1 MN/m^2 and for a plate diameter of 30 cm. Thus, the above equation reduces to ELWD (MN/m^2) =22.5/s (mm), which is used to calculate the LWD modulus based on the measured settlement which is automatically performed by the LWD software.

Dynamic CBR value of in-situ sub soil and morrum are found to be 32%, 38% and 57%, 61% respectively (Fig. 6 & Table 5). But dynamic CBR value of sub-soil and morrum are found to be 41% and 70% respectively in laboratory test. Because of inadequate compaction, the in-situ CBR_d values are less compared to laboratory CBR_d. Similar results are obtained while performing dynamic plate load test using light weight deflectometer. Dynamic CBR value of in-situ sub soil and morrum are found to be 29.9 MN/m^2, 34.5 MN/m^2 and 51.2 MN/m^2, 55.7 MN/m^2 respectively (Fig. 7 & Table 5). But dynamic CBR value of sub-soil and morrum are found to be 37.8 MN/m^2 and 64.6 MN/m^2 respectively in laboratory test.

Table 5. Dynamic Properties of In-situ Materials

Field Test (BCML-MCL)–In Pit				Laboratory Test			
Sub Soil		Morrum		Sub Soil		Morrum	
BR_d (%)	E_{vd} (MN/m^2)	CBR_d (%)	E_{vd} (MN/m^2)	CBR_d (%)	E_{vd} (MN/m^2)	CBR_d (%)	E_{vd} (MN/m^2)
32	29.9	57	51.2	41	37.8	70	64.6
38	34.5	61	55.7	-	-	-	-

CONCLUSIONS

1. Overburden materials have major chemical constituents of silica 33.82–54.80%, alumina 25.87–33.70% and iron oxide 5.89–26.11%.
2. Top Soil, Sub soil and Morrum have high maximum dry density 1974, 1990, and 2055 kg/m^3 respectively and low optimum moisture content 10.4, 6.7 and 10.63% respectively.
3. Soaked CBR values of Top Soil, Sub-soil and Morrum are 1.7, 2.1 and 18% respectively.
4. Untreated Top soil and Sub soil are not suitable as haul road construction material as they posses low compressive strength and CBR value in soaked condition.

Fig. 6. Dynamic CBR test at BCML

Fig. 7. Dynamic Plate Load test at BCML

5. The CBR values of untreated top soil and sub soil are low (<3%) in soaked condition and hence those are unsuitable for road construction.
6. There is not much strength gain in the untreated top soil and sub soil with varying curing periods e.g. from 7 to 28 days.
7. It is found that only untreated morrum is found suitable as a sub-base material. Hence, commercial additive is required improve the CBR of mine overburden materials to have potential as sub-base and base course material.
8. The dynamic *CBR* method, as well as static (classic) method can be used to assess compaction of in-situ material of haul road pavement. The results of studies of CBR_d, and *CBR*, are closely connected with the characteristics of compaction.
9. Dynamic *CBR* test, using Light Weight Deflectometer, should be widely used due to its speed and ease of research as an alternative method to classic method of quality control in compaction process or assessment of bearing capacity of in-situ material.

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