10th Asian Mining CONGRESS & EXHIBITION

November 06-09, 2023 • Kolkata, India

TAAL KUTIR CONVENTION CENTRE

Eco Park, Newtown, Kolkata

"Roadmap for Best Mining Practices Vis-à-vis Global Transformation"

SOUVENIR & SUPPLEMENTARY VOLUME

Supported by

Ministry of Coal, Govt. of India

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Coal India Limited, A Maharatna Company

Organised by :

THE MINING, GEOLOGICAL & METALLURGICAL INSTITUTE OF INDIA (MGMI)

Established 1906

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Responsible Mining

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Venue – Taj Taal Kutir Convention Centre, Newtown, Kolkata

Aerial View of Exhibition and Congress Venue

10th International Mining Exhibition 2023 (IME 2023)
at Eco Tourism Park Plot No. : 11E/65, Action Area II, Newtown, New Town, West Bengal 700156

9th Asian Mining Congress & Exhibition

For Contact :

Prasanta Roy

Convener, 10th AMC Conference
HoD (Geology), CIL

For Mining Exhibition 2023 (IME 2023)

TAFCON

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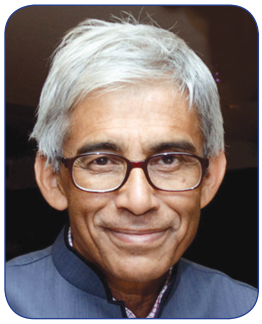
Please Contact :

Mr Amit Kumar

Contact No. : 91-9891296397



PREFACE

The Asian Mining Congress (AMC) and International Mining Exhibition (IME), held concurrently, are flagship international events organized by The Mining Geological and Metallurgical Institute of India (MGMI), biennially. The 10thAsian Mining Congress and International Mining Exhibition, in this sequel, are being held during November 06-09, 2023 in Kolkata, India.

The mining and mineral sectors currently require a serious introspection because their long term sustainability largely depends on an inclusive growth of human civilization. Complexities of mineral deposits, increasing depth of mining, efficient processing and utilisation of coal, minerals and metals and value addition are major technical challenges. At the same time, combating the menace of climate change, energy transition, environmental management and strong societal expectations are of serious concerns. At this juncture, it is very pertinent to brainstorm on best mining practices taking stock of the recent developments, availability of state-of-the-art technologies and equipment and relevant cutting edge innovations. The increased processing power of computers and myriad interpretative software packages available in mining industry have revolutionized in processing and analyzing vast amount of data that are of relevance, both in the present and future contexts. Understanding the pressing priority, the 10th Asian Mining Congress is being organised with the theme of "Roadmap for Best Mining Practices vis-à-vis Global Transformation". We are pleased to be associated with Springer Nature, a publishing house of global repute, for publication of this Congress proceeding volume. We have also included some papers in this volume. A wide spectrum of papers with contemporary relevance such as recent advancements in geostatistics, reserve estimation, application of geophysical techniques, challenges in underground and opencast mining, smart miningthrough adoption of AI/ML and IOT, rock excavation techniques, critical minerals and speciality materials,application of numerical modelling, waste utilisation, miners' health and safety, coal gasification, mine environment, and many more importanttopics aregoing to be presented in this Congress. It is expected that the resulting deliberations and discussions will provide very valued inputs to redefinethe roadmap for best mining practices in tune with the global transformation.

The valuable contributions made by the authors are thankfully acknowledged. Sincere thanks are due to all the reviewers who have supported us by timely reviewing the papers to maintain the quality of the papers. Our sincere acknowledgements are due to one and all who have directly or indirectly supported us in our endeavour. Finally, we thank Springer Nature for value addition to the Congress proceeding volume.

A Sinha

Dr Amalendu Sinha
Chairman, Technical Committee, 10th AMC
& Former Director, CIMFR

MESSAGE

10th Asian Mining Congress & Exhibition

November 06-09, 2023
Kolkata, India

अमृत लाल मीणा, भा॰प्र॰से॰
सचिव
AMRIT LAL MEENA, IAS
SECRETARY
Tel.: 23384884 Fax : 23381678
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सत्यमेव जयते

आज़ादी का अमृत महोत्सव

भारत सरकार
GOVERNMENT OF INDIA
कोयला मंत्रालय
MINISTRY OF COAL
शास्त्री भवन, नई दिल्ली-110 001
SHASTRI BHAWAN, NEW DELHI-110 001
www.coal.gov.in

Message

I am delighted to extend my warmest greetings and sincere appreciation to The Mining, Geological and Metallurgical Institute of India (MGMI), a dynamic consortium of technocrat planners and policy makers both in the private and public sector at State/Central levels, for their commitment for organizing the 10 th Asian Mining Congress on the "Roadmaps for best mining practices vis-à-vis Global Transformation".

Rising concern about climate change and strong societal expectations with increasing complexities of mineral deposits being mined, calls for more innovative exploration and extraction technologies with higher productivity and recovery. Such eco-friendly strategies and policies need in place for long term sustainability of the mining & mineral industry. It is now absolutely necessary to identify and define the best mining industry practices addressing transitional requirements for societal needs.

At this juncture it is very pertinent to brainstorm on best mining practices taking stock of the recent developments, availability of state-of-the-art technologies, equipment and relevant cutting-edge innovations, including digital transformations in the sector. The insights and outcomes of this conference will undoubtedly contribute to shaping policies, fostering technological advancements and partnerships that are essential for a sustainable energy transition.

I commend 'The Mining, Geological and Metallurgical Institute of India (MGMI)' for their dedication in organizing this vital congress, and extend my appreciation to all participants for their active engagement. Your participation underscores our shared commitment to finding equitable, environmentally conscious solutions for the coal and mining industry.

May the collaborative spirit of this event inspire us all to forge ahead with determination and purpose as we work to promote and advance techno-scientific cooperation towards national and international progress in the areas of mineral production. My best wishes for a successful and enlightening congress.

Dated: 18.10.2023

18.X.23

(Amrit Lal Meena)

रामेश्वर तेली
RAMESWAR TELI
ৰামেশ্বৰ তেলী

सत्यमेव जयते

आज़ादी का अमृत महोत्सव

पेट्रोलियम एवं प्राकृतिक गैस और
श्रम और रोजगार राज्य मंत्री
भारत सरकार
Minister of State for
Petroleum and Natural Gas &
Labour and Employment
Government of India

Message

I am very happy to learn that The Mining, Geological & Metallurgical Institute of India (MGMI) and TAFCON are organising the 10th IME 2023 - International Mining, Equipment & Minerals Exhibitions and ISME - International Steel & Metallurgy Exhibition (Concurrent with 10th Asian Mining Congress) from 6th to 9th November 2023 at Eco Park, Rajarhat, Kolkata.

I am sure that the deliberation in the Congress would provide an opportunity to all the stakeholders for a much needed pragmatic roadmap for the growth and development of the mining and steel sector in the country.

I convey my best wishes to the participants and the organisers and wish the event all success.

Rameswar Teli 8/10/23

(Rameswar Teli)

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कृष्ण पाल गुर्जर
KRISHAN PAL GURJAR

केंद्रीय राज्य मंत्री,
विद्युत और भारी उद्योग मंत्रालय
भारत सरकार, नई दिल्ली
UNION MINISTER OF STATE FOR
POWER AND HEAVY INDUSTRIES
GOVERNMENT OF INDIA, NEW DELHI

सत्यमेव जयते

आज़ादी का अमृत महोत्सव

Message

10 OCT 2023

I am glad to note that 10th IME & ISME 2023- International Exhibitions on Mining, Equipment & Minerals and Steel & Metallurgy Sectors (Concurrent with 10th Asian Mining Congress) are being organized by MGMI & TAFCON during November 6th-9th,2023 at Kolkata.

Steel & Mining are an economic activity and has been the prime source for various industrial sectors. Innovation in technologies and skill upgradation is essential for optical production of mineral resources in the country. The Indian Government has opened this sector for private investments including foreign direct investments. These events should provide a platform for indigenous and foreign entrepreneurs and to meet, exchange thoughts and ideas, and collaborate to pen a pragmatic roadmap for the growth of these industries in the country.

Best wishes to the participants and the organizers for the event to be a great success in fulfilling its agenda of creating a platform for the industry.

(Krishan Pal Gurjar)

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Room No. 200, Shram Shakti Bhawan, Rafi Marg, New Delhi-110001 • Phone : 011-23720450, 23720451, 23720452

HEMANT SOREN
CHIEF MINISTER

Message

It gives me immense pleasure to note that MGMI and TAFCON are organizing the 10th IME and ISME 2023- International Exhibitions on Mining, Equipment & Minerals and Steel & Metallurgy Sectors and 10th Asian Mining Congress with theme "Roadmap for Best Mining Practices vis-a-vis Global Transformation" from November 6-9, 2023 and is also bringing out a souvenir on the occasion to commemorate the same.

The exhibition arranged will display the latest machinery with latest technologies and their innovative applications will definitely offer excellent business opportunities for Mining, Steel and Allied industries.

I am confident that this Congress will provide a forum to promote and advance techno-scientific cooperation towards national progress in the area of mineral production thereby helping in meeting the challenges being faced by industry which in turn will lead to improvement in productivity.

I convey my heartiest congratulation to the organizers and wish these events a grand success.

H Soren

(Hemant Soren)

Kanke Road, Ranchi - 834 008 (Jharkhand)
Tel.: 0651-2280886, 2280996, 2400233 Fax.: 0651-2280717, 2400232
E-mail: chiefminister.jharkhand19@gmail.com

सत्यमेव जयते

भारत 2023 INDIA

Azadi Ka Amrit Mahotsav

Bhupendra Patel

Chief Minister, Gujarat State

Dt. 09-10-2023

Message

I am happy to note that MGMI and TAFCON are jointly organizing four-day **International Mining & Steel Exhibitions 2023** and congress on the theme **"Roadmap for Best Mining Practices Vis-à-vis Global Transformation"** during November 6-9, 2023 at Kolkata.

Restoring stability to nature and environment is as important as the extraction of minerals from the earth. There should be a judicious balance between protection of the environment and progress of the industry. We make the world, we live in and hence should shape our environment and try to bring back a green canopy.

The theme of exhibitions and 10^{th} Asian Mining Congress is the need of the time when environment and climate change issues, have become a clarion call for the world over. The exhibitions also would serve as a platform for showcasing latest machinery, equipment and technologies.

To be attended by experts associated with the industry from India and abroad, I am sure there will be exchange of productive ideas, sharing of creative thoughts, and opinions at the event. It should be put into practice, for the progress and development of the industry. I offer my Best Wishes and Success for the Exhibitions & Congress.

(Bhupendra Patel)

To,
Shree I. P. Wadhwa,
Managing Worker, TAFCON,
The Mining, Geological & Metallurgical Institute of India,
GN-38/4, Sector-V, Kolkata-700091. (West Bengal)
Email: miningexpo@tafcon.in, office@mgmiindia.in

Apro/md/2023/10/09/vj

Dr. P. B. Salim, IAS

Secretary
Chief Minister's Office (CMO) &
Department of Co-operation &
Department of Programme Monitoring.

Chairman & Managing Director
The West Bengal Power Development Corporation Limited

Chairman
West Bengal Minorities Development & Finance Corporation

Message

I am very pleased to learn that the MGMI & TAFCON are organizing 10th IME & ISME 2023 – International Exhibitions on Mining, Equipment & Minerals and Steel & Metallurgy Sectors from November 6th to 9th, 2023 in Kolkata.

The West Bengal Power Development Corporation Limited (WBPDCL) is the largest power generation company wholly owned by the Government of West Bengal with the goal to carry on interalia the business of electric power generation and supply in the state of West Bengal, India. In this connection it is our pleasure to inform you that the **Bakreswar Theraml Power Plant of WBPDCL has ranked 1st (performance 92.38%) in the National Ranking of thermal power companies of the country, including private & public sector companies for FY 22-23.** WBPDCL achieved best ever monthly Specific Oil Consumption of 0.09 ml/kWh in Jan'23 , highest ever loading of 342 rakes (avg. 11.03 rakes/day) from Pachhwara North Coal Mine in Oct'22, highest generation of 101.642 MUs recording a PLF of 99.29% in Oct'22 etc.

WBPDCL has under construction project of 660 MW of thermal and 52.5 MW of Floating & Rooftop Solar. We also have 4 nos. of operational coal mines out of which 3 has achieved its Peak Rated Capacity and 2 nos. of new coal mines are under development coal mine.

WBPDCL stepped into solar power generation in 2014 with a 40 KW Rooftop Solar PV Plant at Bidyut Unnayan Bhaban, Kolkata and now has a total renewable (Solar) portfolio of 25.58 MW.

I wish these events a grand success. I also congratulate MGMI & TAFCON for organizing this prestigious event.

09/10/23

(Dr. P.B. Salim, IAS)

WBPDCL

The West Bengal Power Development Corporation Limited
(A Government of West Bengal Enterprise)
CIN : U40104WB1985SGC039154
Bidyut Unnayan Bhaban, Plot No. 3/C, Block-LA, Sector-III, Kolkata-700106
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West Bengal Minorities Development & Finance Corporation
(A Statutory Corporation of Government of West Bengal Enterprise)
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www.wbmdfc.org mdfc.wb@gmail.com

पी० एम० प्रसाद
अध्यक्ष-सह-प्रबंध निदेशक
P. M. Prasad
Chairman-Cum-Managing Director

कोल इण्डिया लिमिटेड
COAL INDIA LIMITED
(A MAHARATNA COMPANY)
A Govt. of India Enterprise
"COAL BHAWAN"
Premises No. 04 MAR, Plot No. AF-III
Action Area - 1A, New Town, Rajarhat
Kolkata - 700 163

Message

The sharp focus of mining sector across the globe is now on the best mining practices and the transformation process. To name few crucial attributes that make mining more sustainable are eco-friendly equipment, reusing mining waste, rehabilitating mining sites, improving mining sustainability and restore land to its best possible natural state. This assumes greater significance for coal mining sector with added emphasis on lowering carbon emissions and coping with transition to renewable energy.

Aptly, this year's theme of '10th Asian Mining Congress concurrent with International Mining, Equipment and Minerals Exhibition' scheduled to be organized by TAFCON in association with MGMI from 6 to 9 November 2023 at Kolkata is "Roadmap for Best Mining Practices vis-à-vis Global Transformation".

I truly appreciate the efforts undertaken by the two entities – TAFCON and MGMI – over past many years in conducting seminars, workshops and exhibitions in the interest of the mining community with global participation of experts, academicians, scientists, policy makers, equipment manufacturers, tech consultants and allied stakeholders. These event have been hugely successful with many technical papers presented.

I am sure this year's Congress-cum-Exhibition will witness similar success with even greater participation.

Best Wishes!

(P M Prasad)

Ph. : Off. : (033) 2324 6611/2324 6622, Fax : (033) 2324 4023 ■ Email : chairman.cil@coalindia.in ■ Website : www.coalindia.in

Message

Goodwill Message

I extend my heartfelt wishes to the Mining, Geological & Metallurgical Institute of India (MGMI) and TAFCON for their considerable efforts in organising the International Steel and Metallurgy Exhibition (ISME) and International Mining, Equipment and Minerals Exhibition (IME) at Kolkata this year. I believe that the platform will pave the way for enhanced cooperation and progressive development in this sector.

In Poland, the mining and steel industries hold a rich history dating back centuries. Even today, this in many ways traditional industry continues to play a pivotal role in the country's economic development. Poland is an important producer of hard coal, lignite, coke, steel, copper, zinc, lead, silver, and many industrial minerals. With 97% of the total EU production in 2022, Poland remains by far the largest producer of hard coal in European Union. Polish mining industry has evolved significantly over the years, embracing modern, sustainable and clean technologies and practices such as selective mining, remote monitoring, methane drainage, autonomous mining vehicles, long wall shearers, CCS and CCU, automation control systems and ice suspension cooling. Poland is also one of the top crude steel producing economies in the EU. With our energy mix also underpinned by a strong coal baseload, and the prosperity of our industrial heartlands dependent on these sectors, Poland thus understands India's strategy and its energy security approach.

With India being one of the largest producer of coal and crude steel globally, I have no doubt that this forum will be successful in fostering new capacity and innovation in the field of mining and steel. I convey my best wishes to all the participants and wish the programme great success.

With best regards,
Dr. Sebastian Domzalski,
Chargé d'affaires a.i.,
Embassy of the Republic of Poland in New Delhi

Message

Dear Delegates,

I am pleased to learn about the 10th Asian Mining Congress (AMC) and would like to congratulate the Mining, Geological & Metallurgical Institute of India (MGMI) on this momentous occasion. The success of this international conference, with participation from renowned experts, innovators and thought leaders, is testament to MGMI's commitment to sustainable growth and technological development.

The theme for this year's AMC, *Roadmap for Best Mining Practices vis-ávis Global Transformation,* is extremely relevant as we focus on technology and innovation to drive growth while being committed to Sustainable Development Goals. I am certain that the discussions at the conferencewill underscore our industry's commitment to advancing scientific understanding of mineral resources.

Tata Steel believes that sustainable mining practices are the foundation for a prosperous future. Through responsible and efficient mineral production, we aim to meet the growing demands of the nation, while also safeguarding the environment and the communities we serve.

As we look to the future, we are confident that the AMC will continue to be a driving force for progress. On behalf of Tata Steel, I extend my heartfelt congratulations to MGMI and wish the conference all success.

T V Narendran
CEO & Managing Director
Tata Steel

Bhola Singh
Chairman cum Managing Director
भोला सिंह
अध्यक्ष सहप्रबन्ध निदेशक

नार्दर्न कोलफील्ड्स लिमिटेड
(भारत सरकार का एक मिनीरत्न प्रतिष्ठान)
सिंगरौली 486889 (म.प्र.)
NORTHERN COALFIELDS LIMITED
(A Government of India Mini Ratna Enterprise)
P.O. & Distt. Singrauli-486889(M.P.)
Phone: 07805: 266621(Off),266459(Fax)
email: cmd.ncl.cil@coalindia.in

Message

*It gives me immense pleasure to know that The Mining, Geological and Metallurgical Institute of India (MGMI) is organizing **10th Asian Mining Congress (AMC)** and **International Mining Exhibition (IME)** during **06th-09th November, 2023** at Kolkata, W.B.*

The theme of this year's congress, "Roadmap for Best Mining Practices Vis-à-vis Global Transformation," resonates strongly with the current dynamics of the mining sector. As the world undergoes significant transformations, driven by technological advancements, environmental concerns, and changing societal expectations, it becomes imperative for us to align our practices with the best and most sustainable approaches.

Northern Coalfields Limited (NCL) is committed to excellence in coal mining and understands the importance of responsible and sustainable operations. We firmly believe that forums like the Asian Mining Congress provide an ideal platform to share knowledge, exchange ideas, and forge partnerships that will help us collectively navigate the evolving landscape of the mining industry.

I encourage all participants to actively engage in the discussions, presentations, and exhibitions during this event. Let us collaborate, learn from each other, and work towards a future where mining not only meets the growing global demand for resources but also upholds the highest standards of safety, environmental stewardship, and social responsibility.

I wish the 10th Asian Mining Congress (AMC) and International Mining Exhibition (IME) great success.

B Singh.

(Bhola Singh)

बीसीसीएल BCCL
Bharat Coking Coal Limited

भारत कोकिंग कोल लिमिटेड
(कोल इण्डिया लिमिटेड की एक अनुषंगी कंपनी)
Bharat Coking Coal Limited
(A Subsidiary of Coal India Limited)
(एक मिनीरत्न कंपनी / A Miniratna Company)
(भारत सरकार का उपक्रम / A Government of India Undertaking)

SAMIRAN DUTTA
Chairman-Cum-Mg.Director

Message

It gives me immense pleasure to learn that MGMI is going to organize 10th Asian Mining Congress (AMC) 2023 on "Roadmap for Best Mining Practices Vis-a-vis Global Transformation" & 10th International Mining Exhibation (IME) on 06-09th November 2023 at Kolkata and is also going to publish a Souvenir and Abstract Volume on the occasion.

Such events, we can adopt new world-class techniques and do better mining with high quality at low cost and friendly to the environment and society.

The Mining, Geological and Metallurgical Institute of India (MGMI) is one of the most illustrious interdisciplinary and old institute of Asia.

I wish the event every success & congratulate the organisers for their endevour.

Dated: 11/08/2023

(Samiran Dutta)

पंजीकृत कार्यालय: कोयला भवन, कोयला नगर, बीसीसीएल टाउनशिप, धनबाद, झारखंड -826005, भारत
Registered Office: Koyla Bhawan, Koyla Nagar, BCCL Township, Dhanbad, Jharkhand-826005, India
फोन / Phone: 0326-2236000, वेबसाइट / Website: www.bcclweb.in, CIN-U10101JH1972GOI000918

ECL

ईस्टर्न कोलफील्ड्स लिमिटेड
Eastern Coalfields Limited
(कोल इंडिया की एक अनुषंगी)
(A Subsidiary of Coal India Limited)
(भारत सरकार का एक उपक्रम)
(A Govt. of India Undertaking)

Message

It is heartening to note that the Mining Geological & Metallurgical Institute of India (MGMI) is organizing the 10th Asian Mining Congress and international Mining Exhibition with theme "Roadmap for Best Mining Practices Vis-à-vis Global Transformation" during 6-9 November, 2023 and bringing out a Souvenir on the occasion to commemorate the same.

Such a grand event will definitely provide a platform for the miners, planners and policy makers to interact on various issues of mining industry for reinforcing their future initiatives.

I am confident that this Congress will help in meeting the emerging challenges for mining industry. I hope that this congress will help the mining industry scattered in different regions to establish a close contact with the manufacturers for timely procurement of equipment & spares for uninterrupted production.

I convey my heartiest complements to the Organizers and wish the 10th Asian Mining Congress & international Mining Exhibition a grand success.

(A.P.Panda)
Chairman-cum-Managing Director

पंजीकृत कार्यालय / Regd. Office
सांकतोड़िया, पो०-डिसेरगढ़, जिला : पश्चिम बर्द्धमान (प०बं०), पिन-713333 ♦ Sanctoria, P.O. Dishergarh, Dist. Paschim Bardhaman (W.B.), PIN-713333
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सीआईएन/CIN : U10101WB1975GO1030295, वेबसाइट/Website : www.easterncoal.nic.in

Message

Thomas M Cherian
Managing Director
Essel Mining & Industries Ltd.

It gives me immense pleasure to be part of the 10th Asian Mining Congress (AMC) and International Mining Exhibition (IME) organised by The Mining, Geological, and Metallurgical Institute of India (MGMI).

Theme of the Asian Mining Congress "**Roadmap for Best Mining Practices Vis-à-vis Global Transformation"** is very relevant in today's dynamic environment particularly for the Mining Industry which is going through major transformation.

Asian Mining Congress will provide a forum to promote advanced thought leadership in next generation practices and opportunities in Mining covering technology, digital and de-carbonization areas which will help us to move towards a responsible and sustainable future that will benefit global mining industry and the planet alike.

Asian Mining Congress would delve on key topics including latest exploration Technologies, best global mining practices, Application of Artificial Intelligence (AI), Machine Learning, Data Analytics in Mine Automation, Information and Communication Technology (ICT) in Smart Mining and Extraction and Utilization of Critical Minerals and Rare Earth Elements and Potential Strategic Investment Opportunity in the Mining Industry.

I wish the Asian Mining Congress and exhibition grand success. Together, let us connect, share and learn from each other for responsible and sustainable mining in an equitable manner.

Singareni Bhavan, Red Hills,
Hyderabad - 04, Telangana State
Telephone : (91-40) 2330 7938, 23393746
FAX : (91-40) 2339 3746 E-MAIL : cmd@scclmines.com

N. SRIDHAR, IAS

Chairman & Managing Director

Message

It is great pleasure to know that The Mining, Geological and Metallurgical Institute of India (MGMI) is organizing **10th Asian Mining Congress and Exhibition** with theme: **"Roadmap for Best Mining Practices Vis-à-vis Global Transformation"** during 06-08 November 2023 at Taal Kutir Convention Centre , New Town, Kolkata

I wish the forum will showcase significant advancements in the evolution of best mining practices and technological developments, best mining practices taking stock of the recent developments, availability of state-of-the-art technologies and equipment and relevant cutting-edge innovations, including digital transformations in the Mining Sector.

I hope this 10th Asian Mining Congress and Exhibition will benefit the mining industry and Society as whole as this forum for exchange of ideas, experiences among industries and policy makers to meet the 1 Billion tonne Coal production during 2023-24 set by the Ministry of Coal

This is also a platform for efficient utilization of mineral resources, major innovations and technological breakthrough to combat the menace of climate change through a seamless energy transition to meet ever increasing societal expectations.

I wish the organizers a great success in organizing the 10th Asian Mining Congress and Exhibition.

(N.Sridhar)
Chairman & Managing Director

Date : 25-09.2023

Message

It is a matter of great pleasure and privilege to extend a warm welcome to the global mining community at the 10thedition of the "International Mining Exhibition (IME)" and "Asian Mining Congress (AMC)" to be held from November 06-09, 2023 at Kolkata. Balmer Lawrie, a Miniratna I PSE under Ministry of Petroleum and Natural Gas, Government of India with a strong presence in both the manufacturing and services sectors, participated in the exhibition last year which was very successful.

The business environment today globally is witnessing numerous disruptions that is demanding all sectors to be agile and future ready. In such a scenario, the theme of the 10th Asian Mining Congress is "Roadmap for Best Mining Practices vis-à-vis Global Transformation" is pretty apt and will enable insightful deliberations during the Congress. The mining sector is significantly contributing to the growth of manufacturing industries such as power, steel, cement etc. and India's GDP as well.

I'm confident that the deliberations in the Congress will address the transformations and core issues of mining and allied industries, and the concurrent exhibition will be a good platform for showcasing new products and technologies.

My best wishes to the organisers, the Mining, Geological and Metallurgical Institute of India (MGMI) for the success of the Congress and the Exhibition! The event will surely be enriching for the exhibitors, delegates and visitors and there will be notable takeaways.

Adika Ratna Sekhar
Chairman & Managing Director
Balmer Lawrie & Co. Ltd.

नालको NALCO

Shri Sridhar Patra
Chairman-cum-Managing Director

Message

I'm indeed happy to learn that the Mining, Geological, and Metallurgical Institute of India (MGMI) and TAFCON are organizing the 10th IME 2023-International Mining, Equipment, and Minerals Exhibition- from November 6th to 9th, 2023, at Eco Park, Rajarhat, Kolkata.

The mining industry has witnessed remarkable growth in recent years, driven by a confluence of technological innovation, sustainable practices, and a growing emphasis on responsible resource management. Automation and robotics, data analytics and AI, remote sensing and GIS, environmental sustainability, advanced materials and processing methods, safety enhancements, circular economy practices, community engagement and CSR, and blockchain technology are being widely used to achieve safety, efficiency, and sustainability in mining operations. These advancements collectively signify a paradigm shift in the mining industry towards a more sustainable, efficient, and socially responsible future. By embracing these innovations, the industry is poised to meet the increasing global demand for minerals while minimizing environmental impact and maximizing societal benefits.

I'm sure that the exhibition, through its myriad displays and demonstrations, will stand as a testament to the dynamism and innovation that define the mining industry on a global scale. The exhibition shall showcase the remarkable progress made in the extraction, processing, and utilization of minerals, along with machinery and equipment that have redefined the mining landscape. I'm hopeful that there will be meaningful conversations, partnerships, and knowledge sharing that will ultimately propel the economic development of the nation while upholding environmental stewardship.

I wish the event all success.

(Sridhar Patra)

डॉ. रंजीत रथ
अध्यक्ष एवं प्रबंध निदेशक
Dr. RANJIT RATH
Chairman & Managing Director

ऑयल इंडिया लिमिटेड
(भारत सरकार का उद्यम)
प्लॉट न॰ 19, ऑयल हॉउस, सेक्टर, 16ए,
नोएडा 201301 (उ.प्र.)

OIL INDIA LIMITED
(A Govt. of India Enterprise)
Plot No. 19, OIL HOUSE, Sector-16A,
NOIDA - 201301 (U.P.)
Tel. : +91-120-2488301, 4217320, 4217328
E-mail : cmd@oilindia.in

Message

At the outset, I wish to extend my best wishes to the grand success of 10th Asian Mining Congress (AMC) 2023 & International Mining Exhibition.

As of bulk minerals, India is mostly self-sufficient for providing raw material and feedstock assurance to the several industries across the value chain. With the recent path breaking reforms in the mining & mineral sector, an enabling ecosystem has now been created for all the entities. It is imperative upon all the stakeholders, now to enhance exploration coverage and expedite production of the natural resources viz. coal & lignite, crude oil & natural gas, bulk minerals such as iron ore, limestone, bauxite and other important minerals such as manganese, copper, lead, zinc, gold, diamond etc.

The current impetus on eMobility, clean energy & lower emissions has amplified the significance of critical minerals and ensuring a reliable & sustainable supply chain is crucial to realise the vision of Atma Nirbhar Bharat. With the clarion call of our Hon'ble Prime Minister, Shri Narendra Modi on India's aim of achieving net zero emissions by 2070, we have to be geared up towards increasing exploration and mining of critical minerals that are essential for economic development, national security and Net Zero emission target of the country.

I am confident that this forum will provide a platform towards developing strategy, innovative solutions for our country's need as well as strategic collaborations in Mining Industry, which can sustain our country's GDP growth above 7%.

Once again, my best wishes for this upcoming august gathering of Senior Government Officials, CEOs, Entrepreneurs, Consultants & companies involved in the Mining & Mineral sector.

Ranjit Rath
Dr. Ranjit Rath

REGD. OFFICE: DULIAJAN - 786602, ASSAM (INDIA), TEL. : 0374 - 2800503, FAX : 0374-2800433

यूरेनियम कॉरपोरेशन ऑफ इंडिया लि०
(भारत सरकार का संस्थान)
परमाणु उर्जा विभाग

URANIUM CORPORATION OF INDIA LTD.
(A Government of India Enterprise)
Department of Atomic Energy

An ISO : 9001: 2015, ISO : 14001: 2015, IS : 18001: 2007 Company
CIN : U12000 JH 1967 G01 000806

Dr. C. K. Asnani
Chairman & Managing Director

Message

It gives me immense pleasure to know that the 10th Asian Mining Congress (AMC) 2023, on the theme "Roadmap for Best Mining Practices Vis-à-vis Global Transformation," is being organized in Kolkata from November 06-09, 2023.

This mega event, covering wide-ranging technological, environmental, and legislative matters with an emphasis on mineral exploration, underground mining, extractive metallurgy, and the application of communication technology in mining, will go a long way in transforming the mining scenario of the country by increasing the contribution of the sector to the GDP of the country, employment generation, and the zero carbon target. The Uranium Corporation of India Limited, having pioneered mechanization in the underground metalliferous mining sector and having mastered both acid and alkali leaching technology for the extraction of uranium from very low-grade deposits, will immensely benefit from this event.

I convey my best wishes for the success of the Congress and the Exhibition of Mining Technology.

(Dr. C. K. Asnani)

जादुगोड़ा माइन्स, सिंहभूम (पूर्वी), झारखंड – 832102 JADUGUDA MINES, Singhbhum (East), Jharkhand-832102

Phone : 0657-2730348, Fax : 0657-2731048
E-mail : asnani@uraniumcorp.in/cmdsect@uraniumcorp.in, Website : www.uraniumcorp.in

Message

P K Motupalli
Chairman & Managing Director NLC

On the occasion of 10th Asian Mining Congress & Exhibition organized by The Mining, Geological & Metallurgical Institute of India, I am glad to note the impact the event is to make in the mining industry not only in India but also across the globe.

With the energy transition happening across the globe, abundant opportunities are presented before the mining industry, capitalizing this opportunities require disruptive innovations.

I strongly believe that, this event will provide the platform for sharing the best practices in the mining industry along with exposure to advanced technology from across the globe. It is a fact that Confluence of knowledge will always result in great outcomes.

My best wishes to the Mining, Geological & Metallurgical institute of India for organizing the 10th Asian Mining Congress & Exhibition on the topic "Roadmap for Best Mining Practices Vis a Vis Global Transformation" and wish them to organize many more such events on imminent topics in future.

Prasanna Kumar Motupalli

मनोज कुमार
अध्यक्ष-सह-प्रबंध निदेशक

Manoj Kumar
Chairman-cum-Managing Director

सेन्ट्रल माईन प्लानिंग एण्ड डिजाइन इन्सटीच्यूट लिमिटेड
(कोल इण्डिया लिमिटेड की अनुषंगी कम्पनी / भारत सरकार का एक लोक उपक्रम)
गोन्दवाना प्लेस, काँके रोड, राँची - 834 031, झारखंड (भारत)
Central Mine Planning & Design Institute Limited
Gondwana Place, Kanke Road, Ranchi - 834 031, Jharkhand (INDIA)
(A Subsidiary of Coal India Limited / Govt. of India Public Sector Undertaking)
Corporate Identity Number (CIN): U14292JH1975GOI001223

Message

It gives me immense pleasure to note that the Mining, Geological & Metallurgical Institute of India (MGMI) is going to organize the 10th Asian Mining Congress (AMC) & International Mining Exhibition (IME) during November 6-9, 2023, at Kolkata. The publication of a souvenir during the ceremony is inspiring & praiseworthy and serve as a goodwill of memories.

MGMI, one of the oldest institutes in Asia, has been promoting the cause of Mineral Industries since its inception in 1906. By organizing such type of international congress and exhibitions, it is contributing to the growth of knowledge and the advancement of our society. The theme of the conference is topical interest looking at the status and aspects of coal production in Coal India as well as in the country. I am sure that the 10th Asian Mining Congress (AMC) & International Mining Exhibition (IME) will provide tremendous opportunities for high level deliberations and exchange of knowledge for all the participants as in previous years.

I wish the 10th AMC and IME a grand success.

Best regards,

(Manoj Kumar)
Chairman-cum-Managing Director

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अमरेन्दु प्रकाश
अध्यक्ष
AMARENDU PRAKASH
Chairman

स्टील अथॉरिटी ऑफ इण्डिया लिमिटेड
STEEL AUTHORITY OF INDIA LIMITED

Message

I congratulate The Mining, Geological and Metallurgical Institute of India (MGMI) for organizing the 10th Asian Mining Congress, a landmark event that brings together some of the brightest minds and industry leaders in the field of mining.

The theme of this year's souvenir, "Roadmap for Best Mining Practices vis-a-vis Global Transformation," resonates deeply with the current dynamics of steel and mining industry. India is looking at a massive capacity expansion of crude steel to 300 Million Tonnes by 2030-31 which calls for a concurrent growth in the demand for iron and other ores required for steel production. As we navigate the challenges and opportunities of a rapidly changing world, it is imperative that we not only embrace technological advancements but also prioritize environmental stewardship, safety, and the well-being of our communities.

Mining, as an industry, has a significant role to play in shaping the future of our planet. We must strive to balance the growing global demand for minerals and resources with our shared responsibility to protect the environment. This equilibrium can only be achieved through innovation, collaboration, and a steadfast commitment to ethical and sustainable mining practices.

In this context, the 10th Asian Mining Congress offers a unique platform for dialogue and knowledge exchange. It is my hope that the insights and solutions presented in this souvenir will inspire us all to embark on a journey towards excellence in mining, one that respects our planet's finite resources and contributes to the betterment of society.

I extend my best wishes to all participants for a successful and productive Congress.

(Amarendu Prakash)

स्टील अथॉरिटी ऑफ इण्डिया लिमिटेड, इस्पात भवन, लोदी रोड, नई दिल्ली 110 003, दूरभाष : (011) 2436 7282, 2436 8094 फैक्स : (011) 2436 5051 ई-मेल : chairman.sail@sail.in
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•Website: https://www.mgmiindia.in

Dr. B Veera Reddy
President, MGMI & Director (T), CIL

Message

The 10th Asian Mining Congress organized by **The Mining, Geological & Metallurgical Institute of India,** holds our great promise as an event to be remembered. When we had launched the 1st Asian Mining Congress little did, we realize that this would form the cornerstone of successive **Asian Mining Congresses** with outreach to many countries in Asia. It is a matter of pleasure and satisfaction to have been associated with these events.

I have no doubt that the **10th Asian Mining Congress** will scale new heights and International Mining Machinery Exhibition will showcase the latest advances in mining technology.

I wish the Congress and the Exhibition all success.

Dr B Veera Reddy

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Ranajit Talapatra
Secretary, MGMI
GM, Washri, CIL

Message

This year, MGMI is organizing the 10th Asian Mining Congress concurrently with 10th International Mining Exhibitions 2023 in Kolkata from **November 06-09, 2023.** The Congress with the theme **"Roadmap for Best Practices vis-à-vis Global Transformation"** is expected to have participation from subject experts and exhibitors from around the world. I am confident that with the participation of international participants, the Congress will continue to hold the window to a brighter future of mankind through sustainable utilisation of mineral resources.

I am happy to inform that **Shri Pralhad Joshi, Hon'ble Minister of Coal, Mines & Parliamentary Affairs, Govt. of India** has kindly agreed to inaugurate the 10th Asian Mining Congress and IME 2023. Also, there has been unprecedented response from allied fields across the globe, especially Australia and the Czech Republic.

As the Secretary of this esteemed Institute, I would like to acknowledge significant contribution made by distinguished experts for finalization of technical papers the summary of which would be brought out by the internationally known publication house Springer for the first time along with a Proceeding Volume during the Congress. I would also like to gratefully acknowledge the guidance and co-operation received from members of the Council and the hard work by all the Organising Committee members and the MGMI office Staff.

I hope that this edition of MGMI's flagship event maintains the global standards the previous Congresses have been famous for, and wish it all success.

Ranajit Talapatra
Honorary Secretary
MGMI

Dr. Ajay Kumar Singh
Honorary Editor, MGMI
Chief Research Coordinator, PMRC Private Ltd., Dhanbad
Former Scientist & Head, Methane Emission & Degasification
CSIR-CIMFR, Dhanbad

Message

The Mining, Geological, and Metallurgical Institute of India (MGMI) in association with TAFCON has been hosting highly successful biennial events, namely the Asian Mining Congress (AMC) and the International Mining Exhibition (IME), since 2006. These gatherings serve as a platform for the exchange of knowledge among diverse sectors within the mineral industry.

The 10th edition of the Asian Mining Congress (AMC) and International Mining Exhibition (IME) is scheduled to take place from 6th to 9th November 2023 in Kolkata. The event, themed "**Roadmap for Best Mining Practices Vis-à-vis Global Transformation,**" is poised to become a landmark gathering of mining industry professionals and experts in the region. Delegates will engage in valuable knowledge exchange, fostering innovation and environmental responsibility, while also fortifying regional and global mining partnerships. This event promises to be a pivotal moment in the mining sector's growth and development.

On behalf of the MGMI Editorial Board, I extend a warm welcome to all the delegates hailing from diverse and interdisciplinary backgrounds. Our heartfelt gratitude goes out to our esteemed keynote speakers, the dedicated authors of contributed papers, the diligent session chairs, and our incredibly generous sponsors. I would like to express my heartiest appreciation to the following individuals for their outstanding leadership throughout this significant event: Dr. B. Veera Reddy, President, MGMI; Mr. P M Prasad, Immediate Past President, MGMI Mr. Manoj Kumar, Chair, 10th AMC; Mr. Bhola Singh, Chair, 10th IME; and Dr. Amalendu Sinha, Chair, Technical Committee, 10th AMC.

Wishing the event, a resounding success that will leave a lasting impact on all those involved.

ASingh

(**AJAY KUMAR SINGH**)

Message

Asia, which is the largest Continent on this globe, possesses largest share of mineral resources in the world, much of which remains untapped. Recent trends indicate that economic growth of Asia will surpass other Continents in the near future. At this juncture it is very pertinent to brainstorm on best mining practices taking stock of the recent developments, availability of state-of-the-art technologies and equipment and relevant cutting-edge innovations, including digital transformations in the sector.

In the above background it is appropriate to organize the **10th Asian Mining Congress** on a topical subject as its **theme "Roadmap for Best Mining Practices vis-à-vis Global Transformation"**. This would be a follow-up of the highly successful 1st to 9th Asian Mining Congress and IME 2006 to 2023 organized by **the Mining, Geological & Metallurgical Institute of India** respectively in which there were participants for around 40 countries spread all over the world. Considering such overwhelming response received from various countries around the world for the **10th Asian Mining Congress**. I am quite optimistic of the success of the Congress.

I would like to express my sincere thanks to all the Patrons and Sponsors and their support for the Congress. I also gratefully acknowledge the valuable contributions made by the Authors for the Technical Sessions. The members of the Organising Committee and Technical Committee have worked untiringly for maintaining high standard set for this prestigious event.

I wish all success for the **10th AMC and IME 2023** to achieve its objective as outlined in its theme.

Prasanta Roy
Convenor, 10th AMC &
HoD(Geology), CIL

ABOUT THE CONFERENCE

10th Asian Mining Congress & Exhibition

November 06-09, 2023
Kolkata, India

10th Asian Mining Congress

The Preamble

The Mining, Geological and Metallurgical Institute of India (MGMI), established way back on 16th January 1906, is an internationally acclaimed professional body and is one of the oldest institutions of its kind in the world. Since inception, it has been working to promote and advance the mining and mineral industries. Its flagship events, the Asian Mining Congress (AMC) and International Mining Exhibition (IME), held concurrently, are international affairs organized biennially. These events provide ample opportunities to all stakeholders including practising engineers, manufacturers of machinery, planners, regulators, academicians, scientists and policy makers, for sharing their knowledge, experience and expertise, and exhibit their products that can benefit the mining and mineral industries not only in the Asian region but also globally.

The first AMC and Exhibition were held in January 2006 to commemorate the centenary of MGMI. The 2nd, 3rd, 4th, 5th, 6th, 7th, 8th & 9th AMCs were held in January 2008, January 2010, January 2012, February 2014, February 2016, November 2017, November 2019 and April 2022 respectively. There was very good response worldwide in each event with participation of a large number of delegates from India and useful contributions by experts from Asian countries including Bangladesh, China, Indonesia, Iran, Mongolia, Oman, Nepal, Pakistan, Russia, Thailand, Turkey etc. Besides the Indian Mineral Industries boosting the events. The conference proceedings were further enriched with valuable association of eminent professionals from Australia, Canada, France, Gemany, Poland, South Africa, Sweden, UK and USA.

The **10th Asian Mining Congress and International Mining Exhibition** have been scheduled to be held during **November 06-09, 2023 in Kolkata.** For this conference, invitations are being extended to all mineral rich Asian countries for active participation. Other countries, who have made significant advancements in the evolution of best mining practices and technological developments are also being requested to participate.

Background

The Asia region is a significant producer of metal ores and minerals; the production of some major metal commodities accounts for more than half of the world's total. This region is also a main producer and consumer of coal. However, the Mining Sector in particular and Mineral Sector at large are at the crossroads of a global transformation for their long-term sustainability. While increasing depth and complexities of mineral deposits, efficient processing and utilisation of coal, minerals and metals and value addition are major technical challenges, combating the menace of climate change, implementing energy transition and living up to strong societal expectations are serious concerns. At this juncture it is very pertinent to brainstorm on best mining practices taking stock of the recent developments, availability of state-of-the-art technologies and equipment and relevant cutting-edge innovations, including digital transformations in the sector.

In this backdrop, the Congress will provide a forum to promote and advance techno-scientific cooperation towards national and international progress in the areas of mineral production, in addition to the development of new opportunities of sustainable business that will benefit both Asian and global mining communities.

Theme :

The Theme of the 10th Asian Mining Congress is

"Roadmap for Best Mining Practices Vis-à-vis Global Transformation"

Lead Topics / Sub-themes

- Cutting Edge Exploration and Drilling Technologies.
- Challenges in deep Opencast, Highwall, Offshore and Placer Mining.
- Transition from Opencast to Underground mining.
- Mass Production Technologies in deep underground mines.
- Application of Artificial Intelligence, Machine Learning, Data Analytics in Mine Automation.
- Advancement in Explosives and Blasting Techniques.
- Extraction and utilisation of Critical Minerals and Rare Earth Elements.
- Application of Information and Communication Technology (ICT) in Smart Mining.
- Innovations in Oil and Gas Industry.
- Advancement in Mineral, Coal Processing and Extractive Metallurgy towards zero waste mining.
- Prospects of CBM/CMM, Shale gas and Gas Hydrate.
- Prospect of Coal Gasification and Coal to Liquid.
- Changes in Mining Legislations and policies.
- The Pathways for Coal Transition and Net Zero Emission.
- Environmental and Safety aspects in Mining, Oil & Gas industries.
- Strategies and Opportunities for Investments, Merger and Acquisition in Mineral Sector.

Participation

The Congress aims at global participation of practising engineers, managers, planners, policy makers, equipment manufacturers, technology consultants, engineering companies, regulators, scientists, academicians and other mining professionals to interact on various issues related to the Mining and Mineral Industries especially in Asia. All major mineral producing countries are expected to present country status papers.

10th international mining exhibition 2023 (IME 2023)

10th in the Series, the IME 2023 is a leading institutionalized biennial international exhibition of the Mining, Equipment, Minerals and Metals industries in India and abroad. It will be organised concurrently with 10th Asian Mining Congress during November 6-9, 2023 at Eco Park, Rajarhat, Kolkata, India. It will offer excellent business opportunities for the mining, machinery, mineral, metals and allied industries. The four days power packed international exhibition will have a display of mining machinery, laest technologies and their innovative applications etc. The event will be an excellent platform for CEOs, Entrepreneurs, Consultants, Senior Government Officials, Decision Makers and Trade Delegations to congregate, brainstorm, showcase and initiate meaningful partnership for doing business.

Highlights

- Large participation of leading Mining Machinery Manufacturers expected from Asia, America and Europe.
- High Level Trade Delegations and Country Level Group Participation expected from Australia, China, Czech Republic, Germany, Poland, Russia, UK, and USA etc.
- Participation of Mineral Rich Indian States, PSUs, Large Corporate, Small and Medium Organisations.
- Parallel "Buyer Seller Meet" at the Exhibition venue having presentations from interested exhibitors.
- Expected participation of 350 Exhibitors with 20,000 footfalls from India and abroad.

Organiser : The Mining, Geological & Metallurgical Institute of India (MGMI)

MGMI has been promoting the cause of the mineral industry since its inception on 16 January 1906. It has always been on the forefront of professional societies in mining and geosciences around the world. MGMI has always provided a forum for sharing experiences and learning of the latest in best practices and technology. The Institute presently has around 3000 members serving the mineral and allied industries. The institute has its headquarters at Kolkata and one of its branch offices in Kolkata and 18 more branches throughout the country.

10th Asian Mining Congress Organising committee

Patron

Shri Amrit Lal Meena, IAS, Secretary, Ministry of Coal, GOI
Dr Samir V Kamat, Secretary DD (R&D) and Chairman DRDO

National Advisory Committee

Shri P M Prasad, Chairman, CIL & Chairman, National Advisory Committee

Member

Dr Ranjit Rath, CMD, OIL
Shri Shantanu Roy, CMD, BEML
Shri Prasanna Kumar Motupalli, CMD, NLCIL
Dr C K Asnani, CMD, UCIL
Shri Adika Ratna Sekhar, CMD, Balmer Lawrie & Co. Ltd.

Principal Coordinators

President, MGMI - **Dr B Veera Reddy,** CMD, CCL & Director (Technical), Coal India Limited (CIL)
Honorary Secretary, MGMI - **Shri Ranajit Talapatra,** GM, Coal India Limited (CIL)

Organisers

Conference (10th AMC)

Chairman, Conference
Shri Manoj Kumar, CMD, Central Mine Planning and Design Institute
Co-Chairman, Conference
Shri DB Sundara Ramam, VP, Tata Steel
Chairman, Technical Committee
Dr Amalendu Sinha, Former Director, CSIR-CIMFR
Convener Conference
Shri Prasanta Roy, HoD (Geology), CIL
Chairman, Cultural Committee
Shri Samiran Dutta, CMD, Bharat Coking Coal Limited
Convener, Cultural Committee
Shri Awadh Kishore Pandey, GM, MCL and Dr Peeyush Kumar, GM/OSD, MoC

Exhibition (10th IME)

Chairman, Exhibition	**Shri Bhola Singh,** CMD, Northern Coalfields Limited
Co Chairman Exhibition	**Shri J P Goenka,** MD, NMC
Convener Exhibition	**Dr C S Singh,** GM, CIL
Chairman, Buyer Seller Meet	**Shri V K Arora,** Chief Mentor, KCT Bros. Ltd.

Members, Technical Committee, 10th AMC

Advisors

Prof. S P Banerjee, Past President, MGMI, Former Director, ISM, Dhanbad & Advisor

Shri N C Jha, Past President, MGMI, Former Chairman, CIL

Chairman

Dr Amalendu Sinha, Chairman, Technical Committee & Former Director, CIMFR

Technical Committee Members :

Sri T K Nag, Former CMD, NCL

Prof Bhabesh Ch. Sarkar, Professor, IIT-ISM, Dhanbad

Dr Anupendu Gupta, Former DDG, GSI

Shri Ranjit Datta, Former Director, GSI

Prof Sumantra Bhattacharya, Professor, CSIR-CIMFR

Dr Prabhat Kr Mandal, Chief Scientist, CSIR-CIMFR

Dr M P Roy, Professor, CSIR-CIMFR

Prof Biswajit Samanta, Professor, IIT-KGP

Prof Ajay Mandal, Professor, IIT-ISM, Dhanbad

Dr Rajesh Mukherjee, Chief Geologist, Tata Steel Limited

Sri Chiranjib Patra, GM (CED), CMPDI

ABOUT THE MINING, GEOLOGICAL AND METALLURGICAL INSTITUTE OF INDIA

With more than 3000 members representing from different fields of mineral based industries, technocrats, planners, researchers, academicians and policy makers, The Mining, Geological and Metallurgical Institute of India (MGMI), is a more than century old Professional Body, established on January 16, 1906. It is one of the oldest professional organizations of its kind in the world. The main objective of this Institute is to promote 'the study of all branches of mining methods and of mineral occurrences in India with a view to disseminating the information for facilitating the economic development of the mineral industries in the country'. The Institute has been recognized as a Scientific and Industrial Research Organization by the Department of Science and Industrial Research, Govt. of India, through which the technical and scientific communities could, work for their mutual benefit. The Institute provides a suitable platform to discuss pertinent problems related to mining and mineral industries, providing rich scientific and technical inputs from its members, majority of whom are expert and specialises in their respective fields. The Institute is having its Headquarters and one of its branches in Kolkata and 18 branches throughout the country.

The mandate of this august body is to encourage, assist and extend knowledge and information connected with Mining, Geology, Metallurgyand related areasby establishment and promotion of lectures, discussions, correspondences, holding trainings and conferences.The Institute has a good Library and regularly publishes Newsletters,Transaction, Training documents and Proceedings of Conferences. It also encourages and recognizes valuable technical and scientific contributions made by Professionals by giving Awards, Medals and Citations.Besides all these activities, MGMI has been organizing International and National Seminars and the flagship biennial Asian Mining Congress and Exhibitions.

It is an autonomous body controlled by a National Council, of elected Members of the Institute. It is a Non-Profit making body having no commercial interest. The income of the Institute is being utilized for its maintenance and to promote various technical and scientific activities related to Mining, Geological, Metallurgical and allied fields as a National Level Professional Organization.

The Institute has been advising in :

- **Coal Advisory Council, Govt. of India**
- **Mineral Advisory Board**
- **Bureau of Indian Standards**
- **National Safety Council**
- **Coal Advisory Council, Govt. of India, Central Geological Programming Board (Apex body which approves annually the total exploration programmes across the country).**

MGMI Head Quarters MGMI Capters

Glimpses of Previous Asian Mining Congresses

1st AMC 2006

2nd AMC 2008

3rd AMC 2010

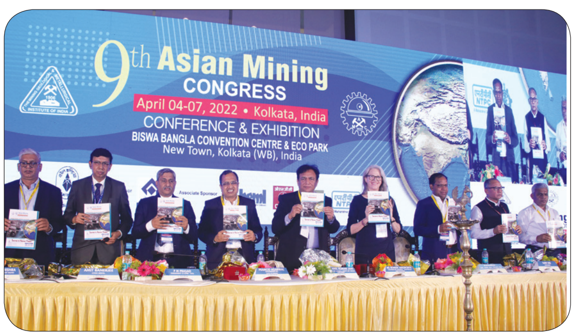
4th AMC 2012

5th AMC 2014

6th AMC 2016

7th AMC 2017

8th AMC 2019



9th AMC 2022

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LIST OF MGMI SPECIAL PUBLICATIONS

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Dr. D.N. Wadia Commemorative Volume*	1965	15	100
Small Scale Mining in India and abroad *	1991	45	450
New Finds of Coal In India – Resource potential and Mining Possibilities	1993	30	300
Computer Applications in Mineral Industry	1993	40	400
Indian Mining Directory (4th Edition)*	1993	40	400
Asian Mining 1993	1993	85	850
Mine Productivity & Technology	1994	75	500
Maintenance Management for Mining Machinery*	1995	60	600
High Production Technology for underground Mines*	1996	50	500
Mineral Industry Development in India – Issues, Perspective & Policy	1996	20	200
Disaster Prevention Management for Coal Mines, Vol I	1996	50	500
Disaster Prevention Management for Coal Mines, Vol II	1996	50	500
Business and Investment opportunities in Mining Industries (BIMI '96) *	1996	40	400
Indian Mining Directory (5th Edition)	1996	50	500
Information Technology in Mineral Industry(MGMIT'97)*	1997	50	500
Technological Advances in Opencast Mining(Opencast'98)*	1998	80	800
Management of Mining Machinery (MMM 1999)	1999	80	800
Mining & Marketing of Minerals (MMM 2000)	2000	80	800
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Mineral Industry : Issues on Economics, Environment and Technology (MEET 2002)	2002	80	800
Development of Indian Mineral Industry Looking Ahead(DIMI 2003)	2003	20	200
Emerging Challenges in Mining Industry (ECMI 2003)	2003	50	500
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Asian Mining Towards A New Resurgence (Vol. I & II)	2006	175	2400
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Coal Beneficiation & Development of Coal Derivatives*	2007	40	400
2nd Asian Mining Congress*	2008	200	2000
Glimpses of Hundred years of MGMI of India (1906 – 2006)	2008	50	500
3rd Asian Mining Congress	2010	160	2000
4th Asian Mining Congress	2012	100	1000
5th Asian Mining Congress	2014 (CD)	100	1000
National Seminar on Indian Mining Industry-Challenges Ahead (IMICA)	2015	15	150
6th Asian Mining Congress (Pen Drive)	2016	100	1000
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7th Asian Mining Congress (Pen Drive)	2017	100	1000
8th Asian Mining Congress (Green Mining: The Way Forward)	2019	250	2500
9th Asian Mining Congress (Technological Advancements in Mining Industy : Status and Challenges)	2022	250	2500

Regular publications: a) News Letter (published quarterly)
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TECHNICAL PAPERS

10th Asian Mining Congress & Exhibition

November 06-09, 2023
Kolkata, India

Keynote Paper

IMPACT OF 2070 NET-ZERO PLEDGE ON THE FUTURE OF INDIAN COAL INDUSTRY

Nirmal Chandra Jha*

Abstract

Net Zero Emission or Net Zero means not adding to the amount of greenhouse gases in the atmosphere. In the 26th Conference of Parties at Glasgow, India made five pledges to reduce carbon and set the time line for Net Zero as 2070. Even though coal accounts for only 55% of the primary energy in the country, it is responsible for more than 2/3rd of the CO_2 emitted to the atmosphere. In the last 30 years, the carbon emission in India has increased from nearly 600MT to 2.7BT. Coal has largely contributed to this increase. Currently India stands 3rd in carbon emission after China and USA. Also, India's carbon intensity in energy generation is the highest in the world at about 275g/kWh.

Total coal usage in the country in the past ten years has increased from 787MT to 1100MT. Futuristic coal demand is projected at 1.1-1.4 BT annually by 2040. The pledge of reducing the carbon from projected level of 2030 by 1BT puts a huge restriction on usage of coal, as this is equivalent to nearly 600 MT of coal usage.

India's energy mix is set to undergo transition from fossil fuel base to non-fossil fuel base, particularly renewable Energy (RE). However, RE requires huge investment in energy storage system (ESS), of the order of Rs. 4,79,000 Crores by 2032.Though, futuristic energy demand increases warrant huge investments in both sectors, i.e., fossil fuel and RE based energy, the ultimate choice will hinge upon the most economic and dependable supply system. Just transition is another issue that will require to be addressed, as in India, currently most of the economic activities are dependent on coal and other fossil fuels.

Key words : *Net Zero, Coal, RE, ESS*

1.0. INTRODUCTION

United Nations Framework Convention on Climate Change (UNFCCC) in its 26th Conference of Parties (COP 26), held at Glasgow, United Kingdom desired different countries to declare their resolve for Net Zero timelines. While USA fixed 2050 for meeting this requirement, China promised it to be by 2060 and India declared it to be achieved by 2070. Before we proceed further on the subject, it would be prudent to understand what is meant by "Net Zero" and what have been the pledges of India, as promised by our honorable Prime Minister. In this article an attempt has been made to assess the impacts of the pledges on the coal industry of India.

2.0. UNDERSTANDING NET ZERO

Net Zero Emission or Net Zero means not adding to the amount of greenhouse gases in the atmosphere. This will be achieved only when all GHG emissions released by human activities are counterbalanced by removing the same from the atmosphere by a process known as carbon removal. Achieving this goal means reducing emissions as much as possible and balancing out the remaining by removing an equivalent amount. Figure-1 graphically demonstrates how net zero GHG emissions can be achieved by the year 2100.

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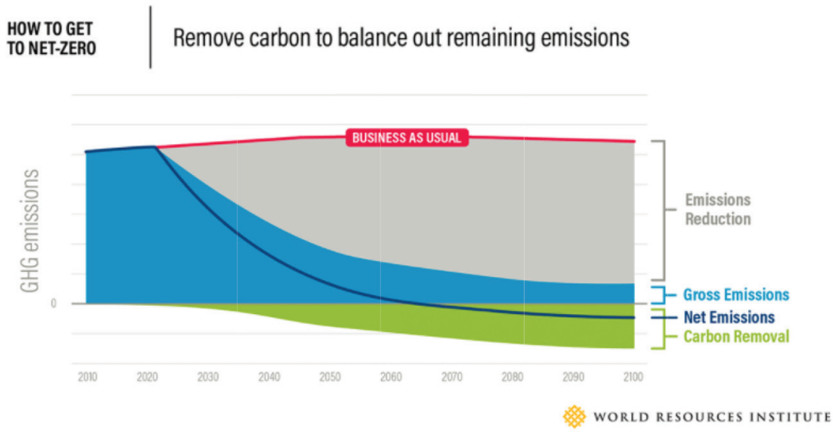


Figure-1 : Graphical Demonstration of Net-Zero

Greenhouse gases like carbon dioxide (CO_2) are released when we burn combustible material, such as oil, gas, coal and biomass, for our homes, factories and transport. Methane is produced through farming and landfill. Such gases released to the atmosphere cause global warming by trapping the energy of sun.

The concept of "Net Zero" finds mention in a 2018 special report of the Intergovernmental Panel on Climate Change (IPCC) which suggested that countries bring greenhouse gas emissions to "net-zero" by 2050 to keep global warming to within 1.5°C of pre-industrial levels. The target for achieving this was kept as year 2050, while limiting that to 2.0°C level was kept as year 2100.

As per the above report, the time frame for reaching net-zero emissions is different for $CO_2$and that for CO_2 and other greenhouse gases like methane, nitrous oxide, and fluorinated gases (Figure-2). For non-CO_2 emissions, the net zero date is later, because models assume that some of these emissions — such as methane from agricultural sources — are more difficult to phase out.

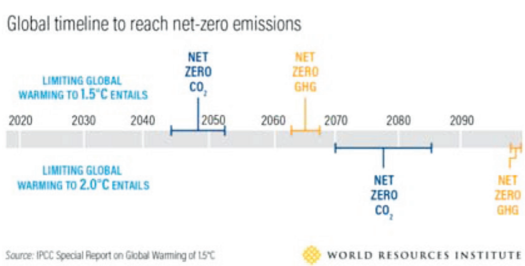


Figure-2 : Global Timeline to Reach Net-Zero Emissions

All countries in the G7 - representing the world's largest advanced economies believe that the human-caused emissions from fossil-fueled vehicles and factories, should be reduced as close to zero as possible. Any remaining GHGs should then be balanced with an equivalent amount of carbon removal, that can be done through actions like restoring forests or using direct air capture and storage (DACS) technology.

It is also necessary that the transition from the current approach of energy generation toward net zero is done in a just manner, especially for workers tied to high-carbon industries and also the population dependent on such activities for their livelihood. It is, therefore, important that the costs and benefits of transitioning to a net-zero emissions economy must be distributed equitably.

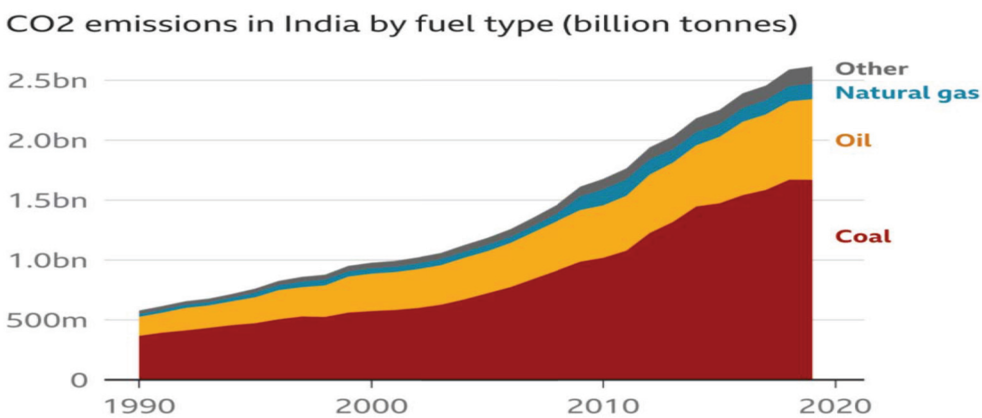
Global action for setting net-zero targets is growing fast, with major economies like China, United States, India, and the European Union making all efforts to meet such commitments. With Bhutan being the first country to set a net-zero target in 2015, over 90 countries, representing nearly 80% of global emissions, have pledged for a net-zero target.

It is pleasant to note that most of the technologies needed to reach net zero targets are already available and becoming increasingly cost-competitive with high-carbon alternatives. Solar and wind now provide the cheapest power in most countries of the world. These developments have led the markets to respond positively and to the risks of a high-carbon economy, and accordingly they are shifting towards renewable energy resources.

However, developing countries including India, aspiring to become advanced economy, believe that the western nations have the historical responsibility over climate change and should provide adequate financial assistance to the developing countries for climate restoration. These countries want the developed countries to provide a Climate Change Finance of $1.5 trillion to the developing countries to achieve Net Zero objective. Hence, the pledges made by the developing countries at the COP 26 summit are conditional. However, every country must make progress in this direction to stop any climate catastrophe.

3.0. CO_2 EMISSION IN INDIA BY FUEL TYPE

Even though coal accounts for only 55% of the primary energy in the country, it is responsible for more than 2/3rd of the CO_2 emitted to the atmosphere. The chart below (Figure-3) shows how the CO_2 emission from coal has increased over the last 30 years.



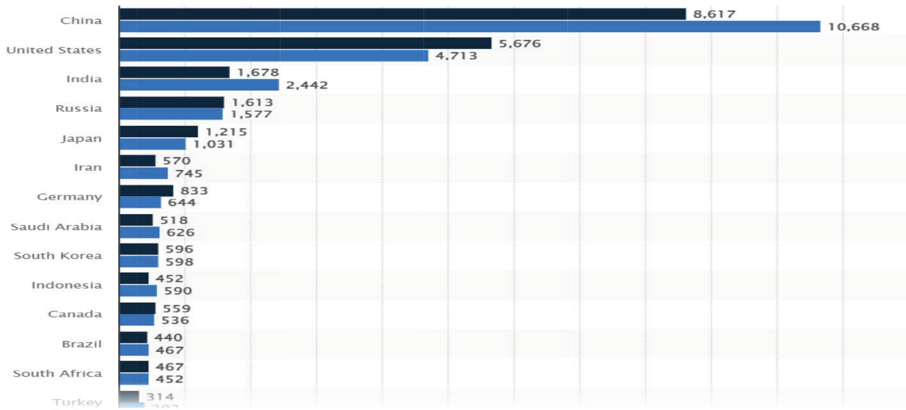
Other includes flaring, cement production and other industrial emissions

Source: Global Carbon Project 2021

Figure - 3 : CO_2 Emissions in India by Fuel Type

4.0. INDIA'S CARBON EMISSION COMPARED TO OTHER COUNTRIES

In the year 2020, though India, as a country, ranked third in global carbon emission, it had contributed only one fourth that of China and nearly half that of USA. Figure-4 shows how India fits in the overall global CO_2 emissions.



Source : Source: Energy & Environment>Emissions

Figure-4 : Carbon Dioxide Emissions in 2010 and 2020 by Select Countries (Figures in million tonnes)

5.0. INDIA'S CARBON INTENSITY OF ENERGY PRO DUCTION – HIGHEST IN THE WORLD.

With the increasing use of inferior grade coal for power generation in India, the amount of carbon dioxide (CO_2) produced for one unit of power (kWh) production is the highest now, at the level of around 0.275 kg/kWh, overtaking China, which had been the topper in this category, so far. The following graph (Figure-5) shows the status of different countries:

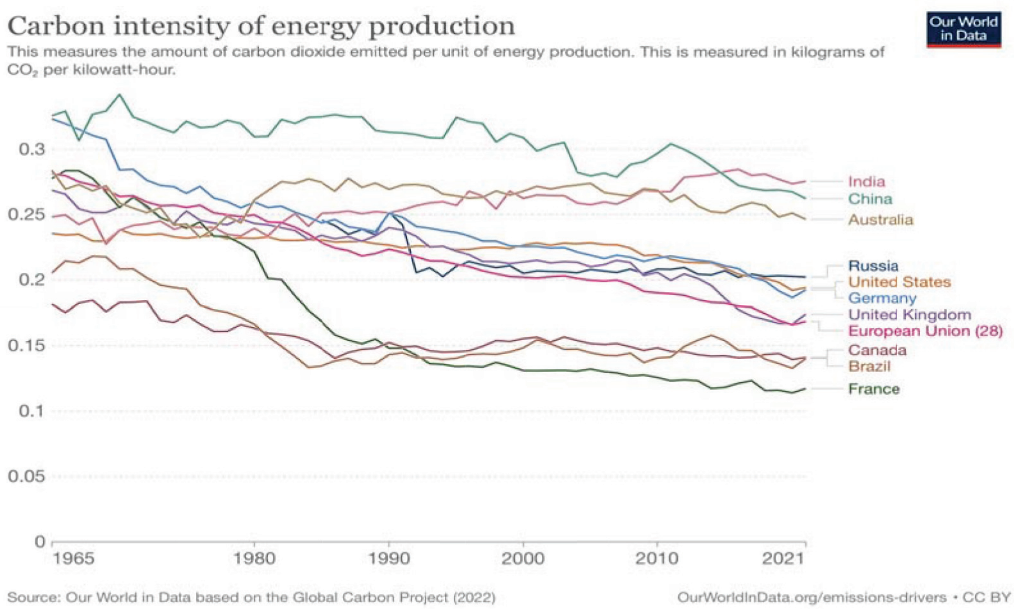


Figure-5 : Carbon Intensity of Energy Production – Major Countries

6.0. INDIA'S COMMITMENT AT COP26

Hon'ble Prime Minister of India during his speech at COP 26 made the following pledges on India's decarbonisation roadmap :

1. Increase non-fossil energy capacity to 500 GW by 2030.
2. Meet 50 percent of energy requirements from renewable energy (RE) by 2030.

3. Reduce the total projected carbon emissions by 1 billion tonnes (BT) by 2030.
4. Reduce the carbon intensity of the economy by less than 45 percent.
5. Achieve net zero carbon by 2070.

6.1. Impact of COP 26 Pledges on Indian Coal Sector

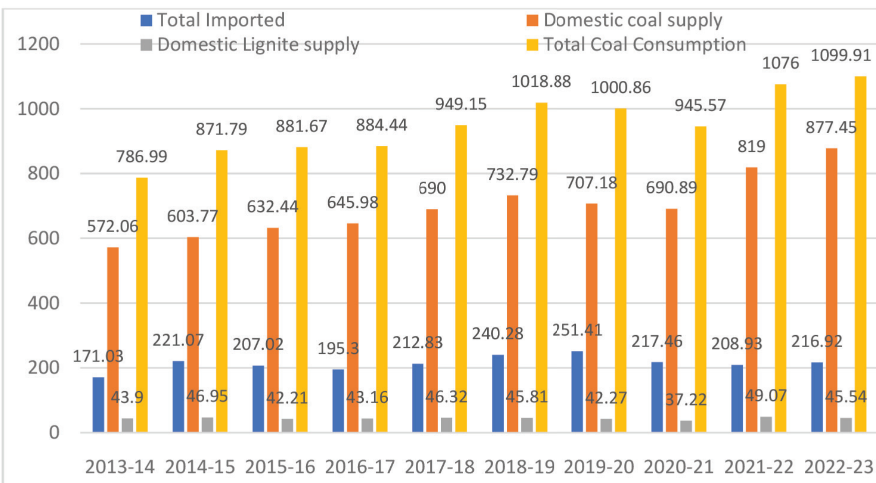
Of the above 5 pledges, the first two relate to building up the capacity of renewable energy to 500GW by 2030, being 50% of India's total energy requirement by this time. This indicates that the total energy from fossil fuels would be around 500GW by 2030 meaning thereby that coal being the major contributor of energy intensity amongst the fossil fuels, its share in quantum as energy provider will increase at least up to 2030, but in percentage terms it is bound to reduce from the current level of 55% in the total primary energy basket. This shows that power generation from coal is projected to increase in near future terms.

In my opinion the major concern for the coal sector lies in pledge No. 3, which requires the country to reduce the total projected carbon emission by 1 BT by 2030. This is a radical pledge as it promises an absolute reduction in carbon dioxide (CO_2) emissions by 2030. While the projected CO_2 emission by 2030 is not known, its reduction by 1 BT would mean reduction of fossil fuel usage by about 590 MT coal equivalent from the projected level for 2030. This is a serious threat on usage of coal as energy provider, as coal currently accounts for nearly 55% in the total source basket for primary energy sources in India.

The last pledge of achieving net zero status by 2070 gives us enough time to adhere to it. It also provides the scope of emitting or generating CO_2 and making arrangements for sequestering it through the trees and artificial processes to keep it at net zero level.

7.0. PAST TREND OF COAL CONSUMPTION IN THE COUNTRY

The trend of total annual coal consumption in the country, including lignite, imported coal, coke and other products is shown in the Figure-6. It shows that the total coal usage in the country in the past ten years has increased from 787MT to 1100MT. Total consumptions in the last 5 years have been hovering between 950 MT to 1100 MT. Years 2019-20 and 2020-21 saw a slight declining trend while the past two years have seen increased usage of the solid fossil fuel in the country.



Source : Data taken from Coal Statistics 2022-23

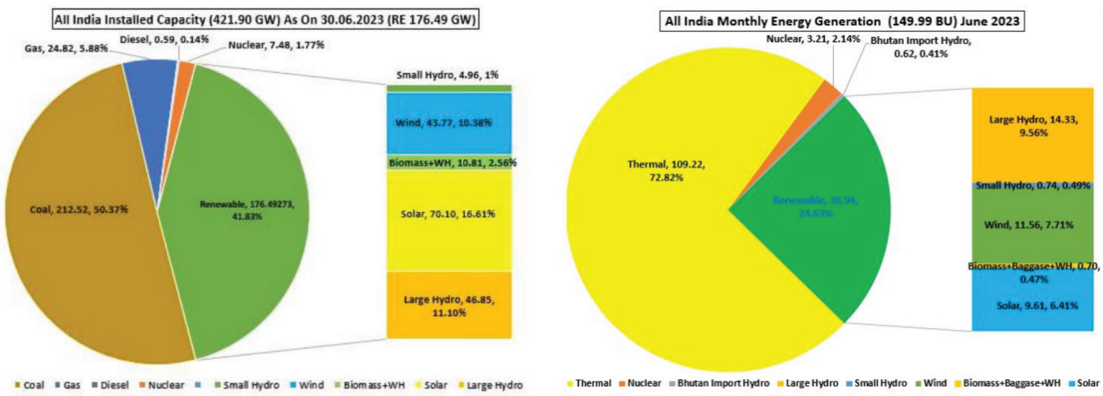
Figure-6 : Total Solid Fossil Fuel Usage in the Last 10 Years

8.0. ALL INDIA POWER GENERATION CAPACITY AND ENERGY PRODUCEDIN JUNE 2023

India's target for capacity creation of Renewable Energy was 175 GW by December 2022, which was missed. However, by the end of June 2023 it has surpassed that target by increasing the capacity to 176.49 GW, out of the total power installed capacity of 421.90 GW, which is 41.83% of the total. Compared to this the share of energy generation has been only 23.83% from the renewables. Installed capacity of renewable based (non-fossil fuel based) generators must be increased to 500 GW by the end of 2030 as per the pledge, which seems to be catching up.

Coal based installed capacity of power generators by the end of June 2023 has been 212.52 GW (50.27% of total of 421.90 GW) contributing 72.82% of the total energy generated in June 2023. This indicates that even though the installed capacity of renewables-based energy generators will increase, the load on energy generation will continue to be on the coal-based generators.

Figure-7 shows the All India installed capacity of power generators by the end of June 2023 and power generated in the month of June 2023 by fuel type.

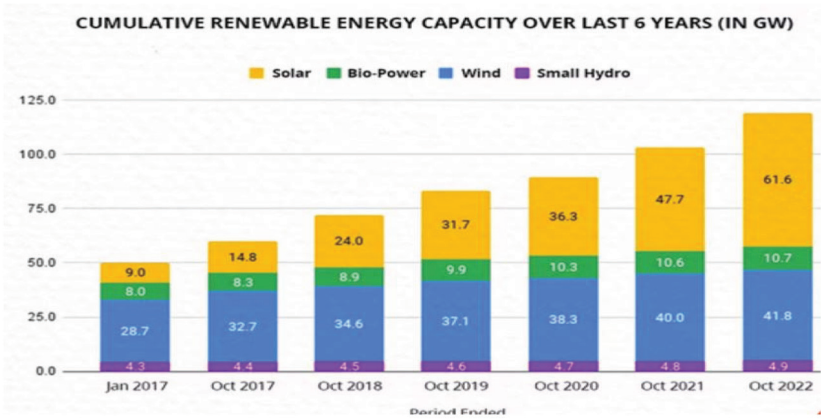


Source – CEA

Figure-7 : All India Installed capacity of Power Generators and Power produced – June 2023

8.1. Growth of RE Installed Capacity in Last 6 Years

In the past 6 years, there has been substantial growth in the installed capacity of renewables based generating capacity creation from nearly 50 GW in January 2017 to 176 GW in June 2023, largely due to increase in solar power from 9 GW to 70.10 GW and wind from 28.7 GW to 43.77 GW (Figure-8). This is also an indicator that the target of 2030 of 500 GW can be reached safely by enhanced drive in solar and wind power.

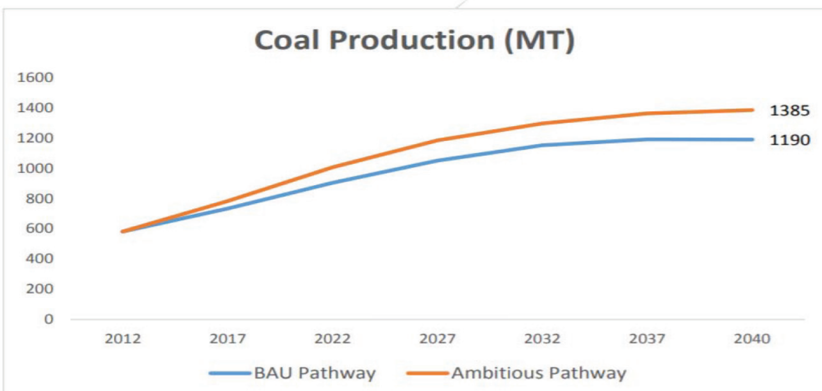


Source - CEA

Figure-8 : Growth of RE Installed Capacity in Last 6 Years

9.0. FUTURE PROJECTION FOR COAL BASED ENERGY PLAN FOR INDIA

The Draft National Energy Policy of 2017, published by NITI Ayog, mentions that the large power requirement and solid fuel demand that the process industries bring to fore the need for efficient exploitation of coal, matching investment in related infrastructure, and a forward-looking regime. Already planned large new coal based thermal capacity is bound to put pressure on coal resources. It further mentions that Coal based power generation capacity is likely to go up to more than 330-441 GW by 2040. This is likely to reflect into a coal demand of 1.1-1.4 billion tonnes per annum. As per this assessment, at high rates of coal demand, domestic coal supplies may plateau by the year 2035 (Figure-9).



Source : Draft National Energy Policy, 2017

Figure-9 : Domestic Coal Demand

The overall coal demand for the country was estimated to be at 1300 – 1900 MT by 2030, as per the Coal Vision 2030 document of Ministry of Coal.

The National Electricity Policy, 2021 also highlights the role of coal in electricity generation. On thermal generation it clarifies that while India is committed to add more capacity through non-fossil sources of generation, coal-based generation capacity may still be required to be added in the country, as it continues to be the cheapest source of generation, though compliance to stricter environmental norms remain a challenge, particularly in older stations. The Policy stresses that all future coal-based plants should only be of Super Critical/Ultra-Super Critical technology or other more efficient technology.

10.0. GOVERNMENT PLANS FOR ENERGY STORAGE SYSTEM FOR RE

Energy mix for India is set to undergo a transition from fossil fuel sources to non-fossil fuel-based sources, dominated by Renewable Energy (RE), in the future. However, the incorporation of a significant amount of variable and intermittent RE into the energy mix poses a challenge for maintaining grid stability and uninterrupted power supply. Power generation from the conventional energy sources as coal, hydro (with storage), nuclear can be controlled and can meet any fluctuation in the power demand in no time. However, the same is not the case with Renewable Energy (RE) sources as these are to be used instantly, and in case they are not utilised they will be lost forever.

Energy Storage Systems (ESS) is a means for storing energy available from RE sources to be used at later times of the day. Storage of energy helps in bringing down the variability of generation in RE sources, improving grid stability, enabling energy/ peak shifting, providing ancillary support services, and enabling larger renewable energy integration.

A National Framework on Energy Storage System (ESS) has been issued by the Government of India in August 2023 to encourage the adoption of Energy Storage for ensuring an environmentally sustainable and financially viable power sector.

10.1. Estimation of Energy Storage Requirement

As per National Electricity Policy (NEP), 2023 the energy storage capacity requirement is projected to be 16.13 GW ((7.45 GW Pumped Storage System (PSP) and 8.68 GW Battery Energy Storage System (BESS)) in the year 2026-27, with a storage capacity of 82.32 GWh (47.6 GWh from PSP and 34.72 GWh from BESS).

For the year 2029-30, the energy storage capacity required is likely to be 60.63 GW (18.98 GW PSP and 41.65 GW BESS) with storage of 336.4 GWh (128.15 GWh from PSP and 208.25 GWh from BESS) and by the year 2031-32, this requirement is expected to increase to 73.93 GW (26.69 GW PSP and 47.24 GW BESS) with a storage capacity of 411.4 GWh (175.18 GWh from PSP and 236.22 GWh from BESS).

For the longer term, CEA projects the requirement of energy storage by the year 2047 to increase to 320 GW (90GW PSP and 230 GW BESS) with a storage capacity of 2,380 GWh (540 GWh from PSP and 1,840 GWh from BESS).

10.2. Capital Required for ESS

CEA has estimated that in order to develop the above storage capacity during 2022-27 the fund requirement for PSP and BESS would be Rs. 54,203 Cr. and Rs. 56,647 Cr. respectively. Further, for the period 2027-2032 the estimated fund requirement for PSP and BESS would be Rs. 75,240 Cr. and Rs. 2,92,637 Cr. respectively. This shows that an investment of the order of Rs. 4,78,727 Cr would be required by 2032 itself. No estimate has been indicated for the period 2047.

11.0. FUTURE PATH SET IN THE COP26 AGREEMENT

The agreement reached at the end of the COP 26 Summit sets the global agenda on climate change for the next decade:

11.1 Emissions

- Countries agreed to meet again the next year to pledge further cuts to emissions of carbon dioxide (CO_2).
- This is to try to keep temperature rises within 1.5°C - which scientists say is required to pre-

vent a "climate catastrophe". With the current pledges, the global warming could be limited to about 2.4° C.

11.2. Coal

- For the first time countries agreed to reduce usage of coal.
- However, the agreement was on a weaker commitment of "phasing down" rather than "phasing out" coal after intervention by China and India.

11.3. Phasing out Inefficient Subsidies to Fossil Fuel

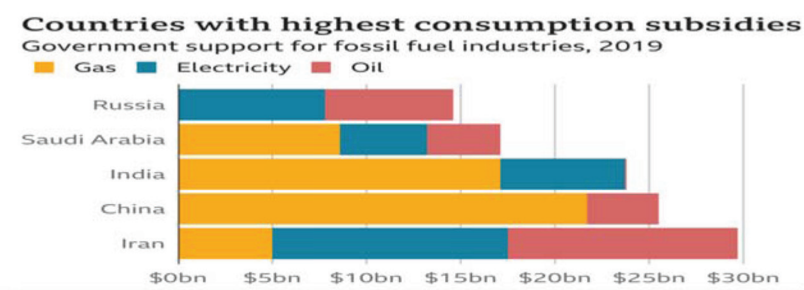
- There was an agreement amongst the world leaders to phase-out "inefficient" subsidies for fossil fuels.
- The agreement called on all countries to accelerate the phasing-out of "inefficient" subsidies for fossil fuels. However, no firm dates were set.
- All countries in the G7 have previously committed to phase out "inefficient" fossil fuel subsidies by 2025.
- An "inefficient" subsidy is defined by IEA as an action that encourages wasteful consumption.

11.4 What are fossil fuel subsidies?

Governments resort to fossil fuel subsidies by artificially lowering the price of coal, oil, or natural gas. These take two forms:

- Production subsidies –by tax breaks or direct payments to reduce the cost of producing fossil fuels
- Consumption subsidies –by cutting down the energy prices for consumers, such as setting fixed prices at petrol stations

In India, the subsidy on fossil fuel is on electricity and oil & gas only (Figure-10). Coal is rather loaded with extra taxes that make the energy cost higher, yet lowest compared to its counterparts. Transparency on fossil fuel funding is generally poor, but about three-quarters of the world's subsidies are estimated to be focused on consumers, and only a quarter on producers. The following chart shows the countries with highest consumption subsidies.



Source : IEA

Figure-10 : Countries with Highest Consumption Subsidies

12.0. ACTIONS REQUIRED FOR CONTINUING USAGE OF COAL IN FUTURE

Several actions are required for continuing usage of coal in the future. Coal has to compete with other sources of energy generation both environmentally and economically. Cost of power generation from renewables has been decreasing over the years and has come to a level much lower compared to that from fossil fuel. The daunting task for coal is the cost of carbon removal. Entire chain of coal sector players, ie., producer, transporter and user has to work together to make coal based energy cost competitive with renewables, including the cost of carbon removal, that is carbon capture and storage.

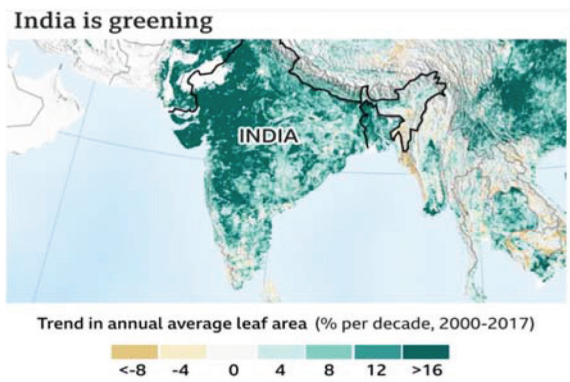
12.1. Carbon Capture and Storage Initiatives in India

The greenhouse gas emission footprint of coal-fired power generation could be reduced by carbon capture, utilisation, and storage (CCUS). India has created a programme for CCS and is interested in promoting it through Mission Innovation. Several oil and gas companies, including ONGC, are investigating the potential for CO_2-based enhanced oil recovery and NTPC is interested in CCS.

R&D in CCS is being pursued by CSIR laboratories and academic institutions under the programme initiated by the Department of Science and Technology. As part of Mission Innovation, initiation has been made for funding opportunity in the Carbon Capture Innovation Challenge for joint R&D in the field of CO_2 capture, separation, storage and CO_2 value-added products to be taken up jointly by Department of Biotechnology and Department of Science and Technology with member countries of Mission Innovation. Large areas of our subcontinent may not be suitable for onshore CO_2 storage due to high seismic activity and population density, and any CO_2 storage activity would need to protect subsurface aquifers, which are vital source of ground water for drinking and agriculture.

12.2. Greening of the Country

One of the actions identified in the country's National Determined Contribution (NDC) under the Paris Agreement sets out plans to create an additional carbon sink of 2.5-3 billion tonnes of CO_2 equivalent through additional forest and tree cover. NASA Earth Observatory also indicates that India is greening (Figure-11). Although, there have been replanting initiatives in the western parts, the north-eastern region has lost forest cover in recent times. With an aim to plant enough trees by 2030, it may be possible to absorb additional 2.5-3.0 billion tonnes of CO_2 from the atmosphere.



Source : NASA Earth Observatory

Figure-11 : Trend in Annual Average Leaf Area Increase/Decrease

13.0. CONCLUSIONS

The Net-Zero Pledge of India necessitates its energy mix to undergo a transition from fossil fuel sources to non-fossil fuel-based sources dominated by Renewable Energy (RE) in the future. Energy Storage Systems (ESS) can be used for storing energy available from RE sources to be used at other times of the day, for which massive investment is required. Investments in carbon removal techniques are also necessary to keep continued usage of coal. The different pathways assessed by the IPCC to achieve 1.5^{0} C by 2050 rely on carbon removal to some extent. Though, futuristic energy demand increases warrant huge investments in both sectors, i.e., fossil fuel based and RE based energy, the ultimate choice will hinge upon the most economic and dependable supply system. Just transition is another issue that will require to be addressed, as in India, currently most of the economic activities are dependent on coal and other fossil fuels.

Different estimates show different amount of coal requirement for the future. World pressure for making all countries carbon neutral between 2050 and 2070, puts a huge challenge on coal and other fossil fuel usage to continue for long. While in the near future terms the requirement of coal may increase by, say up to 2040, in the longer terms it all depends on the progress made in carbon capture, storage and its utilization with its cost competitiveness with renewable based energy generation and the extent of greening the country by massive plantation.

Keynote Paper

GROWTH BY MERGERS AND ACQUISITIONS ROUTE

By Dr. N. K. Nanda

Abstract

Acquisition and Merger activity in the global mining industry is not only necessary but also desirable as consumers stand to be benefitted from industry consolidation in the way of better and more reliable service, product-quality and increased R&D efforts. We have already seen the impact of such activities in the steel industry, and more mergers and consolidations will certainly occur during the next five to ten years. Consolidation within the steel industry in unavoidable and even necessary. Changing technology and the merging global steel industry will mandate that strategic combinations and capacity rationalization occur. The acquisition of Essar Steel by Arcelor Mittal and Nippon combine will definitely bring the efficient operation practice and better technology to Indian steel Industry.

Theoretical orientation of the current narration revolves around various reasons behind the world drive for acquisition and mergers, rational behind it and process of the same. Before barking upon any business deal, Economic evaluation of mining property. Greenfield or brown field mining properties are endowed with different advantages and disadvantages which must be chosen carefully after 360-degree evaluation on the above parameters. Once the due-diligence and economic evaluation of the property is completed, business transactions are materialized based on mutually agreed deal structure. In the M&A, there is no single best acquisition models/deal structure. It broadly depends on the buyer and seller perspective and what they intend to make out of the deal and their financial capabilities.

Indian mining industry cannot remain aloof from the events happening in the world scenario. The leading mining organizations in India are constantly making efforts in this regard to increase their production capabilities to become more competitive through rationalization and consolidations through acquisition and mergers not only at domestic arena but also at global front.

This paper deals with the rationale of acquisition and mergers of mining properties, various aspects of the due diligences, economic evaluation of the property and various deals structures/models of acquisition and mergers.

Keywords : Mining, Mergers, Acquisition, Steel

INTRODUCTION

1. WHY ACQUISITION AND MERGERS?

A) The cross-border trade and investment has become more feasible by using the state of art technology and reduction in cost in transportation and communication.

B) Trade negotiations have opened up markets by removing not only tariff barriers but also non-tariff barriers in both goods and now services.

C) The companies have become more competitive by enhancing the horizon of the market beyond the local market turning organisations global entities through, often, private investments.

D) It is profitable to expand in the present changing global environment.

E) In the present atmosphere the more you are bigger the less is the operation cost as the re-

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dundancy automatically shrink due to multiple use of the same resource.

F) The company vision is to see the future not that in good times to look at the upside only rather reparation to be afoot to control the lower side.

G) It has been seen in in many merger and acquisition that the labor productivity has increased substantially.

H) It is also seen after merger or amalgamation of companies the combined synergy between management and labor force has dramatically improved.

2. CONCERNS NEED TO BE ADDRESSED WHILE GOING FOR ACQUISTION

- **Strategic fit of assets**

I) The company who plans for an acquisition analyses the parameters which enable it to understand it's need and the positive points or the synergy which the new asset will bring to his company and the compatibility factors strategically fitting to his requirement for growth or not. Thus, identifying strategic fit of asset is first and foremost condition for any organization Similarly if we see the steel production, iron ore mining is a low cost affair and a steel company with an iron ore mine is more competitive in comparison with companies who purchase iron ore thus prompting the steel companies to aggressively make effort to acquire an iron ore mine as strategic fit asset.

- **Technical due diligence of property**

Once a strategic decision is arrived at for acquisition of an asset the first and foremost action to be taken is the due diligence of the asset. In case of a mining property the due diligence is much more important because some part of the valuation depends solely on projection of the unseen potential. The quality and quantity of the reserves, the stripping ratio and many other geotechnical parameters needs to be identified way before to reach a proper valuation. In some mining acquisition the available data may have to be supplemented with more information to avoid wrong interpretation of the reserve in both plus minus side.

3. STATIC METHODS

- **Profitability Quotient**

A simple profitability quotient is the ratio of operating profit (OP) and Investment (I). This applies when, instead of buying a deposit directly, someone buys shares in a company controlling the deposit and expects annual dividend form the company.

- **Payback period**

For any investment it is necessary to know the payback period. Considering the mining projects needs initial development to make it operative the payback period may be little longer than any other acquisition. In such circumstances the everyone looks for a shorter pay back period in high risk countries than stable countries.

- **Dynamic methods**

➘ **Cash flow calculations**

The true value of an asset is measured from it's cash flow. It is calculated for a year with a simple assumption that all cash flow are due at every year end.

➘ **Net Present Value (NPV)**

When applying the net present value method, the net cash flows (NC) are discounted at a given interest rate and investments deducted from the sum of the discounted net cash flows. The NPV indicates to the investor the value of a potential investment in a deposit not yet in production by taking the following factors in to the consideration :

- Investment,
- The individual annual net cash flows,

- The date for the net cash flows determined by the discounting factors as a function of the year, in which the cash flow is due,
- The risk inherent in the investment at the chosen rate.

The Net present value is based on the opportunity cost principle - economic assets will be acquired and put to a particular use in production, assuming rational behavior, if their discounted expected net returns exceed the discounted returns from any other investment option available.

Broadly speaking, there are three steps in the NPV estimation of resource rent in the current period. This then needs to be projected into the future. Finally, the set of future resource rents must be discounted to a value in the present period.

Resource rent can be estimate by factoring out an estimate of the return to produced capital (i.e. that element of the economic rent that represents the return to produced or manmade capital) form the net operating surplus. The return to produced capital can be estimated by applying an appropriate rate of interest to the stock of produced capital

Assessing the value of the asset

Once the unit resource rent has been estimated, the value of the resource can be estimated as the discounted net present value of the future stream of rents that the resource will yield until it is exhausted. The resource value is thus a function of the unit resource rent, the years the resources is expected to last until exhaustion and the rate of discount, assuming that the rate of extraction remains constant, the value of the resource rent in constant price terms cab be written as follows :

$$RV = RR \sum 1/(1+r)^2 = \left\{ \frac{RR\,(1+r)^2-1}{r(1+r)^2} \right\}$$

Wnere,

RV: Value of the resource;

RR: Resources Rent;

n: life of the deposit in years.

This in turn can be expressed as S/E where S is the stock of the resource in physical term and E, the annual rate of extraction, assume to remain constant; and r the rate of discount.

Resource Rent

Resource rent is estimated as a residual GOS (gross operating surplus) after adjusting for consumption of fixed capital and return produced capital.

Life of the resource

The life of the resource is estimated as the reserve (including new discoveries) production ratio. In other words, the life of resource each year may be calculated as existing stock less production level plus free discoveries divide by the volume extracted.

Rate of discount

The rate of discount expresses a time preference for income today rather than in the future. This will depend on the ownership of the asset. In general, individuals and business will have higher rates of time preference than governments. It is argued that a social rate of discount, closer to zero, better considers inter-generational equity and should be used to derive the net present value.

Internal Rate of Return(IRR)

The IRR of a potential mining project is the discounting rate of cash flows which equals the total investment and discounted cash flows of the project. Generally, IRR of more than 15-20% may be considered for acquisition of the properly. Many early stage investor target a 30% net IRR while later stage investor target a net IRR of around 20%.

1: IRR of the project

A typical template for cash flows which will serve the basis of IRR calculation is provided at Table 1.

Table 1. Cash flow Template

S.N	Particulars	Year Wise data
A.	Cash inflows	****
1.	Profit/loss before tax	****
2.	Add. Depreciation/DRE	****
3.	Add. Interest on loan	****
4.	Salvage value	****
	Total cash in flows (A)	****
B.	Cash out flows	****
1	Total project cost	****
2	Less: Interest during construction	****
3	Net capital outflow (1_2)	****
4	Replacements of cap assets	****
	Total cash out flow (B)	****
C.	Net cash flow before tax	****
D.	Income tax	****
E.	Net cash flow after tax	****

The value summed at the row E, i.e. Net cash flow after tax known as NPV of the project, when discounted at a rate at which the NPV becomes Zero will be IRR of the project.

Other Methods of Valuation of Mineral Resources

- **Net Price method**

  The net price method is a simplified version of the NPV method in which the value of a resource at the beginning of a period is estimated as the volume of the proven reserve times the difference between the average market value per unit cost of extraction, development and exploration (including a normal rate of return on invested produced capital).In the case of non-renewable resources, this stock comprises only the 'proven reserves that are exploitable under present economic conditions, and therefore have a positive net price' (Bartelms et al. 2001). The net price method is based on the Hostelling rent assumption i.e. in a perfectly competitive market the net price of a natural resource rises at the rate of interest of alternative investment, offsetting the discount rate.

4. ACQUISTION MODELS

In the M&A, there is no single best acquisition models/deal structure. It broadly depends on the buyer and seller perspective and what they intend to make out of the deal and their financial c apabilities.

- **Equal control but no majority stake: 49-49-2**

  In this type of acquisition, the buying and selling company does not have the controlling stake and even the seller does not become a minority. A suitable arrangement is framed by introduction of financial investor to acquire 2% of the shares and manage the company. Further, this model is suitable for Public-Private Partnership where the structure prohibits total control to the private company.

- **Equity contribution but higher capex funding**

  These types of deals are mainly done in case of developmental projects in mining. The owner of the mineral concession carries out preliminary work and raises the EV of the company. The buyer enters in the development phase on the project by providing reasonable equity share in the company. The acquirer has to pay not only for the equity but has to fund the project totally in stages as per agreed terms. The model illustrates a higher contribution in the project than the equity in the project.

- **No entry cost model**

  In the M&A for Mining deals, the strategic investor is very important for the success of the project. The project developer who is not active in the mining space tries to rope in big mining company. The investor matches with the contribution made till date on the project to bring out the project in production stage. This is typically no entry cost model with an equity share in the company.

- **Leverage buyout model**

  In acquisition by strong/resourceful company, the buyer acquires its equity but does not pay for it fro.im its balance sheet. The equity is arranged by loans and the sum is amortized by the dividend and receipts from the target company. Further equity dilution is resorted to payback the debt as the valuation of the target company increases.

- **Big fish model**

  Suppose a Company-A has a mining property which is regionally explored and the results are positive projecting the proposed property having good potential of becoming a viable mining project. Company does not have the adequate financial health to further invest in this property and wants to have a joint venture with another Company-B having good financial position and expertise in exploration and mining. The deal between them may be struck on the following terms:

  - Company-B will further invest in the property right from the detailed exploration, feasibility report preparation up to commissioning of the project
  - There shall be a shareholding agreement in which both the companies will have 50:50 stake.
  - The agreement shall include a clause that if Company-B, the price of the share will he previously evaluated and mutually agreed upon.

  If Company-A wants to sell its stake to another company, it will sell only 49% and the balance 1% has to be provided to Company-a free of cost sot that management control will rest with Company-B.

- **Opportunistic model**

  Company-A has a mining property. The company has initiated exploration and developed it up to a particular stage and stopped the venture for want of extra capital infusion. Now company-B enters in to agreement with company-B and intended to invest further to bring the property into the state of production. The deal between them may be struck on the following terms:

- The major portion of the profit out of sales of the product will be taken by Company-B towards its major contribution in CAPEX required for bringing the property in to commissioning and production stage. This will continue till its portion of the investment is paid back with interest.
- Afterwards, the profit will be shared equally, i.e. 50:50 between both the companies.

➘ **Royalty model**

In this model, seller and buyer enters in to a long term agreement. The buyer gives the seller the acquisition cost derived on the basis of Enterprise Value (EV) and agrees to shell out some percentage of royalty for long term on mutually agreed terms and condition. The advantage of this model is that the seller also becomes accountable for the better performance of the mining project as the more output provides more royalty to the seller.

5. ACQUISTION OF GREENFIELD PROJECTS

A greenfield project is most sought-after object for acquisition as the organization which acquires such an asset is not affected or constrained by any previous infrastructure.

The new organization is at liberty to plan and execute his project without much obstruction. The Foreign Direct Investment always aims for green field projects or investment in green field project. In such cases the organization hires new employees from the local area where the greenfield projects take off.

Multinational companies like enter developing countries through greenfield projects and very often the developing country offer tax- breaks and subsidies against the creation of employment and give a boost to the human capital of the country.

➘ **Investment Strategy in Greenfield Project**

➘ **Market Understanding**

➘ **Understanding Government Policy**

- Licensing
- Incentives offered by State & Central Government
- Understanding of Applicable Taxes
- Impact of Regional Trade Agreements viz.WTO

Demand Supply Scenario

- Market potential
- Existing and Emerging Products Market study
- Analysis of Major Players-Production capacity, Financials, Supply Chain Management, Strengths and Weakness
- Must be based on long-term market fundamentals-"tomorrow's market, not today's"

➘ **Economic Matters**

- Usually higher capital cost, often driven by significant infrastructure requirements
- High NPV
- Long terms payback horizon
- Essential that these project be "armor-plated" ideally in the lowest quartile of the cost spectrum.

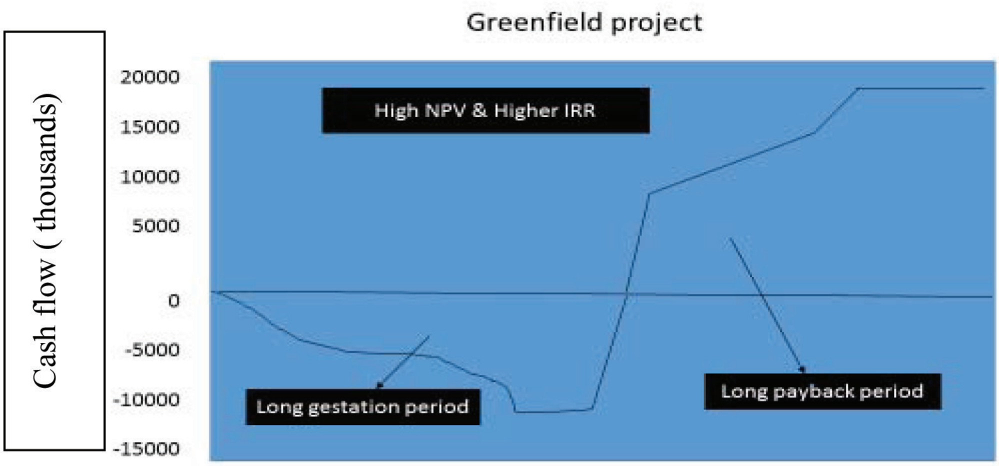

Fig 1 : Cash Flow

6. ACQUISTION OF BROWNFIELD PROJECTS

In spite of negative points which are weighed against any brown field projects there are numerous examples of acquisition of brown field projects. The negative points are that a brown field projects are already possessing many infrastructure and operation processes which may not be fully required for economic exploitation. However, the positive points are that the company if completes a brown filed project similar to previous operation then it stand gained as its capacity increases with very short period. Below we are discussing the pros and cons of acquisition of a brown field project

What affects the planning process?

- Understanding objective for acquisition
- Defining selection criteria
- Preliminary investigation of the potential target companies
- Determine "Best Fit" target
- Entering into Memorandum of Understanding
- Conducting valuation of target company
- Conduction financial and legal due diligence
- Negotiations with promoters of target company
- Advice on Transaction Structuring
- Executing Share Purchase agreement

Typical Project Attributes

- Quick to complete- aim to capture the current market opportunities
- Relatively low capital expenditure
- Leverages existing infrastructure

Typical Financial Attributes

- Short term horizon
- High Rates of Return
- 1-2 year payback expected

Decisions on these types of expansions are made based on the current market environment and consequently and exceptional cost structure is not a vital consideration.

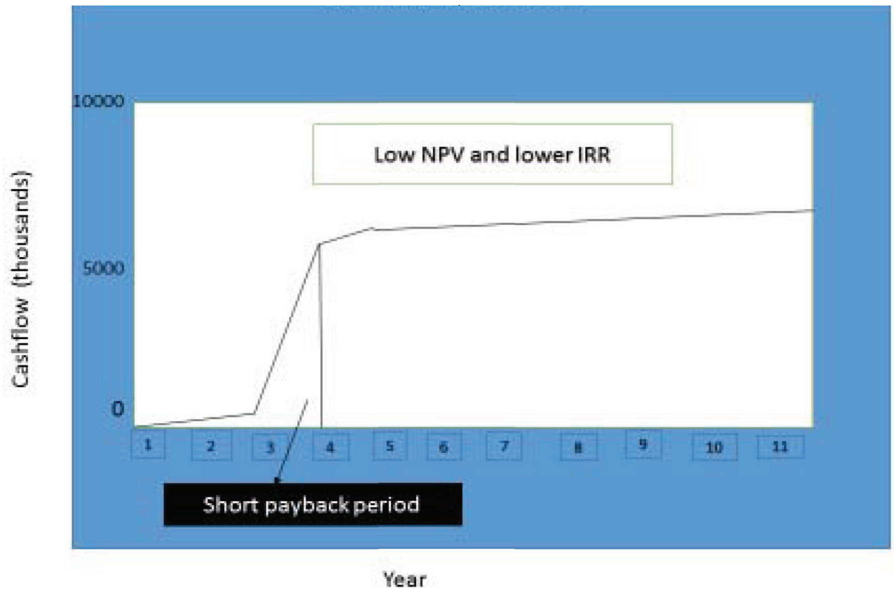

Fig 2 : Brownfield Project

Greenfield vs Brownfield

- **Gestation period**

  It is relatively very high in case of Greenfield mining projects. It takes a lot of time for the mining project to start giving any kinds of return.

- **Risks**

  Risks related to ore quality, mine management issues, geology, etc. are much less in brown field mine as the mine has a baseline (historical) data to form the basis of (and authenticate) further calculations.

- Personnel training

  The requirement for training and scouting for personnel is very less in brown field mine as compared to a Greenfield one.

- **Ease of acquisition**

  Greenfield projects are much easier to acquire as compared to brownfield projects. In addition to this since, brown field projects are usually in high demand, the (remaining) candidates available for acquisition are most probably facing some kind of problem.

- **Complexity in acquisition**

  Brownfield acquisition is a much more complex process as compared to Greenfield one. Various issues and factors like, liabilities, employee retention and welfare, financial/commercial/legal/tax due diligence exercises, etc. have to be looked into. An international brownfield acquisition may also face some regulatory hurdle in the context of welfare of local labor, domestic supply security (of the produced mineral), etc.

- **Regulatory permissions and approval for set-up/expansion**

  They are much easier to obtain in case of brownfield projects.

- **Commissioning the latest technology/ process**

  The Greenfield projects are more amenable to installation of latest technology and processes as unlike brownfield projects they don't have some inherent constraints/ limitations.

- **Fulfilling long term objectives**

  Greenfield projects are much better suited from the long-term perspective as they can be designed from scratch with due consideration to long term objectives and needs. In brownfield projects design and efficiency needs have to be generally compromised to suit existing constraints.

Table 2. Summary of comparison between Greenfield and Brownfield projects.

Description	**Greenfield**	**Brownfield**
Gestation period	High	Low
Risk	High	Low
Ease of acquisition	Easier	Problematic
Need of training to human resource	High	Less
Regulatory permissions and approval	Problematic	Easier
Commissioning the latest technology	More amenable	Less amenable
Long term objectives	Better suited	Has to be compromised

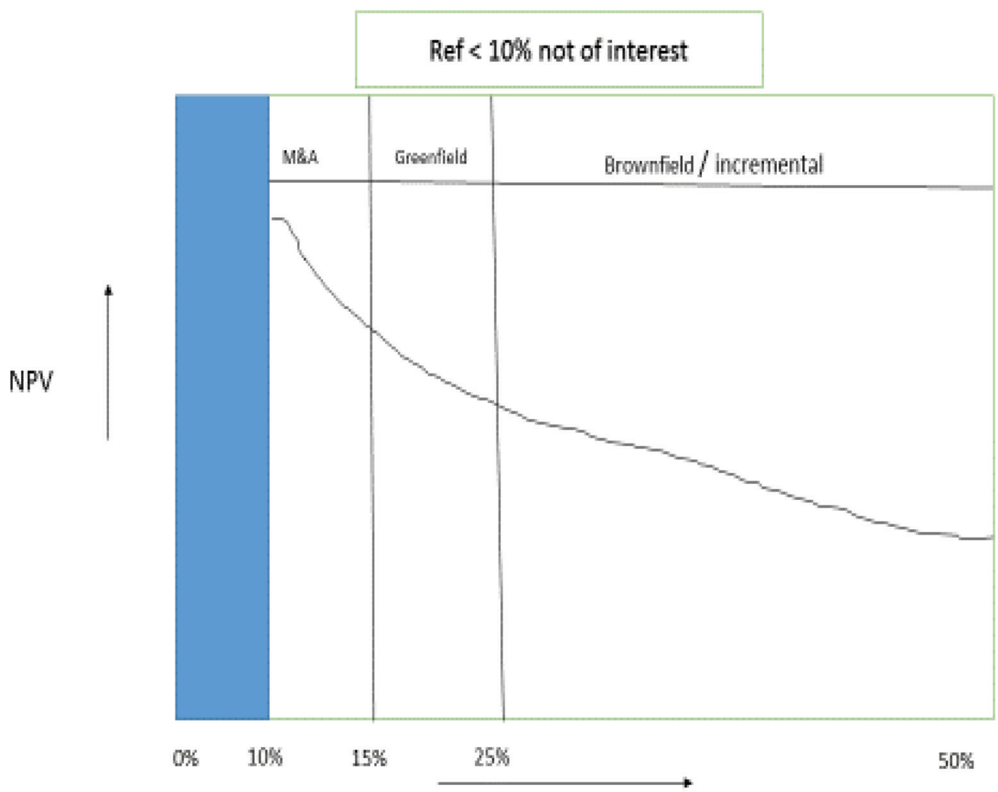

Fig 3. NPV vs rate of return

7. ACQUISITIONS IN MINING

The acquisition in mining mostly targets entrance in to new area or potential area for future. The acquisition of Coking coal blocks by ICVL in Mozambique and magnetite blocks by NMDC in Western Australia are examples of acquisition for security of raw material and potential future growth respectively. The recent decision of Govt. of Odisha to merge all small state PSUs dealing with either mining and mineral beneficiation or exploration to be merged with the most progressive company of Odisha that is Odisha Mining Corporation is an example how industry is positively adopting this route to consolidate growth.

8. CONCLUSION

In the present modern world of electric vehicle, the acquisition of lithium projects is more lucrative and many large companies are seeking to acquire both greenfield and brown filed lithium assets. Apart from that tungsten is another metal which is mostly required in defense application is also another most attractive object for acquisition.

India cannot remain aloof from the events happening in the world scenario. The leading mining organizations in the world have increased their production capabilities to become more competitive through in-house rationalization and consolidations through acquisitions and merges. Consolidations through acquisitions and takeovers lead to increased production capabilities, diversifications of resources, products and markets, thereby increasing the customer base and competitiveness both external and internal.

Keynote Paper

THE PATHWAYS FOR COAL TRANSITION AND NET ZERO EMISSION

Prasanna Kumar Motupalli*

Abstract

Climate change is characterized as a global warming effect that leads to large-scale irreversible effects at continental and global scales due to emission of GHG such as CO_2, CH_4, NOx and O_3. Coal sector is one of the major emitters of carbon dioxide accounting to about 51%. Climate change is disrupting national economies and affecting lives and livelihoods. Weather patterns are changing, sea levels are rising, and weather events are becoming more extreme bringing massive Wildfires, Hurricanes, Droughts, Floods, Water scarcity, Melting polar ice, Catastrophic storms, and declining Biodiversity.

India's per-capita electricity consumption was 1255 kWh during 2021-22, which is around one-third of the global average of per capita electricity consumption. Total energy is considered as indication of development of country and the same is very less in India compared to world average. There is an urgent need to improve the same for which coal/lignite sectors must grow by mitigating the impacts of climate change.

Climate change postulates transition to take place from coal-based energy production to renewable based in a justifiable pathway to achieve Net-Zero emission. India has selected a middle path which aims to pursue a balanced growth based on the principles of Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC). India's roadmap for net-zero emission is emphasized through Panchamrit climate action by 5 goals to reach Net zero by 2070.

At the same time to ensure proper integration of Renewable energy, coal and lignite based thermal process generation continue to play a major role as per India's vision document 2047. A balance is to be maintained to ensure development and sustainability go hand in hand.

This paper details about vulnerabilities caused due to Coal transition, Priorities of Just Transition and its related action areas to be implemented in achieving the Net-zero emission. Also, the paper deals with NLCIL Net zero goals, Coal transition plans which will reduce Carbon emission in line with the National ambition.

The paper also discusses on the implementation strategy of NLCIL on repurposing of mined out lands in line with Just transition principles by establishing Solar plants on mined out areas, Eco-restoration, Reclamation, massive Afforestation programmes, introduction of Clean Technologies, Low Carbon Intensity plans, Energy Efficient system, Waste Utilization which aims at sustainable development towards net-zero emission.

In view of the global climate change, compliance of International Conventions on environment and in line with the India's commitment on global climate change, NLCIL is increasing its capacity in renewable energy to 6071 MW by 2030 through various Solar, Wind power plants. NLCIL is planning to establish clean technologies like lignite to Methanol, use of electrical vehicles, battery storage systems, Lignite to Diesel, Lignite to Gasification and OB to M-sand.

This paper highlights the sincere efforts required to strategize the future scenario for ensuring power to all for development of Nation with co-existence with mother earth.

Keywords : *Climate change, CO_2 emission, Carbon footprint, Coal transition, Net-Zero emission, Carbon capture utilization and storage.*

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1. INTRODUCTION

Global Climate Change : Climate change is characterized as a global warming effect that leads to large-scale irreversible effects at continental and global scales. Greenhouse effect is caused by greenhouse gases (GHG) that trap heat in the earth's atmosphere, a natural phenomenon that keeps the earth warm. The primary greenhouse gases in Earth's atmosphere are Carbon dioxide (CO_2), Methane (CH_4), Nitrous Oxide (NOx), and Ozone (O_3).

Carbon dioxide (CO_2) levels and other Greenhouse Gases in the atmosphere rose to new records which places 2009-2019 warmest decade and 2020 as one of the three warmest years on record globally. Climate change is disrupting national economies and affecting lives and livelihoods. Weather patterns are changing, sea levels are rising, and weather events are becoming more extreme bringing massive wildfires, hurricanes, droughts, floods, water scarcity, melting polar ice, catastrophic storms, and declining biodiversity.

International Conventions on Climate Change: In this context, countries around the world reached an agreement in COP21 held at Paris to mitigate the global increase in climate temperature below 2° Celsius which show the possible catastrophic effect due to climate change and need urgent action to address the need of the hour. In view of this, the core objective of the COP26 held at Glasgow, UK is "wiping off footprints" of both developing and developed countries, to reduce the negative environmental impacts.

Need for Concern: Coal sector is one of the major polluting industries which require serious attention worldwide for alternative renewable energy. Coal based power plants have built the most economies globally, but the major cons are the emission of CO_2 which needs to be reduced rapidly to achieve climate objectives successful for climate change mitigation. Achieving this context demands major research and innovative scientific solutions, financial resources etc.

Many emerging and developing countries like China and India are experiencing rapid growth in energy demand and the peak production will be probably between 2030 to 2040. In view of serious threat to mankind due to climate change impact, there is need for concerted action including downsizing the fossil fuel-based plants/establishments and shift to renewable energy.

Need for Action : Climate change postulates transition to take place from coal-based energy production to renewable energy based in a justifiable pathway to achieve Net-zero emission. India's climate change action and Panchamrit's commitment leads to process stress for low carbon and climate friendly technologies. Transition from coal to renewable energy may result in reduction in coal mine capacities, closure of existing coal mines and coal based thermal power plants in near future. For Just Transition in Coal Sector to be successful, efforts to be made that no one shall be left behind and all communities/Stake Holders to be taken care.

Net-zero emissions, or "Net Zero," will be achieved when the overall emissions released by anthrophonic activities are neutralized by removing CO_2 from the atmosphere. Net zero emission can be achieved through following two major approaches.

i. Emissions from man-made activities such as energy from fossil-fuels, other industries etc. should mitigated through alternate **Renewable energy sources.**

ii. Remaining emissions will be neutralized through **Natural resources** like afforestation, creation of carbon sink, carbon capture utilization and storage techniques.

India's Commitment on Climate Change: Honorable Prime Minister of India expressed country's roadmap at the 26th session of the Conference of the Parties (COP26) to the United Nations Framework Convention on Climate Change (UNFCC) to intensity our country's climate action through Panchamrit by presenting the five nectar elements to the world. This is achieved through Nationally Determined Contribution (NDC) which envisages the Panchamrit action to achieve the long-term goal of reaching net-zero by 2070. India's Panchamrit of climate change consists of the following targets.

1) Increase in non-fossil fuel capacity to 500 GW by 2030.
2) Achieving 50% of the cumulative electric power capacity from non-fossil fuel-based energy resources by 2030.
3) Reduction in carbon intensity of economy by 45% by 2030.
4) Projected total carbon emission reduction by 1 billion Tonnes.
5) Achieving net zero by 2070.

2. COAL TRANSITION AND NET-ZERO EMISSION

India's Energy Mix

Indian coal sector plays a crucial role in the economy and energy department of the country.

India is the world's third largest electricity producer with an installed capacity of 416 Giga Watts and annual generation of 1624 billion units (*Ministry of Power, April 2023*). Fossil fuel sector currently accounts for approximately 57% of the total generation and dominates India's energy generation mix as shown in Table 1.

Table 1 India - Power generation capacity (MW) – April 2023

Category	Installed Generation capacity (MW)	Total Share in %
Fossil Fuel		
Coal	2,05,235	49.3%
Lignite	6,620	1.6%
Gas	24,824	6%
Diesel	589	0.1%
Total fossil fuel	**2,37,269**	**57%**
Renewable		
Hydro	46,850	11.2%
Wind, Solar & other RE	125692	30.2%
Wind	42868	10.3%
Solar	67078	16.1%
BM power/Cogen	10248	2.5%
Waste to energy	554	0.1%
Small hydro plant	4944	1.2%
Nuclear	6780	1.6%
Total Non-fossil fuel	**1,79,322**	**43%**

Approach to Coal Transition and Net-Zero Emission :

Any deviation in the demand and supply patterns that result in a coal shortage would have a cumulative effect on our country's economy. During the year 2019, India's per capita consumption of coal was half of the world's average consumption. In view of the importance of coal in India's energy mix, following are the approaches to coal transition and net-zero emission.

i. India has selected a middle path which aims to pursue a balanced growth based on the principles of Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC). Therefore, instead of a singular focus on lowering coal consumption, the key element for overall strategy is based on lowering total emissions emitted by the coal-based industries.

ii. The closure of coal-based mines needs a proper scientific and objective manner.

iii. To ensure that the livelihoods of the impacted people are secured.

In order to enhancing these action plans, Just Transition points to justifiable, fair and equitable transition for all the stakeholders impacted by the closure of mines.

2.1 Vulnerabilities arising from phasing out of Coal Mining :

The coal-based economy plays a major role in the country's growth there are various risks associated from the phase out of coal mines which are given below.

2.1.1 Loss in Livelihood

- Coal mining industry employs around 0.5 million people through direct employment and many peoples are indirectly dependent on the coal sector for their livelihood.
- Alternate employment in other sectors cannot be 100% which will have a huge impact on the economy of the coal-dependent communities.

2.1.2 Revenue by Coal Mining

- During 2020-21, royalty and taxes are the major source of revenue for mineral rich states amounting to INR 44.5 billion.
- Average revenue generated based on the coal mines accounts to about INR 66.56 billion for the year 2020-21.

2.1.3 Social & Infrastructural

- Industries has statutory requirement of 2% on the net-profit over the 3 preceding financial years on the CSR activities.
- 70% of CSR budget on developing basic infrastructure in the nearby places through improving their sanitation, building of schools and other public oriented activities.
- Upliftment of women.
- Impact on opportunities and the welfare for children.
- A sense of belonging, attachment, and culture.

2.2 Priorities of Coal Mine Closure on Principles of Just Transition

2.2.1 Environmental Aspect

- To take care of the environmental problems arising during mining operations and those likely to arise during the post-closure scenario.
- To restore "the surrounding environment to a state, resembling as closely as possible which existed prior to the commencement of mining, as measured by both chemical and biological parameters".
- To ensure that environmental restoration is adequate to allow the establishment of a diverse and functional ecosystem in the area.

2.2.2 Socio Economic Aspect

- To protect public health and safety. The design and phasing of the closure must identify and manage the factors that will make for the security and safety of the mine site.
- To assess and manage the Socio-economic issues of mine closure and its impact on local communities, workers and their families and the local economy (i.e., employment, income, services, and well-being of the community in the mining area)

2.2.3 Repurposing of Land

Progressive rehabilitation and re-vegetation of mined out land areas along with appropriate landscaping should be carried out for any future repurposing land use activities like installation of Renewable Energy plants, Eco Parks, establishing any Infrastructure activities etc.

2.3 Action Areas

The following are the major action areas for achieving the just transition and net-zero emission.

I. Accelerate the mass deployment of Clean Technologies and Energies

- Implementation of Solar, Wind and Hydro Power plants to reduce the burden on coal energy production.
- Installing the hydrogen energy-based engines in all the commercial vehicles.
- Conversion of the diesel vehicles into Electric vehicles in all the possible sectors.
- Use of Renewable based energy system in all the office buildings.

II. Support Energy-Efficient and Low-Carbon choices

- **Energy Efficiency**
  - New energy efficient technologies will be adopted in all the sectors of the economy.
  - Phasing out the high energy consumption lights with more efficient LED variants resulting in energy savings.
  - Implementation of smart energy efficiency appliances in the residential sectors.
- **Carbon Pricing**
  - Placing a fee for emitting CO_2 and offering incentives on less CO_2 emissions.
  - Calculation of carbon trading based on the carbon footprint assessment.
  - Generated revenue from carbon pricing can be utilized to compensate the affected communities.
- **Material Efficiency**
  - India's population is increasing rapidly which projected coal demand of 1.5 billon tonnes (BT) by 2030 and will achieve peak by 2040.
  - By 2050, Municipal solid waste generation will create a major impact on cities of around 400 million tonnes per year. Around, 85% of municipal solid waste comprises a mixture of biomass and other combustible materials, offering a potential energy rich fuel. This biomass fuel will be alternate fuel in place of Thermal coal.
- **Consumer and Business choices**
  - Manufacturer ratings for different model and efficiency of domestic appliances are very important for optimizing the energy efficient system.

III. Decarbonization

- **Carbon Capture and Storage (CCS), Carbon Capture and Usage (CCU)**
  - CO_2 typically requires geological storage at depths of two or more kilometres.
  - India requires a national study of deep saline formations and of a depleted oil and gas field to identify effective storage potential.
  - CCU aims to convert the captured carbon dioxide into more useful purposes.
- **Nature Based Carbon Removal Solutions**
  - Expansion of forest cover through large-scale nature-based projects can act as a CO_2 sink.
  - Afforestation
  - Reclamation

IV. Repurposing of Mined-out Areas

Mined out land areas can be repurposed by establishing solar power plants, eco-parks, and infrastructure etc.

2.4 NLCIL efforts on Coal Transition and Net-Zero Emission

NLCIL is operating four Lignite Opencast Mines, Mine-I (8 MTPA), Mine-IA (7 MTPA), Mine-II (15 MPTA) at Neyveli, Tamilnadu and Barsingsar Lignite Mine (2.1 MTPA) at Barsingsar, Rajasthan and Talabira II & III (23 MTPA) Opencast Coal mine at Odisha. Also, NLCIL is developing Pachwara South Coal Project (9 MTPA) in State of Jharkhand. NLCIL has operating 4 lignite based thermal power plants with cumulative capacity of 3390 MW at Neyveli, 250 MW lignite based thermal power plant at Barsingsar, Rajasthan and 1000 MW coal based thermal power plant at Tuticorin, Tamilnadu through joint venture with TANGEDCO. Also, NLCIL is installed Solar Power Plant of 1370 MW and 51 MW wind energy plant. NLCIL is implementing 3x660 MW super critical thermal plants at Ghatampur, Uttar Pradesh and setting up of NLC Talabira Thermal plant of 3 x 800 MW, TPS-II 2nd expansion 2 x 660 MW are under pipeline.

2.4.1 NLCIL efforts on Repurposing Mine Lands

Solar Plants on Mined out areas:

NLCIL is planning to establish solar in its mined-out areas in Mines. As part of India's Commitment to reduce Global pollution, NLCIL is identified 225 Ha of the Mined-out dump areas in Neyveli mines for establishing Solar Power Plants. NLCIL has setting up three plants one each at Mine-I, Mine I-A, and Mine-II. Installation of 50 MW Solar Power Plant in Mine-II mined out area is under progress.

Eco Parks :

- NLCIL always maintains a strong focus on sustainable development goals with conservation of natural resources. NLCIL developed Eco parks over 20 Ha area in Mine I & Mine II mined out areas enriched with lot of biodiversity. Eco parks pictures are shown in figure 1.
- NLCIL has entered MoU with Puducherry Tourism Development Corporation to promote eco tourism and showcase sustainable mining activities and eco parks developed in Mine-I and Mine-II.

Figure 1 Eco Park developed by NLCIL in Mine-I & Mine-II

Reclamation :

- NLCIL has visualized the way to minimize the impacts of mining on land and make it available for alternative use in future by implementing a reclamation process.

- A comprehensive plan to rehabilitate all land disturbed by mining operations has been built during the project formulation stage itself.
- Study on the Development of Hi-Tech Agriculture using Hydroponics for reclamation and afforestation activities are being taken up regularly in Mine dumping yards in all three mines in Neyveli which is shown in figure 2.
- The details of the reclamation in NLCIL mines since inception are furnished below.
  - Physically reclaimed – 2720 Ha
  - Biological reclaimed – 2240 Ha
  - No of trees planted – 29,37,945
- The types of land reclamation and progressive mine reclamation carried out by NLCIL are given in figure 3.
- About 25000 acres of land being irrigated by NLCIL mine water covering 40 villages around Neyveli.

Figure 2 Hi-Tech Agriculture using Hydroponics.

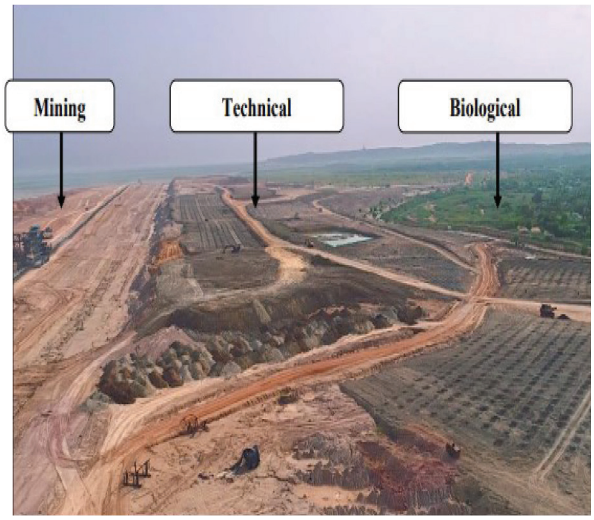

Figure 3 Progressive mine reclamation.

Overburden to M-Sand by focusing on Sustainable Mining & Creation of 'Wealth from Waste':

This initiative is based on promoting sustainable practices for maximizing the utilization of natural resources and bringing back the mined-out lands to its original topography. During

Opencast Mining, the Overburden sandstone is removed as waste to extract Lignite and the overburden is kept in dumps and these overburden dumps will be converted into M-sand which is used as a construction material. Thereby, overburden dumps will be utilized and the same land can be repurposed in future for establishing solar, infrastructure facilities etc. NLCIL plans to establish OB to M-sand plants at Mine-I (6.25 Lcum./year), Mine-IA (2.62 Lcum.year) and Mine-II (6.25 Lcum/year).

2.4.2 NLCIL efforts on net-zero emission

2.4.2.1 Introducing Clean Technologies in line with National Commitment

Renewable Energy:

- NLCIL in alignment with India's Panchamrit has also entered renewable energy sector. Presently the energy generation is about 1370 MW from the Solar Power Plants in various Districts of Tamilnadu and Andaman & Nicobar Islands and 51

MW from the Wind Power Plant in Tirunelveli district of Tamilnadu which is detailed in Table 2. Implementation of solar and wind power plants are shown in figure 4.

- NLCIL is the first CPSE to cross cumulative capacity of 1 GW through Solar Power Generation in the country and also became a member of International Solar Alliance (ISA).
- NLCIL is also aiming to achieve a total cumulative Renewable energy capacity of 6031 MW by 2030.
- A floating solar power plant has been set up at NNTPS Lake with a capacity of 200 kW was successfully implemented.

Table 2 Renewable energy projects implemented by NLCIL

S. No.	Project Name	Capacity	Remarks
1.	Tamilnadu solar power	709 MW	Across Tamilnadu
2.	Tamilnadu solar power	500 MW	
3.	130 MW Neyveli solar power	130 MW	Synchronized with the grid in Neyveli.
4.	Andaman solar power	20 MW	Provided with battery energy storage system.
5.	Neyveli solar power	10 MW	Synchronized with the grid in Neyveli.
6.	Neyveli top roof solar power	1.06 MW	Provided on non-residential buildings in township
7.	Wind	51 MW	Commissioned in Southern Tamilnadu.

Figure 4 Implementation of Renewable energy plants by NLCIL

Future Plan on Renewable Energy :

NLCIL's major focus in the near future is proposed to be on coal- based power generation and will be actively considering the core opportunities in capacity addition in renewable space (wind and solar) with the additional renewable energy production is around 4610 MW.

- Setting up of Solar Power Plants of 150 MW hybrid comprising of 100 MW solar and 50 MW wind in SECI, 500 MW capacity through CPSU scheme-IRDA and 1000 MW plant in Assam in collaboration with APDCL are in pipeline.

- With the implementation of the proposed projects on thermal and renewable energies, NLCIL's power generation capacity would reach 17,171 MW by 2030.
- Total cumulative capacity of the renewable energy plants will be around 6031 MW which is around 35% of the cumulative electric power generation from non-fossil fuel-based plants.
- To utilize the renewable power generation and with the futuristic growth of hydrogen-based plants, NLCIL is planning to produce Green Hydrogen using the renewable energy power generated.
- NLCIL are also exploring the possibilities of developing pumped storage hydro projects in Mine voids.

Electrical Vehicles and Battery Systems:

- Electric vehicles are used for public movement in Hospital within the campus as shown in figure 5.
- NLCIL commissioned 20 MW SPP, integrated with 8 MWHr Battery Energy Storage System at Andaman Island.
- NLCIL is exploring the possibilities of implementing EV charging infrastructure facilities.

Figure 5 E-vehicles inaugurated by NLCIL.

2.4.2.2. Low Carbon Intensity plans

Lignite to Methanol :

- NLCIL has also proposed to establish Lignite to Methanol and Gasification projects with methanol plant of 0.4 MTPA/1200 MTPD capacity at Neyveli.
- 1200 MTPD Methanol will replace 1.5 MMSCMD Natural Gas and will annually save Rs. 1000 Cr. of LNG import with indigenous source.
- This initiative of NLCIL will support Prime Minister's vision to achieve a target of 100 MT Coal Gasification by 2030.

Lignite to Diesel :

- The project's main goal is to investigate the possibility of producing diesel from lignite and to provide a viable technology for an alternative use of lignite, which calls for tested technologies. To find the tested technology and sources, a global EOI has been floated in this regard. LEMAR Industries, USA has been given the role for conducting the feasibility study.

Innovation –Incubation Centre:

- NLCIL established Incubation centre with IISC and Anna University for promoting new innovative technologies for the industry.

E-Office :

- Digital activities like electronic office (E-office) are being implemented widely in all the offices to reduce the consumption of paper.

2.4.2.3 Introducing Energy Efficient System

- Temperature and pressure are the key performance indicators between subcritical, supercritical, and ultra-supercritical technologies for their operation and the heat carrying capacity of the stream and subsequently the efficiency of the plant.
- NLCIL has switched over to CFBC boilers in place of PF (Pulverized Fuel burning) for NLCIL's

new and expansion Thermal Power Plants at Neyveli and Barsingsar and it is a remarkable breakthrough for minimizing the emission of CO_2, SO_2, NOX which have higher thermal efficiency and lower emission.

- NLCIL already introduced 2x500 MW lignite-based boilers in NNTPS which is the first of its kind in India.
- NLCIL is also establishing the super critical boilers in NUPPL of 3x660 MW, 4x800 MW NLC Talabira coal fired boiler and TPS 2 II expansion lignite fired boiler of 2x660 MW with ultra-super-critical technology.
- Flue Gas Desulphurization Systems (FGD) are being implemented in NNTPL and NTPL.
- NLCIL is also carrying out pilot scale studies on the Lignite to Syngas integrated with clean power generation by Integrated Gasification Combined Cycle (IGCC) and production of value-added chemicals.

3. CONCLUSIONS

To achieve net GHG neutrality by 2070, emissions from coal-based electricity would need to plateau by 2035, however, it is set to peak by 2040 considering the present trend in capacity additions. By the accelerated iteration in energy transition, it should reach decline to more than 90% by 2065. The pathway for achieving this transition to net zero requires contribution from either end by adopting clean coal technologies and also by continually adding green energy in the mix. Emphasizing the indigenization of net – zero technologies is critical to the success of sustainable transition.

NLCIL is the first CPSU to achieve installation of 1 GW of Renewable Energy. NLCIL already installed 1421 MW of Renewable and Generated Highest Ever 2.2 BU in FY 2022-23 which is Highest among CPSU Coal companies. By 2030 NLCIL will be +6 GW Renewable power Company. NLCIL is implementing various action plan for energy transition and net-zero emission through various technologies like establishing solar power plants in mined out areas, introduction to energy efficient technologies, eco-parks, OB to sand plants etc. and contributing towards India's net zero emission through Panchamrit.

Need to ensure that the transition does not take place in an ad hoc fashion, but it shall maximize opportunities for economic prosperity, social justice, rights and social protection for all, leaving no one behind.

Transition from coal to renewable energy helps in achieving the primary objectives by addressing climate change and advancing economic development by improving the energy security.

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Keynote Paper

SEISMIC BRINGS PARADIGM SHIFT IN COAL SEAM RESOLUTION : ENHANCING COAL MINING EFFICIENCY AND SAFETY

Dr Rabi Bastia

Abstract

Seismic technology is an indispensable geophysical tool in the coal mining industry, offering precise and cost-effective imaging of coal seams. Its significance reverberates through the economic and safety dimensions of coal mines globally. Unlike conventional borehole drilling, seismic data provides a continuous and detailed picture of the target coal seam. This advantage alone revolutionizes the efficiency of coal mining operations. By employing seismic-derived depth surfaces and detecting faults and stratigraphic anomalies, mining engineers can strategically plan borehole drilling for fault assessment and grout pattern design. Further more, it aids in anticipating shifts in roof, floor, and seam conditions, facilitating more effective mine planning processes.

One of the key contributions of seismic lies in its ability to identify potential paths of water percolation, a critical factor in maintaining the stability and safety of coal mines. Recent advancements in 3D seismic interpretation and converted wave seismology have further expanded its capabilities. These developments focus on detecting subtle stratigraphic features, pinpointing gas locations, and mapping lithology, even in areas distant from borehole locations. However, it is important to acknowledge that the accuracy of seismic data is contingent upon both technological limitations and the geological context of the survey site. Vertical and lateral resolution constraints inherent in seismic datasets place restrictions on the size of features that can be effectively imaged, underscoring the need for a nuanced approach to its application in coal mining ventures.

Across the globe, notable instances of seismic technology's integration in coal mining operations can be observed. For instance, in the United States, particularly in regions like Appalachia, seismic surveys have become instrumental in optimizing coal extraction processes. Similarly, in Australia's coal-rich regions such as the Bowen Basin, seismic imaging techniques have been adopted to enhance the precision of coal seam mapping and characterization. Additionally, China, a powerhouse in coal production, has embraced seismic technology to bolster safety measures and increase the efficiency of their coal mining endeavours. These examples illuminate the widespread applicability and significance of seismic technology in the coal mining industry worldwide. A beginning has been made in India with few initiatives in this direction.

I. INTRODUCTION

The world of coal mining is undergoing a seismic shift, and it's not just a play on words. Seismic reflection, once limited to the world of geophysics, is now causing a significant stir within the coal industry, poised to usher in remarkable transformations. This paper is your guide to understanding this transformation, exploring how seismic technology is making mining more efficient, productive, and safer. One of the pivotal advantages of seismic data lies in its capacity to provide a continuous and detailed image of a target coal seam, surpassing the information gleaned from traditional borehole drilling. Seismic data equips miners with

CEO (E&P), Oilmax Energy & Global Geoscientist

vital insights, including depth surfaces, and the identification of faults and stratigraphic anomalies, all of which contribute to optimized borehole placement and the anticipation of shifting seam conditions. Recent strides in advanced 3D seismic interpretation and converted-wave seismology have further expanded the method's capabilities, enabling the detection of subtler stratigraphic features, gas localization, and the mapping of lithological variations, all without the constraints of borehole locations.

II. FUNDAMENTALS OF SEISMIC REFLECTION

Seismic reflection involves imaging the sub-surface using artificially-generated sound waves. Typically, small dynamite explosions or vibratory sources (e.g. Vibroseis) are used to generate seismic waves at or near the surface. Receiving devices (geophones) are placed on the surface to detect the seismic energy that originates from the seismic source, travels down into the earth and gets partially reflected back to the surface at each geological boundary (Figure 1). 2D seismic exploration involves acquiring seismic data along a single line of receivers. The resultant 2D seismic image can be used to detect features in the subsurface along the particular survey line. 3D seismic exploration involves using a grid of surface receivers to detect the reflected seismic energy generated by each seismic source. 3D seismic data yield a much more extensive and higher-resolution image of the subsurface than 2D seismic data (Figure 2). This makes 3D seismic more attractive in terms of the ability to contribute to the structural and stratigraphic understanding of a mine area.

Conventional coal-seismic acquisition assumes that typical coal-seismic sources will result in only compressional (P) waves arriving at the surface. P waves are longitudinal sound waves that have particle motion in the direction of travel. Hence reflected P-wave energy travelling upwards from a geological boundary will have particle motion with a strong vertical component at the surface receiver (Figure 1). Conventional 2D and 3D seismic acquisition records only the vertical component of seismic energy arriving back at the receivers. This type of seismic recording can also be referred to as single-component (1C) recording, and is by far the most common method of seismic exploration used in the coal environment.

In reality, however, both reflected P and shear (S) waves arrive at the surface during a seismic survey. S waves are transverse sound waves that have particle motion perpendicular to the direction of travel. Since coal-seismic sources dominantly produce P-wave energy, most of the S energy arriving at the surface is, in fact, mode-converted PS energy. In other words, energy from a wave that travels down to a geological boundary as a P wave, gets partially converted to S energy at the boundary, and then travels back to the surface as an S wave. Any PS-wave energy arriving at the surface will have a strong horizontal component of particle motion (Figure 1). Multi-component seismic recording measures both the vertical and horizontal components of ground motion to enable exploitation of both the P and PS energy arriving at the surface. It is to be noted that multi-component recording may also be referred to as three-component (3C) recording since the vertical and two orthogonal horizontal components of ground motion are generally recorded.

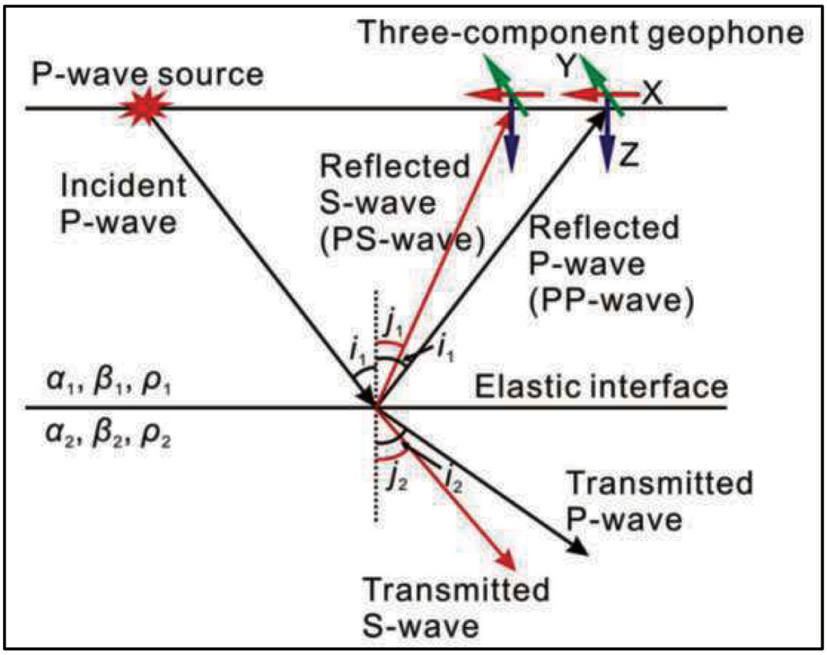


Figure 1 : Seismic Reflection Survey

As stated earlier, majority of seismic projects on coal fields across the globe involve acquisition, processing & interpretation (API) of only compressional waves i.e., conventional seismic (Figure 1).

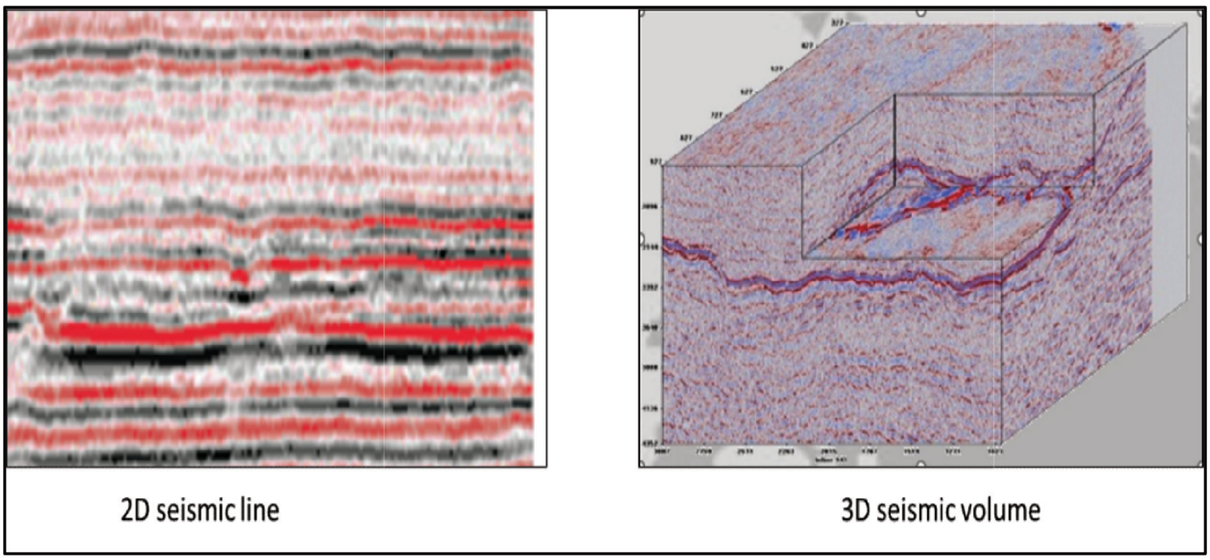


Figure 2 : 2D & 3D Seismic

Seismic interpretation, in simple terms, is the process of tracking significant geological boundaries (e.g. target coal seams) in the seismic data and producing two-way time (TWT) horizons or surfaces. Whereas the interpretation of 2D seismic data is confined to a single vertical plane, the spatial redundancy of 3D data provides the user with high-density maps of the coal seam topology. In both instances, the major advantage of seismic exploration is the ability to produce a more continuous image of the target coal seam as compared to the one achieved via borehole drilling alone.

Provided sufficient geological control exists (e.g. borehole data), a reliable time-to-depth conversion can be performed on the interpreted seismic TWT horizons to yield coal-seam depth surfaces. These surfaces can give a more accurate indication of relative changes in coal-seam depth that can be extracted from widely-spaced borehole data. Typically, accurate delineation of structure is the primary objective of a seismic reflection survey. Seismic TWT horizons, together with the seismic data, can be used to generate a number of seismic attributes that can help to highlight structural features e.g., faults, one of the key hindrances to mining operations.

III. APPLICATIONS: CASE STUDIES

As stated above, seismic bears its usefulness to coal industry in myriads of ways. Several such applications have been tried to be captured in the following case studies.

1) Case Studies : Overseas

a) More continuous mapping of the target coal seam compared to boreholes :

As stated earlier, the major advantage of using seismic data is its ability to map a target coal seam & faults as compared to the one derived via borehole drilling alone (Figure 3). The seismic data helps in producing more continuous image with actual locations of faults. The seismic image can further be improved using PS wave (Figure 4). Due to data redundancy, seismic data can produce better image than boreholes (Figure 5).

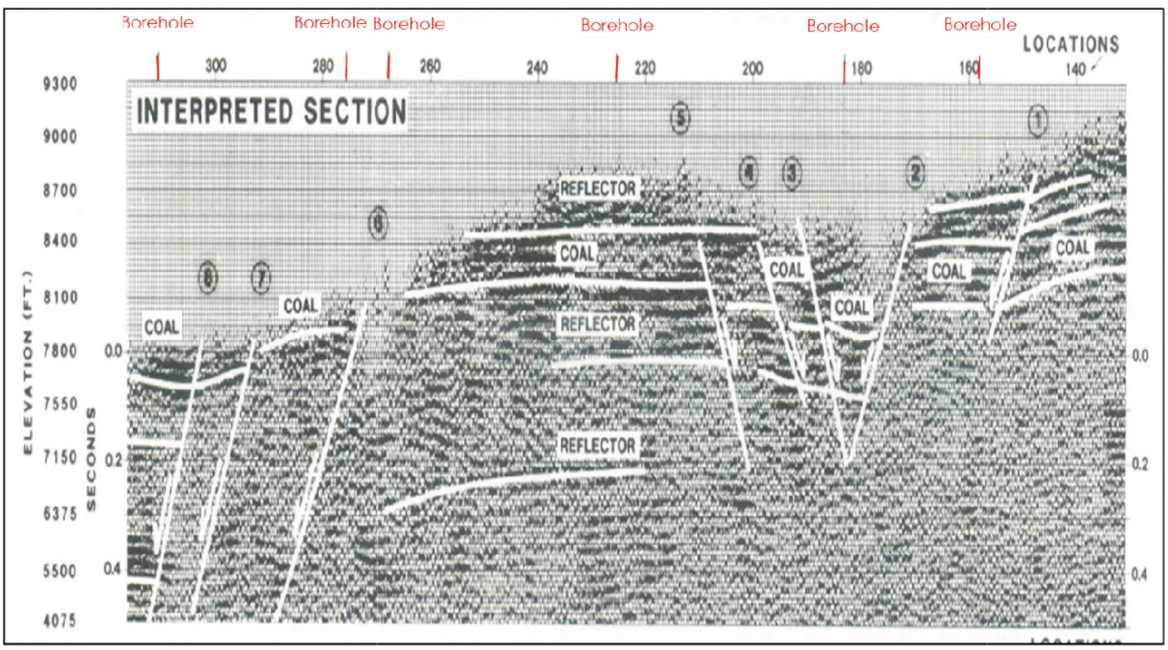


Figure 3 : Seismic section showing better continuity & fault position

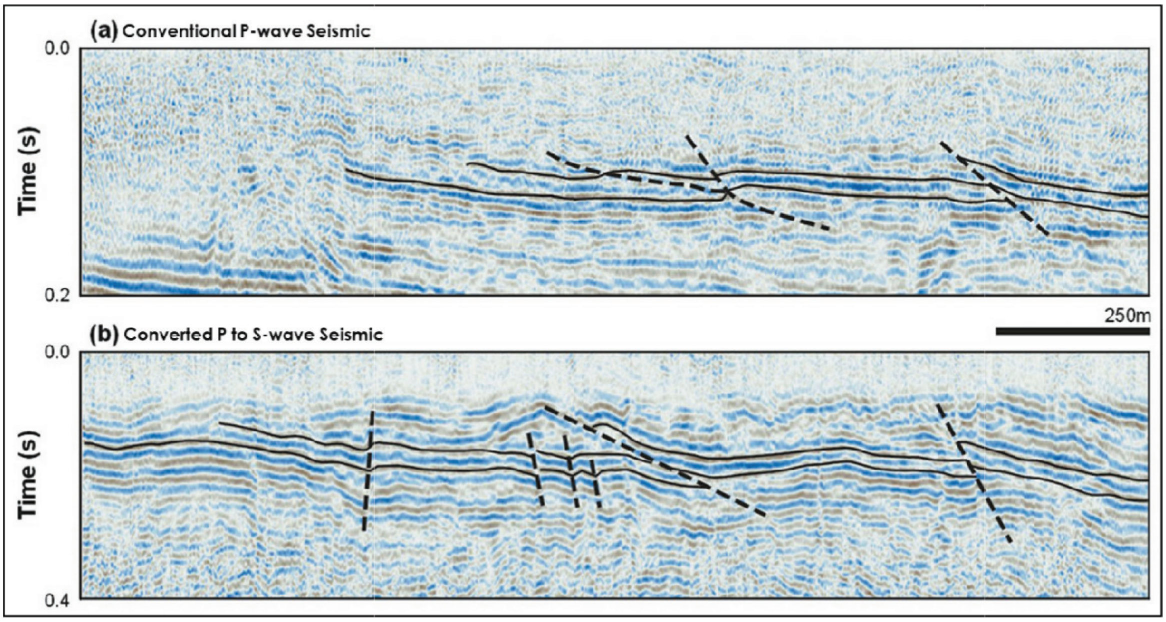
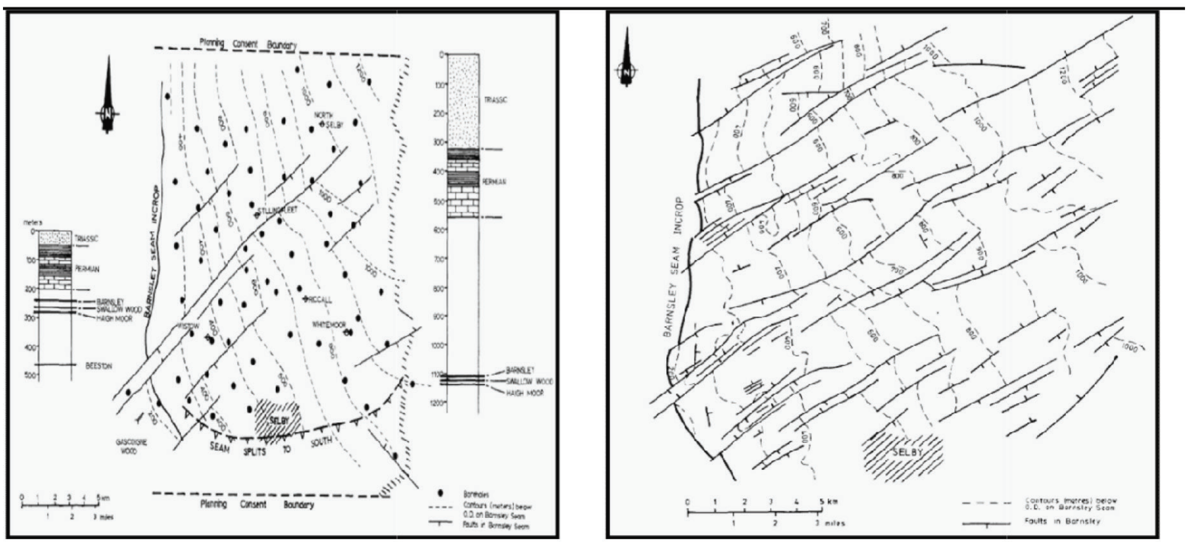


Figure 4 : Seismic section showing better continuity & fault position in PS image



Selby Coalfield – Geological structure obtained from borehole data.

Selby Coalfield – Geological structure obtained from borehole and seismic data.

Figure 5 : Improved Structure Map

b) ***Ability to capture thickness of coal seam (within the limits of seismic resolution):***

Seismic has shown its ability to locate the thickness variations & trends of coal seams within the limits of seismic resolution (Figure 6). The data is highly desirable in mine planning and development. Thickness derived from the combined interpretation of seismic and boreholes helps in better estimation of tonnage & recovery.

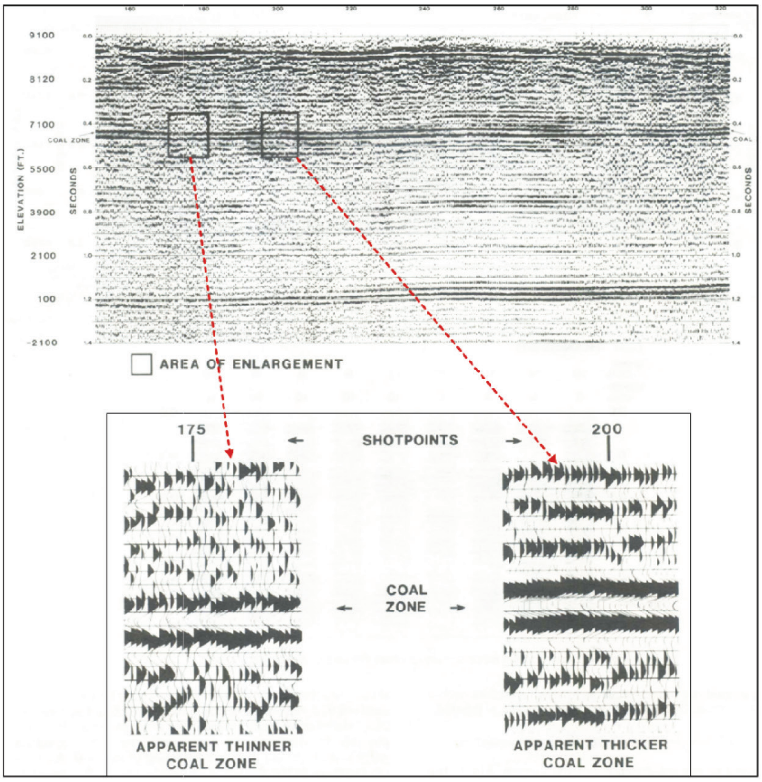


Figure 6 : Ability to capture thickness of coal seam (within the limits of seismic resolution)

c) Prediction of Fractures:

The current study demonstrates application of seismic to fracture identification using P-to-S converted waves in Huainan coalfield, China. Fractures that develop in coal seams threaten safety in many ways, but they can be predicted using fracture parameters derived from multi-component seismic data performing interlayer travel-time inversion of the fast shear waves using geophysical logs, rock-physics parameters, and tunnel-excavation information as constraints to derive fracture azimuths (Figure 7). Using joint PP- and PS-wave inversion, anisotropy parameters were derived for use in fracture prediction. Finally, unsafe mining areas were predicted with a high probability of coal and gas outbursts (Figure 7). The applicationresults were verified by excavation data from the mine tunnels.

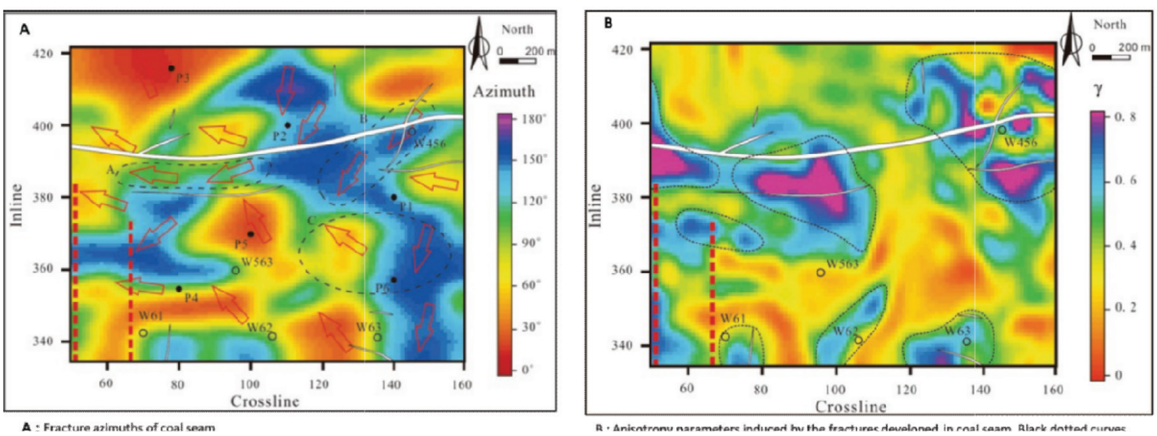
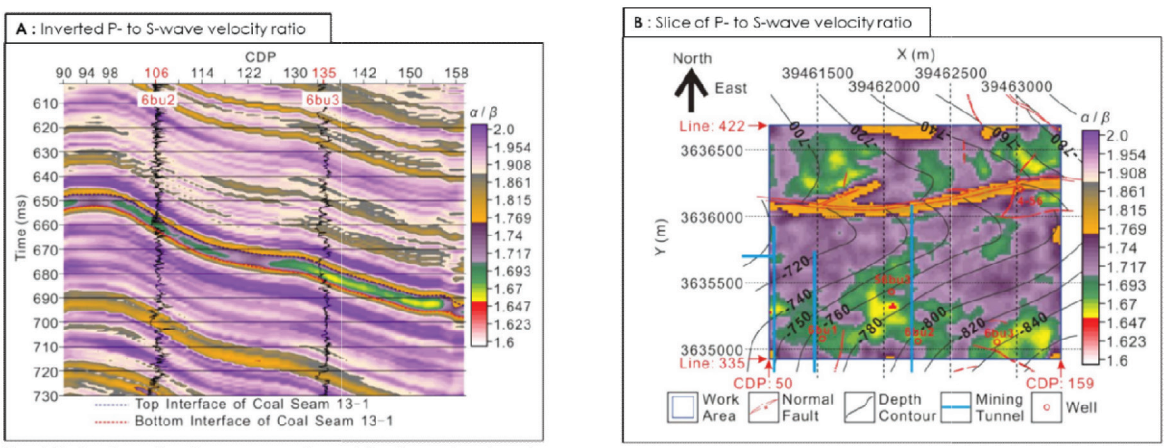


Figure 7 : Prediction of Fractures

d) Detection of Tectonically Deformed Coal Using Model-Based Joint Inversion of Multi-Component Seismic Data :

The case study represents a work area of the Guqiao mine in China. Tectonically-deformed coal (TDC) is a potential source of threats to coal-mining safety. Finding out the development and distribution of TDCs is a difficult task in coalfield seismic explorations. In general, the P- to S-wave velocity ratio (α/β) is a stable parameter for the identification of TDCs and most TDCs have α/β values of less than 1.7. In the current case study, a TDC detection method using a model-based joint inversion of the multi-component seismic data is shown. Following the least square theories, the amplitude variation with offset gathers of the PP- and PS-waves are jointly inverted into the corresponding □/□ values. The prior models generated from the P- and S-wave velocity and density logs are employed in the joint inversion to enhance the inversed models. Model test results show that the model-based inversion is of high anti-noise ability and has a good recognition ability of TDCs. The TDCs developed in coal seam (Figure 8) are effectively identified according to their inverted α/β values of less than 1.7. The detection result is verified by the well and tunnel excavation information.



The drilled wells confirm the presence of crumbling & powdered coal.

At the north of the big normal fault, there are some areas marked by

Figure 8 : Detection of Tectonically Deformed Coal Using Model-Based Joint Inversion of Multi-Component Seismic Data

4D Seismic Monitoring to Modern Coal Mining: The current study demonstrates the application of 4D seismic to a coal mine in western China. Four-dimensional (4D) seismic is a powerful tool of monitoring of subsurface reservoirs. The application of 4D seismic, with multiple 3D seismic datasets, for the monitoring of coal seams under modern coal mining conditions allows us to monitor the background status before coal mining, mining-induced changes during mining, and time-lapse changes due to the coal mining over the full life cycle of a modern coal mine (Figure 9). The seismic character gets diffused as the mining activity continues.

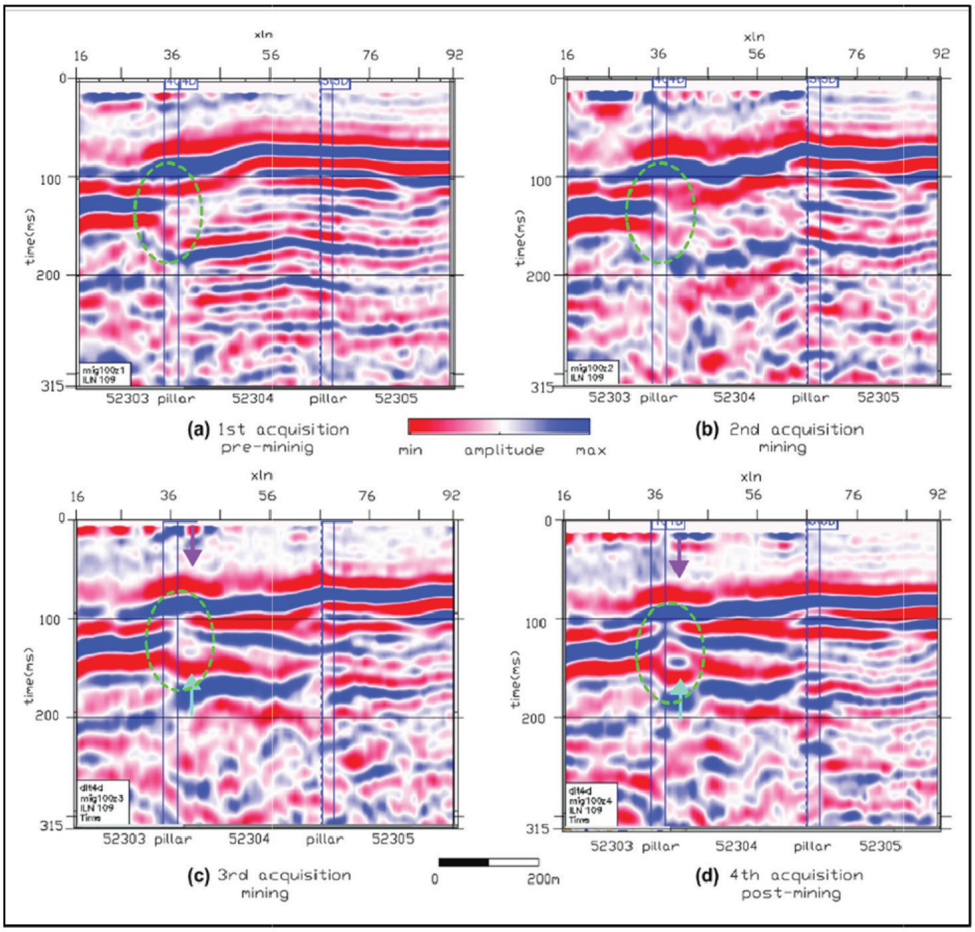


Figure 9 : 4D Seismic Monitoring to Modern Coal Mining

e) Mapping of Coal Mine Water Structure (with electromagnetic survey):

The current case study describes the application of seismic to one of the coal mines in China. Generally, the water-bearing structures of coal mines mainly include coal seam, roof, coal seam, floor, and goaf, while the main water-conducting structures include faults, collapsed columns, and collapsed goaf areas. The most used methods for the detection of the above structures include the seismic method, high-density electrical method, controlled source audio-frequency magneto telluric method, and transient electromagnetic method. Theoretically, the seismic methods have a higher resolution, which can be used to determine the target geometry, but unable to determine whether the target is filled with water, while the electromagnetic methods are capable of this, although with lower resolution. The case study demonstrates successful integration of seismic with electromagnetic survey in identifying water bearing structures (Figure 10).

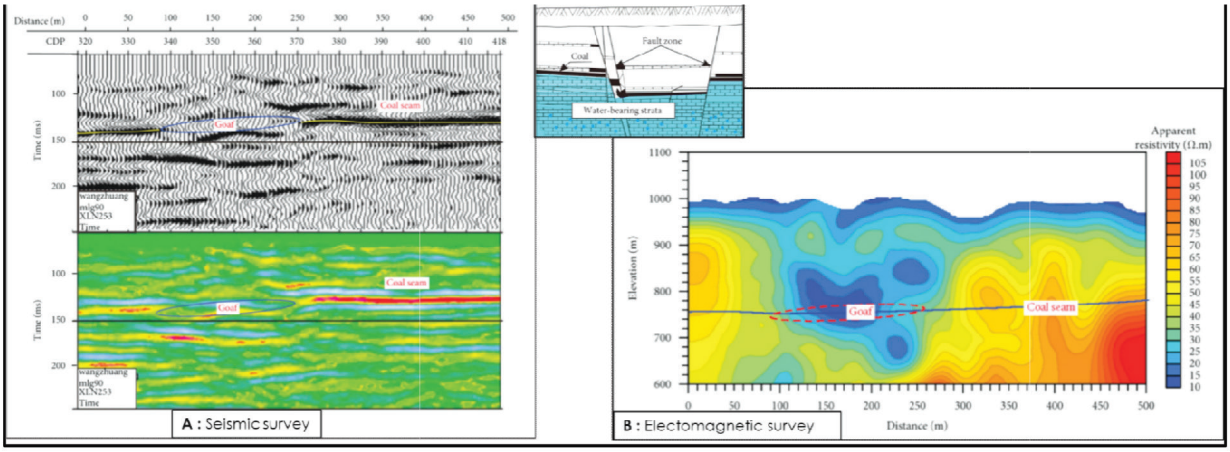


Figure 10 : Mapping of Coal Mine Water Structure (with electromagnetic survey)

2) A beginning in India

Aforesaid application of seismic to one of the coal blocks has been successfully established & demonstrated to a large extent in the following section.

a) Well to Seismic Tie:

One of the first steps in interpreting a seismic dataset is to establish the relationship between seismic reflections and stratigraphy. Although some information can be obtained by relating reflectors to outcrop geology, by far the best source of stratigraphic information, is well control. Using sonic & density logs of a well, it is possible to construct a synthetic seismogram showing the expected seismic response for comparison with the real seismic data (Figure 11).

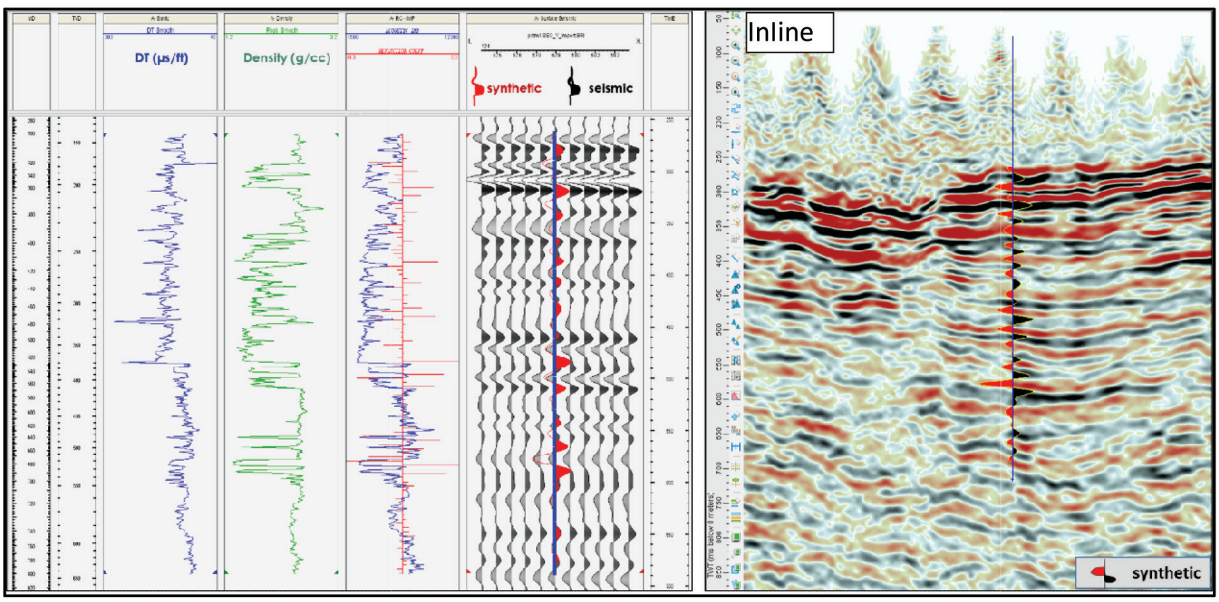


Figure 11 : Well to Seismic Tie (synthetic seismogram)

As evident on visual comparison, the synthetic exhibits high correlation between wells & seismic events, despite the absence of any VSP/check-shot data. The high degree of correlation is further demonstrated quantitatively by high correlation coefficient (58%).

b) Depth structure map :

As stated earlier, major advantage of using seismic data is its ability to produce a more continuous image of a target coal seam as compared to the one derived via boreholes alone (Figure 12). Seismic-derived depth surfaces, and information about faults and other stratigraphic anomalies located via seismic imaging, can be used by miners to target borehole drilling, and help predict changing seam conditions.

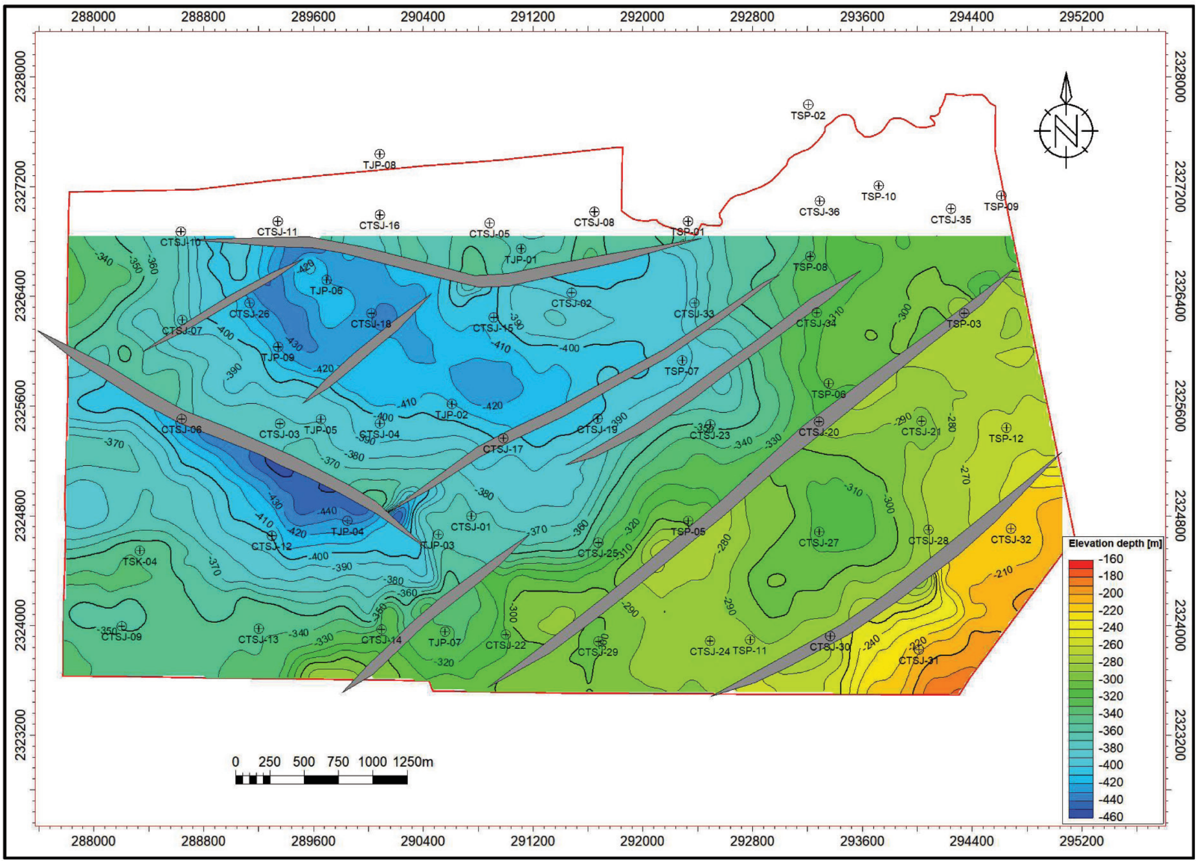


Figure 12 : Depth structure map at the base of a major seam

c) AVO & Inversion :

Conventional seismic can generate structural maps but has limitations in distinguishing facies pertaining to Coal seams and surrounding lithologies. AVO & Seismic inversion studies (post stack and prestack) involving Vp, Vs, Vp/Vs ratio, density and resistivity volumes etc., has successfully demonstrated its capability to distinguish coal seams & other lithologies (Figure 13 & Figure 14).

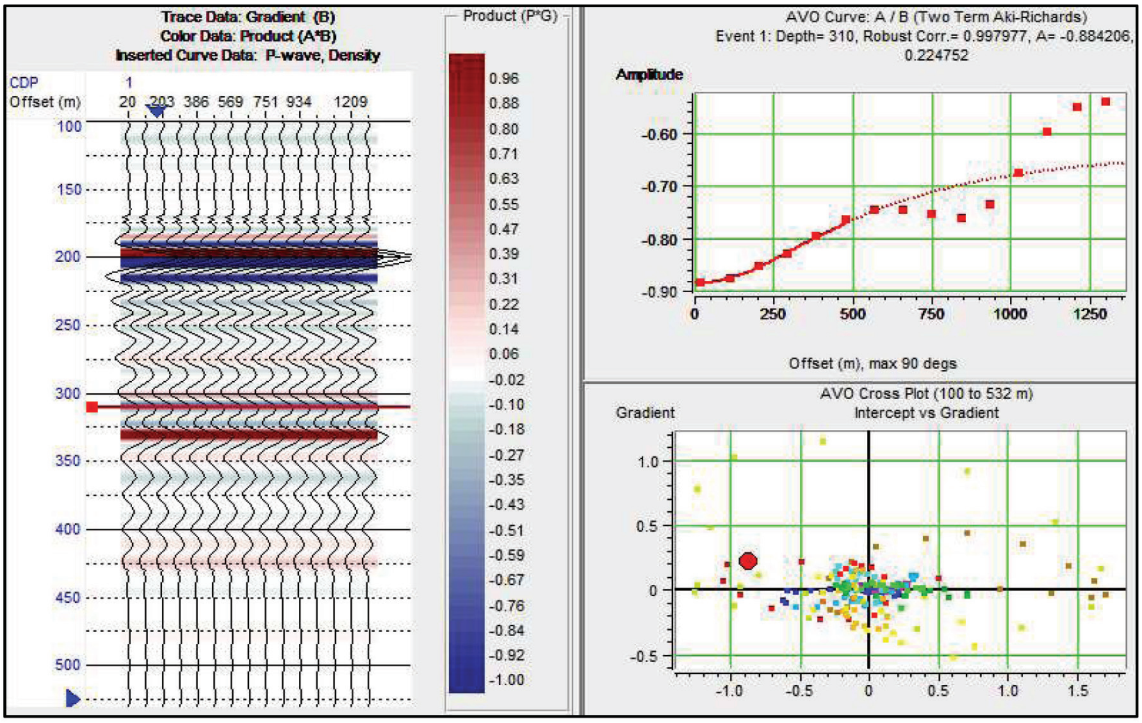


Figure 13 : Classic class IV response is exhibited by pre stack gathers & various attributes

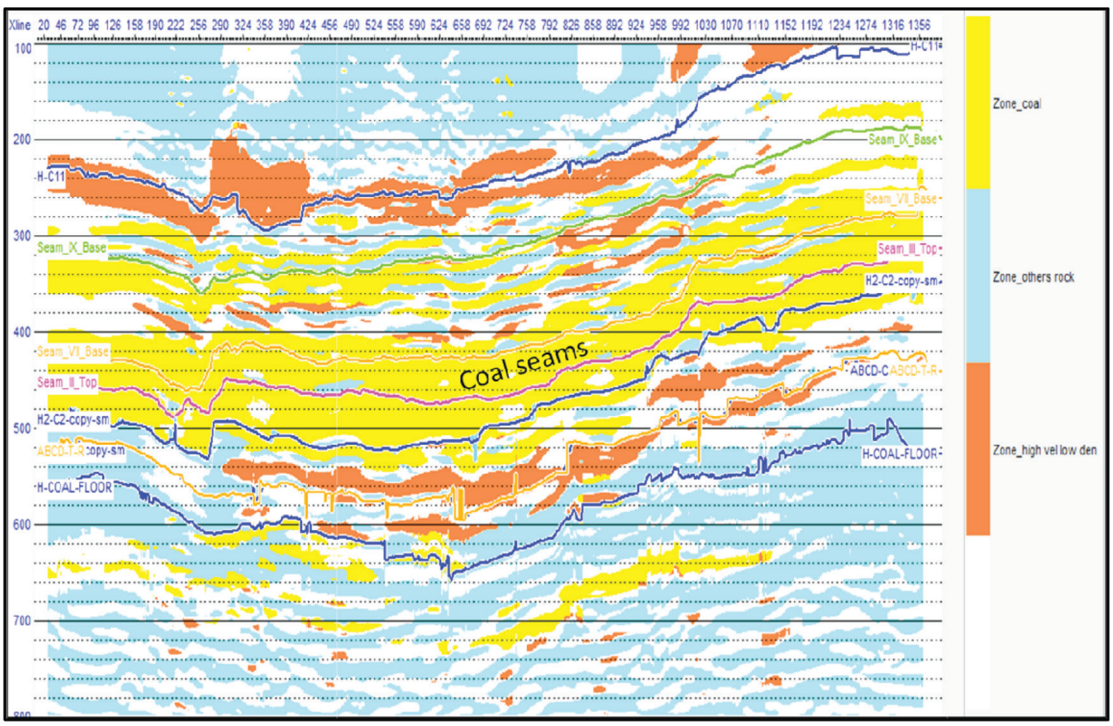


Figure 14 : Coal Seam Identification using Cross-plot of VpvsVp/Vs

IV. CONCLUSIONS

In summary, seismic reflection has emerged as an indispensable geophysical tool for the precise and cost-effective imaging of coal seams, exerting a profound influence on the economic viability and safety of coal mining. Its primary strength lies in its capacity to deliver a seamless and detailed depiction of coal seams, surpassing the capabilities of traditional borehole drilling. This invaluable information, including depth surfaces, fault identification, and stratigraphic anomalies, guides borehole placement, aiding in fault evaluation and grout pattern design, and facilitates the anticipation of changes in roof, floor, and seam conditions. These predictive capabilities enhance the effectiveness of mine planning and safety measures for miners, while also contributing to the identification of potential water percolation paths, further bolstering safety and sustainability within mining operations. Recent advancements in 3D seismic interpretation and converted-wave seismology have extended the technology's utility, enabling the detection of even more subtle stratigraphic features, gas localization, and lithological mapping away from borehole locations. These innovations promise to open additional avenues for improving mining practices.

Nonetheless, it is essential to recognize that the effectiveness of the seismic method is shaped by its inherent limitations and the geological conditions in which it is employed. Vertical and lateral resolution constraints within seismic datasets can limit the size of features that can be accurately imaged, and geological conditions significantly impact the quality of the results. In conclusion, seismic reflection's integration into coal mining represents a profound transformation within the industry. It not only enhances efficiency, productivity, and safety but also fosters the sustainability of mining practices. As we look to the future, continuous advancements and innovations in seismic technology are poised to further refine coal seam imaging, ensuring a more prosperous and secure future for the coal mining sector.

DESIGN OF EXTRACTION METHODOLOGY FOR HIGHWALL MINING UNDER MULTI-SEAM CONDITIONS - A CASE STUDY

Arka Jyoti Das*, Prabhat Kumar Mandal, Nilabjendu Ghosh, Subhashish Tewari, Rana Bhattacharjee

Abstract :

In India, a number of opencast mines are attaining the ultimate pit limit and their extension is not possible due to the high striping ratio or reaching the mine boundary. As a result, a huge amount of coal is locked up in the highwall of the opencast mines which is being extracted by the highwall mining technology by driving parallel web cut/roadways with the help of the remotely operated continuous highwall miner. The success of highwall mining mainly depends on the proper design of web pillars, kept between two adjacent web cuts. Design should be in such a way that there should not be any subsidence at the surface to protect surfacestructures or overlying coal seams. The stability of web pillars and surrounding rock mass is affected more in the case of multi-seams with close vicinity or multi-pass extraction of thick coal seams. This is because of the interaction effect among the coal seams during multi-seam or multi-pass highwall mining. In this paper, an attempt has been made to quantify the effect of the aspect ratio/rectangularity of the long web pillars on their strength and to derive the formula to calculate the effective width for the long web pillars. A case study of West Bokaro Mine of M/s Tata Steel Limited has been elucidated where three coal seams viz. VII, VI, and V are being extracted by highwall mining. The parting between the VII and VI seams is 12.3-20 m and that of between VI and V seams is around 5.7-10.6 m. Web pillars are designed by considering the aspect ratio and the interaction effects among the coal seams during their extractions. By considering various geological and geotechnical factors, the proposed design approach in this study minimizes the risks associated with highwall mining while maximizing the extraction from multi-seam conditions.

Keywords : *Highwall mining, Multi-seam, Web pillars, Web cut, Rectangularity, Effective width*

1 INTRODUCTION

In India, most of the coalproduction comes from opencast mines which are gradually approaching their ultimate pit limits and/or mine boundaries. Thus, the coal lockedup in the highwall of the open pit mines, cannot be extracted by conventional opencast mining.Under these conditions, highwall mining is adopted to recover the locked-up coal by driving a series of parallel entries by leaving coal pillars among them (Verma et al., 2014; Porathur et al., 2017). The design of the optimal size of the pillars and their stability analysis isof paramount important importance for the success of highwall mining. The goal of stability analysis is to prevent catastrophic failure even if a few isolated pillars fail to function to their predicted capacity.Minor instability in a mine may arise due toa slight increase in the mined-out area or by slight local failures (Adhikary et al., 2002).However,a higher percentage of extraction may result in global instability (Huang et al., 2021). The instability is further exacerbated under the conditions of multi-seam mining.The major challenges of mining under multi-seam conditions are to protect the working of overlying seams and the surface structure, if any. The presence of multiple seams often causes interactions in terms of strata movements, instability, etc. depending on the characteristics of parting among the coal

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seams. These interaction effects are significant when the partings are weak and parting thicknessesare less. In these conditions, the strength of web pillars is reduced significantly when they are situated above the web-cut of the underlying seam. Thus, the web pillarsare designedin vertical superimposition for coal seams situated in close proximity. Many studies were carried out to design highwall mining by analyzing the stability of the web pillars under different conditions like thick seams, inclined seams, multi-seams, etc.

Porathur et al. (2013) provided the design approach for web pillars in highwall mining under different geo-mining conditions. They performed a number of numerical simulations to decipher the behaviour of long web pillars. Ross et al. (2019) designed the highwall mining for a coal seam having a thickness of 7.32 m and a dip angle of 200. Under these conditions, the penetration depth of the highwall miner was 182.88 m. Shen (2014) described the failure characteristics of the web pillars and elucidated a failure case of the highwall mining panel where subsidence was observed at the surface. The failure extended about 80 m along the highwall and 50 m inside the highwall. The depth of cover of the coal seam was 40-50 m and the average strength of the coal was 7.88 MPa. The widths of the web pillars within the failed panels were 2.9-3.36 m and the barrier pillars were 3.64-6.39 m. The height and width of the web cuts at the failed panels were 4.8 m and 3.5 m respectively.They calculated the safety factors of the panel by numerical modelling and found that the maximum safety factor of the failed panel was 1.27. He concluded that the severe roof fall caused the failure of the panel as it resulted in a heightened pillar, thus reducing the strength of the web pillar. Zipf and Mark (2005) studied the characteristics of web pillars of coal seams situated in close proximity. They showed that the combined strength of the coal pillar-roof system reduced drastically when the web pillars were formed in a staggered manner in coal seams having less parting. They also described some failure cases of the multiple seams highwall mining and suggested maintaining vertical superimposition of web pillars to minimise the instability of the pillars.

In this paper, an attempt has been made to quantify the effect of the aspect ratio/rectangularity of the long web pillars on their strength and to derive the formula to calculate the effective width for the long web pillars. A case study of West Bokaro Mine of M/s Tata Steel Limited has been elucidated where three coal seams viz. VII, VI, and V with thicknesses 6.0-8.1 m, 3.0-6.0 m, and 2.4-3.3 m respectively are being extracted by the highwall mining. The parting between the VII and VI seams is 12.3-20 m and that of between VI and V seams is around 5.7-10.6 m. Web pillars are designed by considering the aspect ratio of the web pillars and the interaction effects among the coal seams during their extractions. By considering various geological and geotechnical factors, the proposed design approach in this study minimizes the risks associated with highwall mining while maximizing the extraction from multi-seam conditions.

2 STRATEGIES FOR WEB PILLAR DESIGN

The stability of web pillars is quantified by the factor of safety (FOS) which is expressed by the ratio of the strength of the web pillar and the load on the pillar. The strength of the pillar is calculated by the following equation (Sheorey et al. 1987; Sheorey, 1992):

$$S = 0.27\sigma_c h^{-0.36} + \left(\frac{H}{250}+1\right)\left(\frac{w_e}{h}-1\right) \quad (1)$$

Where, S = Strength of coal pillar in MPa; σ_c =

Uniaxial Compressive Strength in MPa; h = Working height in m; H = Depth of cover in m; w = Width of the web pillar, w_e = Effective width of web pillar in m.Several researchers proposed effective width formulae of rectangular pillars, like $w_e = \sqrt{wL}$, $w_e = \frac{w+L}{2}$ and $w_e = 4A/O = 4(wL)/2(w+L)$.

Where L = Length of web pillar in m. The widely used formula for the effective width of a rectangular pillar is $w_e = 4(wL)/2(w+L)$ where w is the width of web pillars in m and L is the length of the web pillar in m (Wagner, 1974). When L>>w for a web pillar, $w_e = 2w$. However, the effective width needs to be established by the numerical modelling.

The load on web pillars is estimated using the tributary area method, which is given as:

$$P = \gamma H\left(\frac{w + w_c}{w}\right) \quad (2)$$

Where P = Load on web pillar in MPa; γ = Unit rock pressure (0.025 MPa/m); H = Depth of cover in m; w = Width of the web pillar in m; w_c = Web cut width in m.

The limitation of this formula is that the load does not depend on the length of the cut or penetration depth. Also, this formula may not be suitable for multi-seam conditions as it does not consider the interaction effect among coal seams. Thus, numerical simulation is found to be suitable to assess the load on the web pillars.The FOS is calculated by the following expression:

$$FOS = \frac{Strength\ of\ pillar}{Load\ on\ pillar} = \frac{S}{P} \quad (3)$$

Failed web pillars are analysed to understand their characteristics for highwall mining in Australia. Fig. 1 shows the widths of failed web pillars havinga height of pillars of 4.8 m and a width of web-cuts of 3.5 m (Shen, 2014). It is found that the maximum width of the failed web pillar is 3.36 m. From Fig. 2, it is obtained that the maximum value of the FOS of a failed web pillar is 1.3 and the maximum number of failed web pillars has FOS between 1.05 and 1.1. For the Indian mining scenario, the web pillar is designed with a minimum FOS of 1.5 for multi-seam conditions to take care of the interaction effect and a minimum FOS of 2.0 to prevent surface subsidence. Generally, the web pillars with w/h ratio < 1.0 or FOS < 1.5 is avoided during the design. Otherwise, barrier pillars are left after a certain number of web-cuts to prevent catastrophic failure.

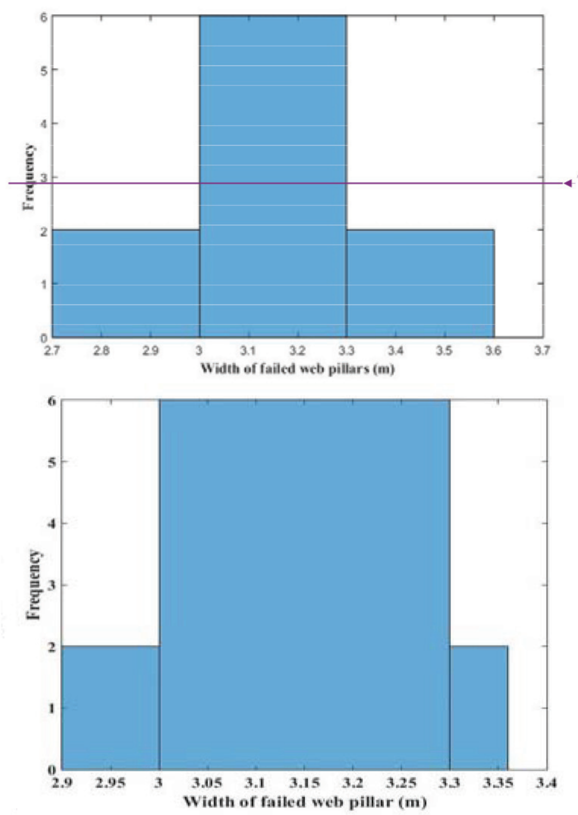


Fig. 1: Histogram of the widths of failed web pillars.

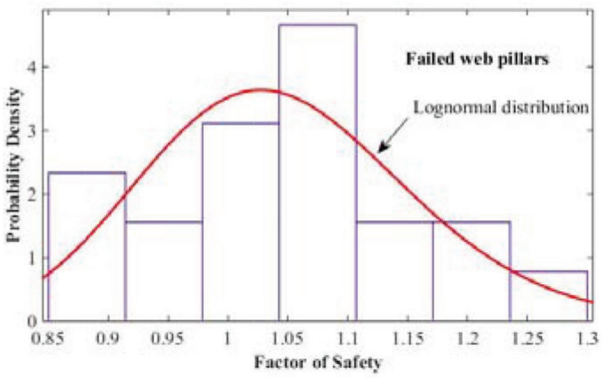


Fig. 2: Probability distribution of the factor of safety of failed web pillars.

3 Development of formula for effective width of rectangular pillar

Numerical simulation is carried out to know the effect of rectangularity (i.e. L/w) on the strength of pillars. It is well known that the strength of a rectangular pillar is more than the strength of a square pillar subject to the same smaller width. With the increase in the length (L) of the pillar, the strength increases and after a certain value of the length, the strength shows an asymptotic nature. It means a negligible increase in strength with an increase in length after a certain limit. Thus, a parametric study is carried out by varying the L/w ratios by keeping the value of $w_e = 4A/O$(widely used effectivewidth formula, where A = Area of rectangular Pillar, O = Perimeter of rectngaular pillar) constant.As per the existing formula, the strength of rectangular pillars would be equal for constant 4A/O values. However, Fig. 3 shows that for a particular value of 4A/O, the strength of the rectangular pillar decreases with the increase in L/w ratios.

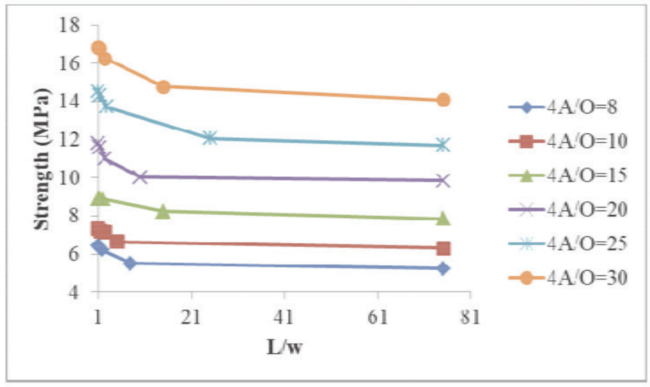


Fig. 3: Variation of strength with respect to L/w ratio for different 4A/O.

Back analysis is carried out by numerical modelling to find out the widths of square pillars (i.e. termed as equivalent width) whose strengthsare equal to the respective rectangular pillars. Fig. 4 illustrates the width of a square pillar whose strength value is equal to the respective rectangular pillar having particular values of L/w ratio and 4A/O. It is depicted in Fig. 4 that for a particular value of 4A/O, the effective width (w_e) decreases with the increase of the L/w ratio and becomes constant after a certain value of the L/w ratio. The formula for the effective width is derived through regression analysis by using the values of effective widths obtained from numerical modelling. Fig. 5 shows the correlation between the effective widths predicted by regression and the effective widths predicted by numerical modelling. The developed formula to calculate the effective width is as follows:

$$w_e = w + (4A/O - w)0.66 \qquad (4)$$

Where w is the width of a rectangular pillar (m), A is the area of the rectangular pillar (m^2)and O is the perimeter of the rectangular pillar (m). For long web pillars L>>w, the effective width will be 1.66w as obtained from Eq.(4).

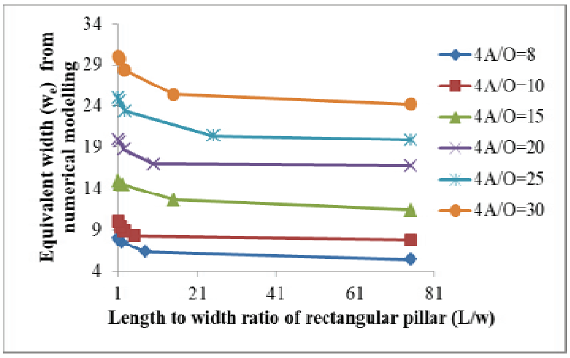


Fig. 4: Effective widthof rectangular pillars for different L/w ratiosand 4A/O as obtained from numerical modelling.

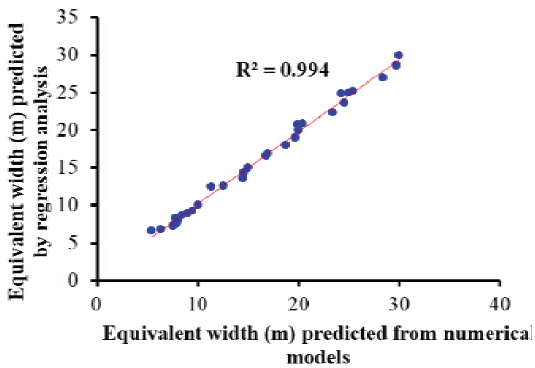


Fig. 5: Correlation among predicted and observed effective width (w_e).

4 Site conditions

The West Bokaro Mine lease area of M/s Tata Steel Limited lies in the central part of the West Bokaro coalfield. The strata formation of the area is mainly sandstones, shales, and coal seams of the Barakar formation of the Damuda group of the lower Gondwana subgroup. Most of the coal seams are confined to the upper and middle sections of the Barakar formation. The general strike in the leasehold is NE-SW to E-W and gently dipping from southeast to southern directions between 3^0 to 7^0. The leasehold forms a horst formation being enclosed between two major faults viz. the Banji fault in the west and the Kedla fault in the east. The northern boundary is marked by the Chutua fault.

Due to the presence of F19, F20, F20A, F25, F26, and F27 faults of varying amounts of throws, the identified Panel-F in the PCP-3 area at Quarry AB is divided into three areas marked as 1, 2, and 3 for the implementation of Highwall technology as shown in Fig.6.Surface structures are present at Area-1 and Area-2 as shown in Fig. 7.

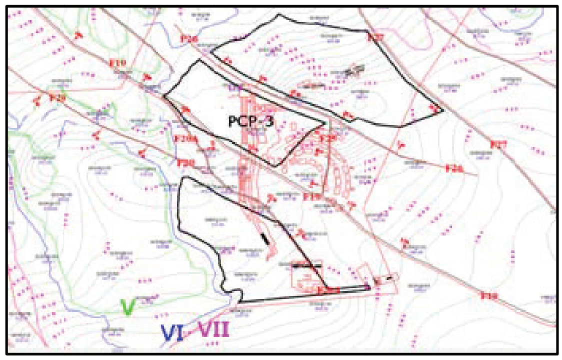
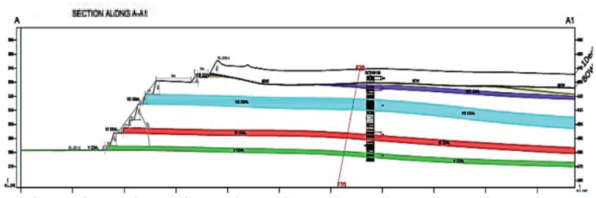


Fig. 6: Location of the highwall mining site at PCP-3 area, West Bokaro Mine, Tata Steel Limited.

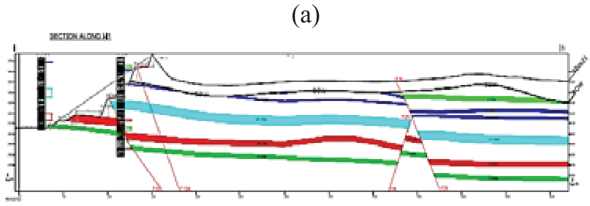
In these areas, the highwall mining is to be carried out in seams VII, VI and V as shown in Fig. 8. The thickness of the overburden varies from 15 m to 80 m above the VII seam within the area for the application of Highwall Mining Technology. The variation of the parting thickness between the VII seam and VI seam is 12.3 to 18.2 m and that between the VI seam and V seam is 5.7 to 10.6 m.Thethickness of the VII, VI, and V seams varies from 6.0-8.1 m, 3.0-6.0 m, and 2.4-3.3 m respectively within the PCP-3 area. To understand the variation of seam profiles in the proposed PCP-3 area at Quarry AB, vertical sections in different locations covering the entire area were plotted and are shown in Fig. 9.

Fig. 7: Highwall mining sites having surface structures at the surface.

Fig. 8: Highwall mining site under multi-seams conditions.



(a)



(b)

Fig. 9: Sections along highwall showing different seams.

5 Extraction methodology of multiple coal seams by highwall mining technology

Surface structures in the PCP-3 area like the excavator hangar/workshop, Pit office, Canteen, Water treatment plant, and New CHP (Fig. 7) are present in the identified area. There is no further scope of extension of opencast mining in that area in Quarry AB. As further benching is not possible, Highwall Mining can be done in ascending order from the bottom Seam V to the topmost Seam VII at that part of the pit. After completing the mining of Seam V, a platform is formed by filling the bottom of the pit up to the floor of the immediate overlying Seam VI and so on and so forth. For extraction under multi-seam conditions in ascending order, the web pillars should be stable throughout and after the mining operation to ensure the safety of upper seams workings as well as surface structure, if any. As the water treatment plant and New CHP are located in Area-1 and Area-2, respectively, web pillars should have a minimum safety factor of 2.0 with long-term stability to avoid the occurrence of surface and sub-surface subsidence. For Area-3, a web pillar having a safety factor of around 1.5 to 1.8 should be sufficient for medium-term stability purposes so that developed web pillars in lower seams should remain stable during extraction through Highwall mining in upper seams. The 8m thick VII seam should be extracted in two lifts considering the maximum cutting height of the Continuous Highwall Mining (CHM) equipment.

The Continuous Highwall Mining (CHM) equipment used in the West Bokaro Mine of M/s Tata Steel Limited operates with 3.5m wide web cuts and a maximum penetration depth of 300m. An important aspect of web pillar designing is the accuracy of the cuts, which determines the maximum and minimum size of the resulting web pillars. The required strength and safety factor of the pillars are to be decided based on the maximum deviation of the roadways and, thus, the resulting minimum width of the web pillars. If the web pillar is designed with a smaller width, in such cases poor accuracy may result in a very narrow pillar or even a crossing of entries, leading to surface subsidence. Therefore, the CHM to be employed should have a deviation within certain limits. For the current design, an accuracy of 0.2% i.e. deviation of 20 cm per 100 m penetration depth is assumed. Therefore, the resulting web pillar will have a width w = w_{avg} ± 0.4L/100, where the variation in pillar width is calculated twice as that of the deviation, and L is the maximum penetration depth.

6 Numerical simulation study for analysis of overall stability

The overall stability, including the roof stability and the parting stability, has been analysed using numerical modelling studies. 3-D model is constructed that includes the Area-1, Area-2, and Area-3 for Panel-F in the PCP-3 area at Quarry AB using FLAC3D software (Itasca, 2017). The Physico-mechanical properties parameters for the models are as per Table 1. The yield zones in the rock mass are identified by numerical modelling.

Table 1: Rock and rock mass properties used for empirical and numerical studies

Rock Type	Compressive strength (MPa)	Tensile Strength (MPa)	Density (Kg/m^3)	Poisson's ratio	Young's Modulus (GPa)	RMR
VII Seam roof	35	3.5	2500	0.25	10	55
VII Seam	20	2	1500	0.25	2	55
VII-VI parting	31	3.1	2500	0.25	10	55
VI Seam	20	2	1500	0.25	2	55
VI-V parting	30.7	3.07	2500	0.25	10	60
V Seam	20	2	1500	0.25	2	55

The physico-mechanical parameters of the laboratory-testedrock sample (Table 1) are required to be converted to the rock mass properties for field scale simulation (Das et al., 2023). The rock mass properties are deduced from the intact rock properties using Sheorey's failure criterion of rock mass (Sheorey, 1997). The in-situ stresses are important considerations when evaluating the stability of undergroundstructures.Thus, the in-situ stresses are considered in the numerical simulation as per the following equation (Sheorey, 1994):

$$\sigma_H = \sigma_h = 2.4 + 0.01H \text{ and } \sigma_v = \gamma H \qquad (5)$$

Where $\sigma_H$is the major horizontal in-situ stress (MPa),$\sigma_h$is the minor horizontal in-situ stress (MPa),σ_v is the vertical in-situ stress (MPa),H is the depth of cover (m), γ is the unit of the rock (MPa/m).

In general, the modelling process entails (i) creating a grid (Figs. 10 and 11), (ii) discretizing the model, (iii) choosing an appropriate constitutive model for material behaviour, (iv) incorporating material properties, gravity, in-situ stresses, and boundary conditions, and (v) finding the equilibrium of the initial elastic model to generate the in-situ stresses in the model (Fig. 12). (vi) converting the current model for the Mohr-Coulomb strain-softening model. (vii) the creation of web pillars through web cuts; (viii) running the models to determine the condition of the web pillars and the overlying strata; and (ix) evaluating the model behaviour, such as stress, failure zones, etc.

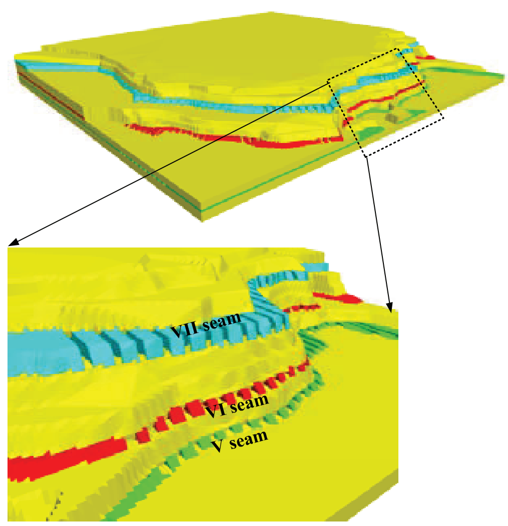


Fig. 10: Grid used in numerical modelling.

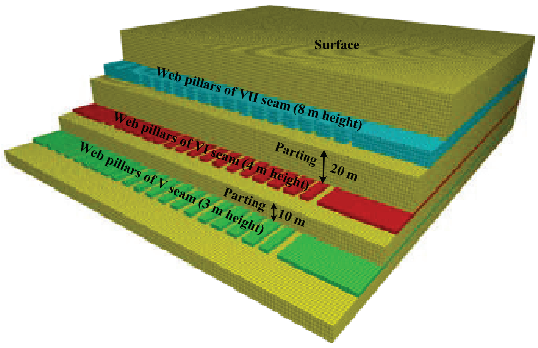


Fig. 11: Grid showing the height of the developed web pillars and parting thickness between various seams in numerical modelling.

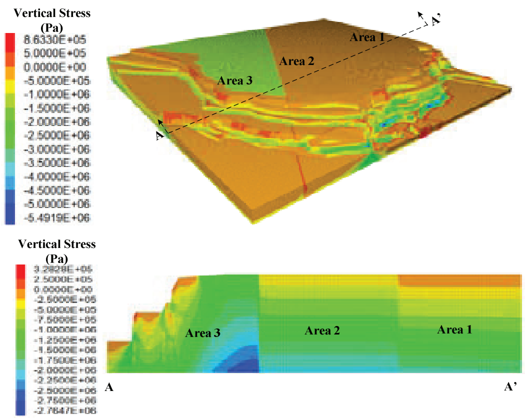


Fig. 12: Vertical in-situ stress condition before highwall mining.

7 Results of the numerical simulation

The development of vertical in-situ stresses both average and maximum on the web pillar in different seams in all three identified areas are shown in Figs.13 to 15. The strength of the pillar is calculated by Eq.(1). The Factor of Safety (FOS) of the pillars is calculated as a ratio of the strength of the coal pillar and the load on the pillar.Tables 2 to 4 show the FOS of the web pillars in different areas of PCP-3. The web pillars in Area-1 and Area-2 are found to be stable from the stability point of view as the FOS is close to 2.0. The FOS of web pillars in Area-3 is found to be 1.6 to 1.7 for maximum stress conditions which are considered medium-term stable. Therefore, the surface structures from this area are to be shifted before starting the extraction. The dimensions given in Tables 2, 3 and 4 are being followed during the extraction of coal from Highwall of Panel - F in the PCP-3 area of West Bokaro Mine of M/s Tata Steel Limited.

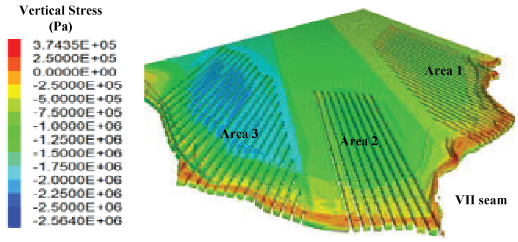


Fig. 13: Vertical stress developed on web pillars of the three areas in VII seam.

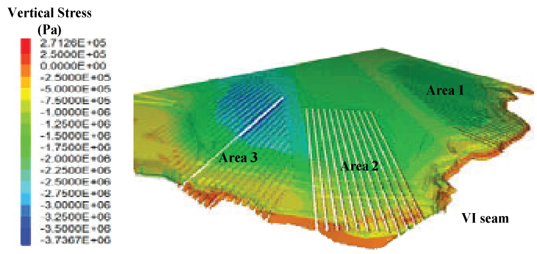


Fig. 14: Vertical stress developed on web pillars of the three areas in VI seam.

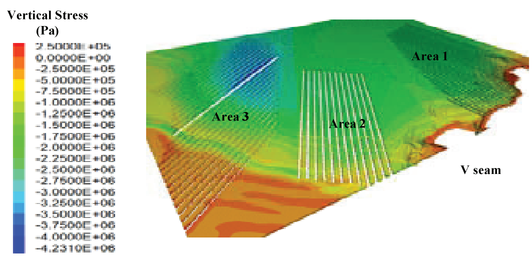


Fig. 15: Vertical stress developed on web pillars of the three areas in V~~I~~ seam.

Table 2: Safety factor of the pillar by numerical modelling method for VII Seam

VII Seam	
Area-1	
Width and length of web pillar	**8 m x 300 m**
Web Pillar strength (MPa)	3.0
Average stress on the web pillar (MPa)	1.5
FOS based on average stress	**2.0**

Web cut = 3.5 m, Height of pillar = 8.0 m; Compressive strength of coal = 20 MPa; Depth of cover = 24.0 m	
Area-2	
Width and length of web pillar	**9.5 m x 300 m**
Web Pillar strength (MPa)	3.37
Average stress on the web pillar (MPa)	1.6
FOS based on average stress	**2.1**
Web cut = 3.5 m, Height of pillar = 8 m; Compressive strength of coal = 20.0 MPa; Depth of cover = 34 m	
Area-3	
Width and length of web pillar	**12 m x 300 m**
Web Pillar strength (MPa)	4.12
Average stress on the web pillar (MPa)	2.41
FOS based on average stress	**1.7**
Web cut = 3.5 m, Height of pillar = 8.0 m; Compressive strength of coal = 20.0 MPa; Depth of cover = 66 m	

Table 3**:** Safety factor of the pillar by numerical modelling method for VI Seam

VI Seam	
Area-1	
Width and length of web pillar	**7 m x 300 m**
Web Pillar strength (MPa)	4.14
Average stress on the web pillar (MPa)	2.2
FOS based on average stress	**1.9**
Web cut = 3.5 m, Height of pillar = 5.0 m; Compressive strength of coal = 20 MPa; Depth of cover = 52.0 m	
Area-2	
Width and length of web pillar	**8 m x 300 m**
Web Pillar strength (MPa)	4.59
Average stress on the web pillar (MPa)	2.29
FOS based on average stress	**2.0**
Web cut = 3.5 m, Height of pillar = 5 m; Compressive strength of coal = 20.0 MPa; Depth of cover = 62.0 m	
Area-3	
Width and length of web pillar	**9.5 m x 300 m**
Web Pillar strength (MPa)	5.44
Average stress on the web pillar (MPa)	3.43
FOS based on average stress	**1.6**
Web cut = 3.5 m, Height of pillar = 5.0 m; Compressive strength of coal = 20.0 MPa; Depth of cover = 94.0 m	

Table 4**:** Safety factor of the pillar by numerical modelling method for V Seam

V Seam	
Area-1	
Width and length of web pillar	**7 m x 300m**
Web Pillar strength (MPa)	5.25
Average stress on the web pillar (MPa)	2.4
FOS based on average stress	**2.2**
Web cut = 3.5 m, Height of pillar = 3.8 m; Compressive strength of coal = 20 MPa; Depth of cover = 62.0 m	
Area-2	
Width and length of web pillar	**7.5 m x 300m**
Web Pillar strength (MPa)	5.62
Average stress on the web pillar (MPa)	2.7
FOS based on average stress	**2.1**
Web cut = 3.5 m, Height of pillar = 3.8 m; Compressive strength of coal = 20.0 MPa; Depth of cover = 76.0 m	
Area-3	
Width and length of web pillar	**8.5 m x 300m**
Web Pillar strength (MPa)	6.47
Average stress on the web pillar (MPa)	4.1
FOS based on average stress	**1.6**
Web cut = 3.5 m, Height of pillar = 3.8 m; Compressive strength of coal = 20.0 MPa; Depth of cover = 108.0 m	

Stability analysis of parting due to the development of web pillars in different seams at Area-1, Area-2, and

Area-3 is identified by detecting the yield zones from the outputs of numerical modelling. Fig. 16 shows the combined view of the yield zones of V, VI, and VII seams after the development of web pillars. From the figure, it is clear that there is no significant interaction between the seams due to the development of the web pillars. Hence the parting between V and VI seams and that between VI and VII seams will be stable during the development of the web pillars. From the analysis, it is also found that there is no significant interaction between the seams due to the development of the web pillars if the parting among the seams is more than 6 m. Where the parting between the two seams is less than 6 m, one seam should be extracted to prevent the failure of parting. Fig. 17 shows the stable conditions of the web pillars and surrounding rock mass after extraction of the coal seam.

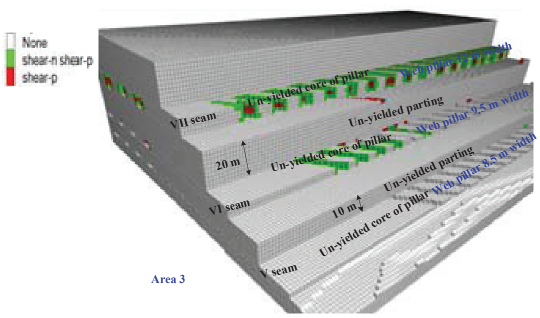


Fig. 16: Yield zones in the web pillars and rock strata in Area-3 showing stable parting.

Fig. 17: Stable highwall and web pillars after driving the web-cuts.

8 Conclusions

Highwall mining technology is an effective and efficient method to recover the coal locked-up in the highwall of open pit mines.The success of highwall mining depends on the optimum size of web pillars whose stability should be ensured during and after the mining operation. As the slenderness ratio (w/h) of the web pillars is less, the pillars are more prone to fail unless they are designed properly. The design of web pillars should consider the effect of slenderness (w/h ratio) as well as aspect ratio or ~~/~~rectangularity (L/w) of web pillars on their strengths. Most of the pillar strength formulae are derived under the conditions of the square pillars. In present practice, the strength of a long web pillar is estimated with these formulae by using the concept of effective width, i.e. equivalent width of square pillars for a given dimension of the long web pillar, subjected to the equal strength for both cases. It is obtained that the existing formula to calculate the effective width of web pillars overestimates their strength which may lead to unsafe working. In this study, an attempt has been made to quantify the effects of the aspect ratio or~~/~~rectangularity (L/w ratio) of the long web pillar on their strength and to derive the formula [Eq.(4)] to calculate the effective width for the long web pillars. It is found that when the L>>w for a web pillar, $w_e = 1.66w$, where w is the width of the web pillar (m). This finding has been implemented in the West Bokaro Mines of Tata Steel Limited to extract the coal under multi-seam conditions by highwall mining.

9 Acknowledgement

The authors are thankful to the Director, CSIR-Central Institute of Mining and Fuel Research, Dhanbad, India for his kind approval to publish this paper. A part of the studyhas beencarried out under the project funded by the Core Research Grant (CRG/2022/007750) of the Science and Engineering Research Board (SERB), Govt. of India. The views communicated in this paper are those of the authors and not necessarily of the organisation with which they are associated.

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PRINCIPLES OF SUSTAINABLE DEVELOPMENT OF MINING

Daria Goncharova

Abstract

This article discusses the principles of ensuring sustainable development of mining enterprises during periods of heightened risks and global challenges. The main directions of transformation in mining production are determined, based on the development of automated management systems with a constant increase in the number of objects and elements equipped with autonomous monitoring and accounting tools. It is shown that an important stage in the company's transformation is the restructuring and improvement of the organization of all technological processes, the development of personnel competencies with broad communication to all stakeholders, and establishing trust in new digital technologies. The main stages of transition to new technological paradigms in the development of mineral deposits using intelligent systems and digital technologies are defined, considering the specifics of mining production.

The ways to make mining companies stronger in times of risk and global challenges are presented. They say that we need to change how we do things by using automated management systems and more tools for tracking and recording. It's also important to restructure and improve how we organize our work and train our employees to trust and use new digital technologies. There are some main steps we should take when developing mineral deposits, like using smart systems and digital technology, while understanding the specific needs of mining production.

Keywords : sustainability, ESG, transformation

INTRODUCTION

The problem of ensuring the sustainability of large mining companies is currently the most relevant and widely discussed topic in scientific conferences, public forums, and the media. However, the concept of "sustainable development" in a global context and sustainable development of mining enterprises is understood differently by different authors (1-4). Sustainable development historically refers to the requirement of meeting current societal needs in changing conditions without compromising the future development of future generations. This approach is philosophically justified. However, an analysis of the functioning of mining systems in the face of global challenges has shown that in order for the systems themselves to develop safely and profitably, it is necessary to ensure their profitable operation throughout the entire period of mining by managing internal mining reserves in specific conditions of natural deposit development and technogenic formations, taking into account changes in mining, conjunctural, and socio-economic factors of the internal and external environment (5).

Sustainable development should ensure the absence of conflicts between the industries and nature with minimal impact of the technogenic environment on the ecosystem of the mining

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region. It is understandable that minimal disruption to the atmosphere, hydrosphere, lithosphere, and biota occurs when there are no technogenic changes to the state of the mineral resources during mining operations, and therefore, when refraining from extracting valuable minerals. Obviously, this contradicts the development of human society itself, which cannot exist without mining and consuming mineral resources, with the demand for them steadily increasing.

Principles of Sustainable Development of Mining Systems

To achieve this the above objectives, it is necessary to ensure sustainable development of mining systems based on the following principles :

- Profitability at all stages of mining, including the stages of resource development, operation, processing of technogenic raw materials, land reclamation, and multifunctional use of open and underground spaces.
- Efficiency, resource and energy saving in the extraction and processing of minerals with the generation of electricity directly in the mining system and the minimization of CO_2 emissions into the atmosphere.
- Development of environmentally balanced geotechnologies, which include the implementation of compensatory measures to mitigate the damage caused to the environment by mining and processing activities.
- Creating conditions for the growth of material well-being and solving socio-economic, cultural, spiritual, and sports and recreational problems, not only for the employees of mining companies but also for the entire population of mining regions (6).
- Development of openness and transparency in the corporate governance system of mining companies, including all its structural units, with adherence to business and corporate ethics.
- Digital transformation of mining systems, which involves the implementation of digital technologies in various business processes of industry enterprises.

The abovecan only be achieved through the intelligence of geotechnologies and the digital transformation of mining production with access to up-to-date information on the state of the technogenic and natural environment, production, and social processes. The mining industry does not meet the challenges and global trends associated with changes in the mineral resource base and the complexity of industrial exploitation of natural and technogenic resources. This necessitates the development of scientific and methodological foundations for the sustainable development of mining systems based on the establishment of patterns of interaction between natural and innovative technological processes in the conditions of intensive comprehensive resource development of the Earth using a rational structure and a combination of various, including non-traditional, geotechnological processes with specified parameters when transitioning to digital geotechnologies and robotics.

Ensuring sustainable development of the mineral raw material base is possible by determining the rational combination of geotechnological processes, their scale of implementation, and the introduction of innovative processes in mining operations. This includes innovative processes such as mineral separation, underground mining with mobile complexes, heap leaching, in-situ leaching, and energy production (7). These processes should be implemented in a programmable manner, while simultaneously utilizing natural and man-made resources of different qualities, including those previously considered non-commercial.

Mining Systems are Unique to Mining Sites

The functioning of mining systems is characterized by the uniqueness of each mining site, the changes that occur over time and space, the high unpredictability of the commodity market, and the lack of reliable information about the state of the mining site. Additionally, it is essential to consider the mutual influence of different geotechnological processes and parameters of mining structures on the properties of rock masses and the overall performance of the mining system. In these conditions, the sustainable functioning of mining systems can be ensured by synthesizing and expanding the range of geotechnological processes. This will provide rational values of mining system parameters during the design stage and throughout the entire life cycle of the mining site. These parameters should fully satisfy society's needs for mineral raw materials and guarantee the profitability of mining operations.

Development of scientific and methodological foundations for the sustainable development of mining systems - a necessity

It should also be noted that mining systems typically involve processes related to various technological methods.

At the same time, it is possible to combine manual and mechanized labor with elements of systems with automated production management in a unified technological space. In some cases, fully robotic intelligent geotechnologies with programmable management of mining equipment can also be used. This poses additional difficulties and requires a special approach to designing a sustainable mining system. In terms of ensuring the stability of the mining system, it is important to note the system's ability to change and destroy the basic conditions for which it was designed. Indeed, during the operation of the mining system, the balance reserves of the deposit are inevitably depleted, geological, geomechanical, gas and hydrodynamic conditions dynamically change because of man-made impact, and the economic and mineral resource potential of the developed area decreases. This necessitates the development of scientific and methodological foundations for the sustainable development of mining systems based on establishing the patterns of interaction between natural and innovative technological processes in the conditions of intensive comprehensive development of the Earth's mineral resources on the principles of sustainable development. However, the innovative development of geotechnology is hindered by the discrepancy between the levels of development of mining education and mining sciences.

Transformation of Mining

Over the past two decades, mining has undergone significant transformation towards digitization due to the development of mining transportation equipment and information systems. The digitization of mining production is based on the advancement of automated control systems, which continuously increase the number of objects and elements equipped with autonomous monitoring and accounting capabilities. The issue of digitization of mining production is addressed both in terms of the digital transformation of mining technical systems throughout the entire cycle of comprehensive subsoil development, as well as the creation of a methodology for rating the investment attractiveness of mining companies. Many investors take into account the company's rating when making decisions regarding investments.

ESG rating is based on the principles of responsible investing: Environmental + Social + Governance, evaluated according to global criteria applicable to all mining companies worldwide. The rapid growth of responsible investing forces Russian corporations to follow global trends. According to the British auditing and consulting company EY, 97% of investors today rely on the ESG index when making investment decisions. Therefore, in terms of popularity, ESG can be compared to credit rating evaluation - one of the key indicators for investors. The sustainable development of mining industrial territories implies the coordination of three aspects, the successful interaction of which can only be achieved through the alignment of interests of the resource owner, resource users, and the population of mining regions, along with the balanced development of higher mining education and science and the leading role of mining companies.

Sustainability in mining refers to the adoption of environmentally and socially responsible practices in the extraction, processing, and management of mineral resources. As a global industry, mining has a profound impact on the environment, human health, and the welfare of local communities. Thus, the need for sustainable mining practices has gained increasing recognition, prompting many mining companies to undertake business transformation to integrate sustainability into their operations.

The importance of business transformation lies in the fact that traditional mining practices often result in significant environmental degradation, including deforestation, habitat destruction, water and soil contamination, as well as greenhouse gas emissions. Moreover, mining activities can have adverse social impacts, such as displacement of communities, violation of indigenous rights, and compromised labor conditions.

To address these challenges, mining companies are undertaking business transformation to mitigate their environmental footprint and improve the social and economic outcomes associated with mining activities. This transformation involves adopting innovative technologies and practices that minimize resource usage, reduce waste generation, and promote energy efficiency. Additionally, companies are increasingly focusing on community engagement, stakeholder consultation, and responsible supply chain management to build stronger relationships with host communities, ensure local benefits, and respect human rights.

Business transformation in mining also includes enhancing transparency and accountability through robust monitoring and reporting systems. By disclosing environmental and social performance indicators, companies can demonstrate their commitment to sustainable practices and engage in constructive dialogue with various stakeholders, including regulatory bodies, local communities, and investors.

Ultimately, the importance of business transformation in mining lies in its potential to create a more sustainable future for the industry. By integrating sustainability into their core operations, mining companies can mitigate environmental and social risks, protect biodiversity, improve resource efficiency, and enhance the long-term viability and reputation of the sector.

CONCLUSION

Thus, ensuring the stability of the mining technical system throughout the entire period of field operation is only possible by changing the requirements for the natural resources involved in operation in line with the dynamics of mining work development, with the corresponding changes in their design component and justification of the principles of creating information technologies for working with large amounts of data in solving design, operation, conservation, and elimination tasks of mining technical systems. More complex stages in the company's transformation are the restructuring and improvement of the organization level of all technological processes, development of personnel competencies with wide dissemination to all interested parties, and building trust in new digital technologies.

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NEAR SURFACE GEOPHYSICAL INVESTIGATIONS FOR MAPPING THE SUBSURFACE FEATURES RESPONSIBLE FOR THE CRACKS DEVELOPED IN THE VIEW POINT PATCH, DIPKA OC MINE, SECL.

Dr Sayan Ghosh, Ayush, Amit Joshi, Bikas Kumar, S. Chatterjee, I D Narayan

Abstract

Dipka Opencast mine is one of the mega mines of CIL operated by SECL in Korba district of Chhattisgarh state. The annual production of Dipka OC mine in the FY 2022-23 was around 40 MT and the coal dispatch of 36.90 MT which was the highest ever recorded by the mine since commencement. The massive contribution of this OC project depicts the significance of the mine with respect to the production and safety point of view.

While removal of the overburden through blasting in the month of March '23 in the view point patch located in the North Eastern part of the project, severe cracks and displacement was recorded by the slope stability radar installed in the project by the mine officials and the production in the patch was paused due to safety factors. Urgent investigation was sought by SECL from CMPDI with a fast remedial solution and the geological conditions responsible for development of the cracks.

High resolution electromagnetic scanning was accomplished using Ground Penetrating Radar (GPR) at two locations with frequencies of 20MHz and 350 MHz for mapping low resolution higher depth anomalies and high resolution lower depth anomalies respectively. The objective of this survey was to support the inference drawn for the slope stability on the following grounds :

1) *To locate the position of the Faults F10 and F13 over the working coal face of the view point patch.*
2) *To correlate and examine the reasons behind the cracks developed.*
3) *To examine the findings from the survey and derive mining recommendations.*

The near surface data acquisition were performed using GPR and ERI equipment by the geo-scientists of CMPDI RI-V on 21.03.2022 and 24.03.2022 respectively. The data acquired was brought to the Processing and Interpretation Centre of CMPDI RI-V, Bilaspur and was processed and interpreted. Three major fault intersection was clearly depicted from the interpreted sections of the data acquired, which were the weaker planes near the development mine phase and were responsible for the development of cracks and also the displacement.

CMPDI RI-V Bilaspur

LOCATION OF DIPKA OC MINE

Dipka Opencast Mine located in Korba coalfield, geographically located in Korba district of Chhattisgarh state. The annual production capacity of Dipka OC mine is 35 MTy as per records.

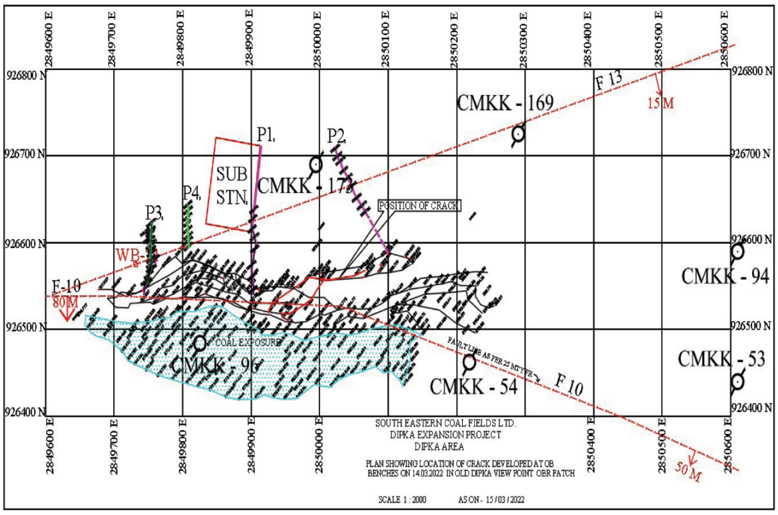

Figure 1(a) : Location of the GPR and ERI scans locations across the bench in mine plan

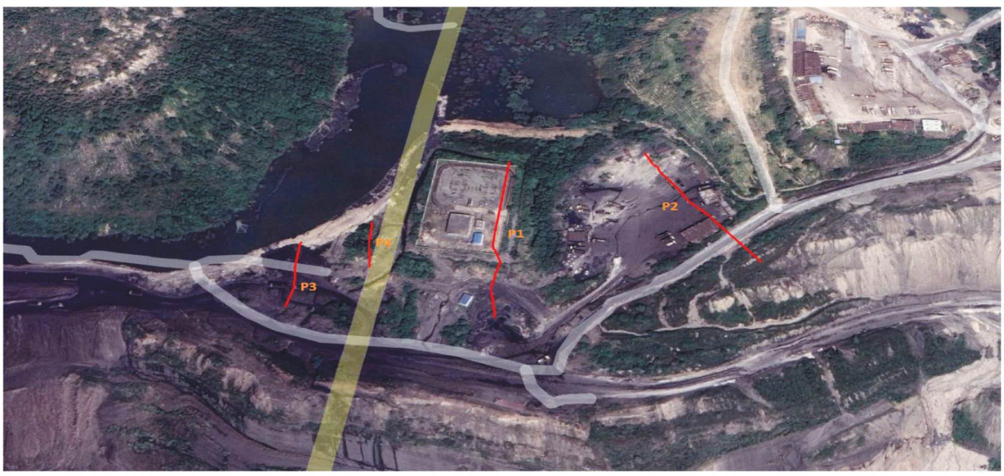

Figure 1(b) : Satellite imagery of GPR and ERI scans locations across the bench in mine plan

DATA ACQUISITION PRINCIPLES & METHODOLOGIES

Ground Penetrating Radar

Ground-penetrating radar (GPR) is an equipment which uses radar pulses to image the subsurface. It is a non-intrusive method of surveying the subsurface to investigate underground utilities. This method uses electromagnetic radiation in the microwave band (UHF/VHF frequencies) of the radio spectrum, and detects the reflected signals from subsurface structures.

GPR uses high-frequency (usually polarized) radio waves, usually in the range 10 MHz to 2.6 GHz. GPR requires two main pieces of equipment – a transmitter and a receiving antenna. The transmitter sends electromagnetic energy into the soil and other material. When the energy encounters a buried object or a boundary between materials having different permittivity, it may be reflected or refracted or scattered back to the surface. A receiving antenna can then record the variations in the return signal. The principles involved are similar to seismology, except GPR methods implement electromagnetic energy rather than acoustic energy, and energy may be reflected at boundaries where subsurface electrical properties change rather than subsurface mechanical properties as is the case with seismic energy. The equipment used in this survey is by the manufacturer M/S GSSI, USA with antennae 350 MHz and 20 MHz Model 3200 MLF of CMPDI RI-V, Bilaspur.

Multiple scan were carried out in the Dipka OC, using multi-frequency combinations GPR over the insitu OB bench (shown in the Figure 1). The orientation length of the profiles along with the GPR parameters are mentioned in the Table 1 below:

Profile Name	Length in (m)	Orientation Strike	Location	Type of Survey	Frequencies (in MHz)	Maximum Depth (m)
P1	160	N-S	Sub-Station	GPR (70m) & ERI (160m)	20 MHz	35m
P2	140	NW-SE	OB bench	GPR (120m) & ERI (140m)	350MHz; 20 MHz	8m; 35m
P3	70	N-S	Across Haul Road	GPR only	350MHz; 20 MHz	8m; 35m
P4	50	N-S	Across Haul Road	GPR only	350MHz; 20 MHz	8m; 35m

Table 1 : Details of the profiles over which the ERI and GPR scans were carried out to delineate the reason behind the cracks

ELECTRICAL RESISTIVITY IMAGING (ERI)

The resistivity methods are active geophysical techniques that are used to study variation in the apparent resistivity due to the change in the rock composition of the earth in both vertical and horizontal directions. The apparent resistivity of the formation is calculated by measuring the change in the potential (excluding the passive potential naturally present in the formation) in the vicinity of the applied external electric current. Since the external applied electric current is known so the apparent resistivity of the formation (given as ?) can be calculated with the help of Equation 1, where ?V is the potential difference created due to the induced current I and K is the geometrical factor.

$$\rho = \frac{\Delta V}{I} K \quad \text{... Eqn. (1)}$$

The conventional resistivity measurement, as developed by the Schlumberger brothers in the early 1920's consisted of four electrode setup (two potential electrodes named as M&N separated by a distance MN and two current electrodes A & B separated by a distance AB) arranged in different arrays such as Wenner-Alpha, Wenner-Beta, Wenner-Beta, Schlumberger, Pole-Pole, Wenner-Schlumberger, Pole-Dipole, Dipole-Dipole etc. The geometrical factor K is different for the above-mentioned arrays.

The profiling and sounding techniques are used to measure the 1D variation of apparent resistivity in either horizontal or vertical direction. Therefore imaging method also known as the electrical resistivity tomography (ERT) was carried out to see the variation in both horizontal as well as vertical direction.

DATA INTERPRETATIONS

The low frequency 20 MHz data was acquired to increase the depth of investigation of the survey upto 35m as well as to capture the Faults F10 and F13 in the seam across acquired section over the profile lines P1, P2, P3 and P4. The objective of acquiring the data in this specification is to observe the difference in the continuity of the in situ seam LK after faulting.

Since, the depth of interest was more than 10m across the study area, so the high frequency 350 MHz sections acquired over the profiles showed less anomaly. The data low frequency GPR data processed in software RADAN were utilised to generate depth sections along profiles P1 to P4 shown in Fig 2 to Fig 4.

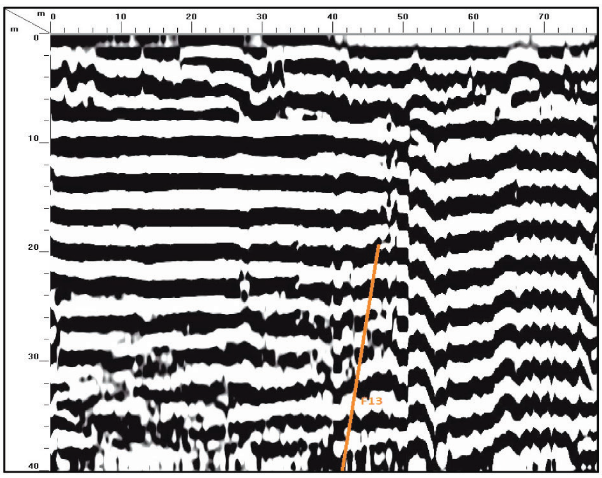

Figure 2(a)

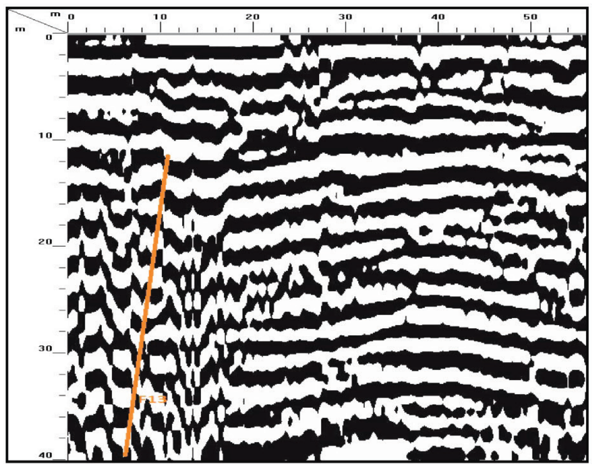

Figure 2(b)

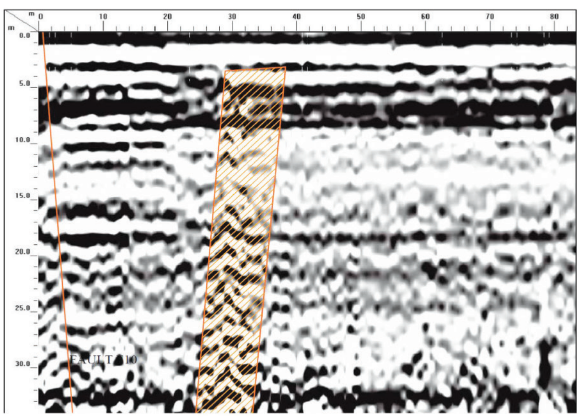

Figure 2(c):

Figure 2(a): 20 MHz processed sections acquired over profile P3 marked with Fault F13.
Figure 2(b): 20 MHz processed sections acquired over profile P4 marked with Fault F13.
Figure 2(c): 20 MHz processed sections acquired over profile P1 marked with Fault F10.

The profiles P1 laid near the sub-station orienting almost N-S showed stratified events from the surface because this profile was almost laid over the surface (with in-situ soil cover). The profile was started from the maximum southern extent on the surface proceeding towards north, where traces of the Fault F10 was observed in the very initial position of the section (shown in Fig 2(c)). In addition, a zone with ambiguous reflection was observed from 28m to 38m distance from 0 on P1 shown in Plate 1 which could be due to a loose fractured zone developed due to the fault F10. However, the strike of F10 could not be traced due to limited approachability in the southern extent in the view point patch.

The profiles P3 and P4 acquired near the Weight-Bridge 21 was from South-North where the fault F10 could not be intersected due to limited approachability in the south. However, the fault F13 could be visible in the depth sections of Profile P3 and P4 at 50m and 12m respectively shown in Figure 2(a) and Figure 2(b).

Two number of profile lines as P1 and P2 were taken at Dipka OC mines in which P1 is taken over the Substation from South to North direction of total spread of 160m and P2 is taken over the OB bench in NW to SE direction of total spread of 140m for measuring the variation in the apparent resistivity in the formation. Resistivity imaging were carried out to get the pseudo depth section based on true resistivity model (obtained from inversion algorithm) of the formation.

Sl. No.	Profile	Easting	Northing	Direction	Length
1.	P1 Start	2849903.46	926541.42	S-N	160m
	P1 End	2849914.64	926711.67		
2	P2 Start	2850021.93	926710.19	NW-SE	140m
	P2 End	2850099.59	926589.07		

Table 2. Coordinates of the profile line along with their respective length

Electrical Resistivity Imaging with Wenner configuration and unit electrode spacing 4m were carried out over the profile line P1 at substation (having spread length of 160m). The Rapp plot and respective Pseudo depth sections are shown in Figure 3. The Fault F13 marked in the section at distance of 80m from 0m towards South to North direction. Figure 3 ERI section of the Profile P1 over the Haul road marked with the tentative Fault F.

The southern part of the fault zone in ERI section shown in Figure 3 shows low resistivity stratified formation above the depth of 20m whereas beneath the depth of 20m, the resistivity sharply increases up-to more than 3000 ohmm which is a probable indication of existence of the carbonaceous horizon.

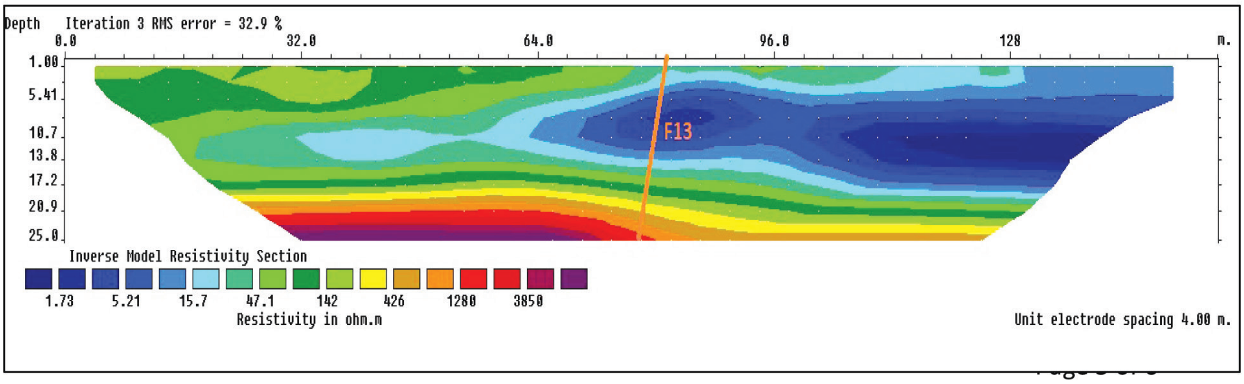

Figure 3 : Electrical Resistivity Imaging with Wenner configuration and unit electrode spacing 4m showing intersection fault F13.

CONCLUSIONS

- GPR sections clearly depicts the Fault F13 in Profile P3 & P4 over the working coal face of the view point patch.

  The strike of fault F10 was attempted to be interpreted through the GPR and ERI section, but the same was intersected in only P2 due to limited approachability.
- After integration of the findings from the Electrical Resistivity Imaging (ERI) and Ground Penetrating Radar (GPR) sections, the existence of Fault F13 is located.
- The dipping direction of the Fault F13 is towards the southern side and the continuity of the strata across the fault is seen to be discontinued.
- The probable existence of the coal seam across the fault is interpreted from the high resistivity zone seen in the ERI section from depth of around 20m to 25m in the South of fault F13.
- The GPR section also showed a similar structure where the event beneath the depth of 20-30m is interpreted as the target carbonaceous horizon.

SOCIO-PSYCHOLOGICAL APPROACH FOR SUSTAINABILITYIN COAL SECTOR IN INDIA

Dr Peeyush Kumar*

Abstract

Coal Mining plays an important role towards economic development of the country. Coal is a major source of energy and accounts for about 55% of requirement of the country. However, use of coal has always been considered unfriendly to environment and to the community living nearby. There has been adverse impact on the population due to displacement, reduction in income from agriculture, loss of natural assets and capital, pollution and adverse impact on health. Despite the fact, Coal Mining promises better infrastructural expansions like transport infrastructure like roads, medical facilities, electrification etc. and is a key driver of the economy of the reason.

Coal is a non-renewable resource and has been formed over thousand years of favorable conditions below earth crust. The need of coal is not only for present generation but also for future generations as well and as such sustainable development of Coal Sector is very-important consideration especially in the eastern part of country. To ensure conservation of coal, its continuous availability for the present generation, number of efforts have been taken to ensure environment friendly mining and diversified use of coal other than power. However, the sustainability of the sector primarily depends on social acceptance and the mind-set of the community living around. In order to ensure continuation of operations and attain conservation of coal, there is a need to positively affect the behavioral traits of community so as to align them with the objective of organization.

Most of the coal in India is produced from open cast mines and sustainability of the sector depends on enormous acres of land required. A number of challenges are being faced by coal companies in rehabilitation and resettlement of PAFs and these become even more challenging in case of expansion of existing projects. In order to take up any coal mining projects, economic and mining feasibility are ascertained and in line with the provisions of Environment Impact Assessment and Environment Management Plan, suitable actions are taken to protect environment and the interest of local community. Despite better R&R package and financial assistance, it has been observed that there is a bit of hesitation among the local community in parting their land or cooperating with management in mining activities. This shows that there is something else than the economic need of the population and may be related to social and psychological need.

Challenges being faced with mining organizations are to understand the social and psychological need of the community and find out factors which can influence them. The

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psychological climate is an individual's perception and interpretation of various indications & connotations from these Rules, processes and rehearses of the organization within the working environment. It has been found that positive psychological climate is a contextual factor that affects the behavioral traits of individuals and can affect positively to guide the behavioral intension of community to contribute towards coal mining sector. It has also been found that Perception of Corporate social responsibility, Perception of Organizational Fairness & Perception of Organizational Support, are main factors that affect the Positive Psychological Climate.

Organizational behavior plays a significant role in generating positive psychological climate in the community. Considering perception of organizational support which shows a major role in creation of positive psychological climate, there is a need for policy makers to give priority while setting policies & strategies for the organization. Though perception of corporate social responsibility is not rated as the main factor, but a number of organizational supports to community come from the schemes of corporate social responsibility. Policy makers need to understand and try to convert the scheme in developing better perception of organizational support. A positive psychological climate affects the behavioral traits of individuals to contribute to the sustainable environment of the coal mining sector. Felt Obligation, Virtues, Strength, Openness to Change & Attitude played a crucial role and positively impacted Behavioral Intension of the community to contribute to the organization.

Coal Mining Sector is site specific and requires long gestation period for implementation. Cooperation from local community is very important not only for getting required workforce or land but also to develop support industries such as workshops, developing small scale industries etc. Mining Sector has separate provisions of fund for Corporate Social Responsibility and Welfare of local community and the attention of socio-psychological aspect will guide the managers and organization in prioritization of resources towards creating positive psychological climate. Investment made and infrastructure created to guide the behavioral intention of local community with help in generating goodwill and thus ensuring sustainability of the sector.

Keywords :
energy security, sustainability, coal sector, socio-psychological model, mining

1. INTRODUCTION

Coal is the most important source of energy in India and is abundantly available in the country. Keeping in mind energy security of the country, Sustainability in coal sector plays an important factor. Further, Coal is a raw material for various other industries and its mining plays an important role in sustainability of various industries. However, there is an adverse impact of coal mining on the community living thereby, environmental conditions in the areas nearby thus resulting into negative health impacts. Sustainability in coal sector can be achieved with proper attention to the inclusive growth of community, economics in operations and minimal impact to environment. For taking up any industry, economics plays the most important role but the environmental and social considerations have now become an integral part in taking up any project and provisions have been made in the Rules and Regulations to take care of these concerns. Various measures have been taken by the Government to ensure environmental protection and it is ensured that environmental impact assessment (EIA) are conducted in the proposed area so as to ensure that there is not substantial change in the parameters in pre and post operations. Environment protection measures are captured in Environmental Management Plan (EMP), which is a mandatory requirement while starting any coal mining project. Further, to augment the EMP and to include impact on social and economic life of community, a provision has also been made to conduct public hearing before finalization of EMP. However, in practice, public hearing takes care of the economic benefits to the community and it does not capture the social and behavioral need of the community. It has been seen that the social acceptance of the project is dependent not only on economic need but also on many other factors and as such the resistance to the project continues in the mind of community which adversely affect start of new project or expansion of existing project.

2.RESEARCH GAP :

It is a fact that Mining has always been considered to have negative impact on environment and is associated with large scale displacement thus developing adverse attitude of local population towards the sector. This is perceived as a threat to the local traditions and living practices. In India, coal is available in abundance and is not only the prime source of energy but also a major input for various industries. Growth of sector is highly dependent on availability of land especially in open cast mines. There are many positive aspects in coal mining such as assurance to get better infrastructure and healthier income-earning atmosphere, which is the main factor influencing the local community to accept starting of the coal mining projects.

A number of researches have been done on dealing social and economic aspects of local community. The impact of these considerations has also been studied in detail to find out satisfaction level of community. Studies have also been done on the psychological aspects of the employees and their role in helping the organization to grow. However, studies are lacking to find out the social and psychological mindset of the community living thereby and the factors which can affect behavioral traits of the community. Consent of community is very important for starting a project and also for its continuous operation and as such there is a need to understand various behavioral traits of the individuals which plays an important role in shaping their behavioral intension. Further, organizational behavior also plays an important role in shaping the mind of people living nearby and studies are lacking to find out impact of organizational behaviors on the behavioral traits of community and means to satisfy the social and psychological needs. An attempt has been made to find out relationship of these factors to ensure positive approach of organization in its behavior towards community to achieve its objective.

3.RATIONALITY OF STUDY :

Considering the importance of coal and need of energy for the growth of any country, number of studies has been made to ensure continuation of coal mining operations. Majority of these studies are done in the areas such as impact of coal mining, economic benefits to the community as well as to the organization, overall development of the region, behavioral aspects of employees and approach for motivation etc. Inclusive growth of the region is very important and for any organization to grow in the region it has been found in practice that dealing with only economic and environmental aspects has yielded negative results in continuation of the sector. There are many aspects, such as, affinity towards their land, culture and practices also play very important role. There is a need to understand the factors that can have positive impact on the behavioral traits of individuals and understanding the impact of organizational behaviors so as to modify and fine tune it for the benefit of organization. Eastern part of the country is relatively less developed and there is a need to improve basic facilities such as education, health and development of the region. The region is blessed with coal deposits and as such sustainability of the sector will help in economic growth of the region. Accordingly, a model has been conceptualized so as to study the roles coal companies can take up so as to motivate the community to contribute positively for the organization.

4. LITERATURE REVIEW

Organizations consist of individual's like- family, neighborhood, social networks, community etc. As such, individual plays an important role in sustainability practices in an organization. The fundamental requirement for sustainability lies in the responsible operations of the organization (Pojasek,2012). Operation of an organization can be influenced and changed by espousing its activities to the concept of sustainability and this eventually help all the stakeholders like the individuals, employees, community nearby, economy, environment and also the next generation. Various organizations attempt to escape the delineation plight by adopting the version of Brundtland commission- as the progression that addresses the issues and requirements of the present without compromising the ability to meet the essential requirements of coming generations (WCED, 1987).

Psychological Climate can be defined as an employee's perception of the rules, rehearses, practices, systems and processes and this indicates as to what is significantly appreciated and rewarded in the organization (Schneider, 1990). The psychological climate is the perception and interpretation of individual about the organization at the individual level (James et al., 2008). Rousseau (1985) in his study has claimed that psychological climate is a more proximate predictor of behavior than organizational climate because both psychological climate and behavior are individual-level constructs. Growth of an organization can only be achieved by ensuring inclusive growth of the entire region. Organization believes in giving back to society for its development through Corporate Social Responsibility. This is very important recently when the community has become aware of the environmental and health impact. In a business context, it has been suggested that "a sustainable company generates benefits for its shareholders while protecting the environment and improving the lives of those with whom it interacts.

It has also been found in many studies that individuals with solid exchange ideology reciprocate organizational support to support organizational objectives by changing their behavior (Eisenberger *et al.*, 1986). Further, it has also been found that the perception of organizational support is related to the happiness of individuals. Individuals' capacities, emotions, virtues, and strengths and the consequences of these traits, such as satisfaction, psychological well-being, and happiness, are essential determinants of pro-environmental actions (Verdugo V.C., 2012). In a study done by (Eisenbergeret al.2001) and (Baran *et al.*, 2012), it was found out that perceived organizational

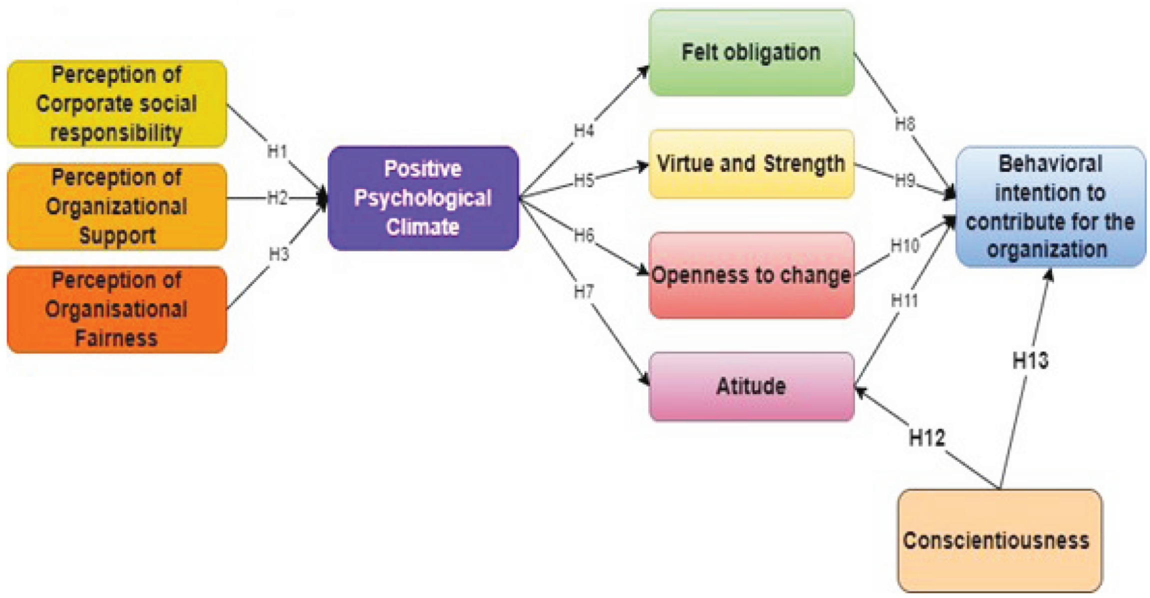
Support (POS) will lead to a felt obligation (FO) from a person to participate in the growth of the organization. It has also been established that openness to change (OC) in the mind of individuals positively influences the development and changes occurring (Ziegler et al., 2012). Openness to change can also be explained as a behavioral trait in an individual about willingness to accept new stimuli (Trapp & Ziegler M (2019). Attitude is defined as the "Behaviour based on conscious or unconscious mental views developed through cumulative experience". Often it has been found that a regular pattern exists in the behavior of individuals to follow the norms of society and Rules and Laws, approach towards achieving a goal and work as per plan. The same is termed Conscientiousness (Roberts, Jackson, Fayardand Edmonds, 2009). Individuals who are open to experiencing changes have high imagination skills. Also, agreeable people usually possess traits such as sympathetic and helpful, whereas individuals with high conscientiousness scores are associated with responsibility, persistence, trustworthiness, and purpose.

Behavioral intention is the intention of any individual in a community to perform in a particular way. It is assumed that intentions capture the Motivational factors which influence behavior. In simple words, a solid intention to engage in a particular behavior results in a higher chance of its performance. However, It should be kept in mind that behavioral intention leads to behavior; only the person can decide whether to perform or not. In many studies, evidence has been studied of which were responsible for actions due to behavioral intentions, and studies have also been performed on the relationship between intention and actions. The behaviors have ranged from straightforward strategy choices to actions of social significance, like having an abortion, smoking marijuana, etc. You can see some examples of behaviors involving a choice among available alternatives.

5. CONCEPTUALIZED FRAMEWORK:

After going through the literature available and consulting practicing managers in coal mining sector, Positive Psychological climate has been identified as contexual factor which plays an important role in modifying behavioural traits of community. Organisational behaviour, positive psychological climate, behavioural traits and its impact on behavioural intention to contribute towards organisation have been linked with each other and have been linked with 13 hypothesis for testing through survey in the region affected by mining operations.

A Model showing the impact and connections between organization behaviors and its impact on individual's traits to guide community participation towards sustainable Mining.



A Model showing the impact and connections between organization behaviors andits impact on individual's traits to guide community participation towards sustainable Mining

6. HYPOTHESIS DEVELOPMENT :

Development of Positive Psychological climate: Psychological climate is the perception of individual and interpretation of various indications & connotations from the rules, processes and rehearses of the organization within the working environment (James et al., 2008 & Schneider, 1990). At the onset, individuals living in community nearby the organization perceive the organization's rules, policies and its purposes and then understand the signals from organizational events within the surrounding and then act upon it or behave accordingly (James et al., 2008). The policies and practices of organization affect significantly individual behavior but it may not directly influence desired individual behavior with its practices and policies rather it influences through various mechanisms (Jiang et al., 2012). Psychological climate is always considered as one of the contextual factors which acts as the fundamental mechanism in transmitting the influence of the policies, processes & practices in the organization to change the desired behavior of individual.

Influence of psychological climate : Climate as contextual factor do have substantial potential to stimulate the attitude and behavior of individuals and social exchange is regarded as a significant theory in predicting and understanding the attitude and behavior of the individuals. Social exchange theory is regarded as a significant theory in predicting and understanding the attitude and behavior because the ways individual reciprocate in group on the perception of the psychological contract follow social exchange theory. Based on the above discussions & grounded on the idea of social exchange theory it is suggested that, the likelihood of the employees in reciprocating positive actions that are desirable to the organization's objectives through positive attitude, felt obligation, virtue & strength and change adaptiveness will be enhanced when the employees perceive and interpret a positive psychological climate.

Felt obligation & Behavioural intention : The way individuals reciprocate is contingent on the perception of the psychological contract which is decided on Social Exchange Theory and accordingly social exchange is regarded as a significant theory in predicting and understanding the attitude and behavior of the employees in organization (Hui et al., 2004a). The reciprocal action in accordance to the perception perceived by an individual as per social exchange is to maintain an equilibrium in the exchange relation. Accordingly, it is hypothesized that Felt obligation of an individual is directly related to Behavioural intentions.

The link between Virtue & Strength with Behavioural Intention: Empirical evidence suggests that virtues & character strength are linked to pro-social behavior, and provide early indications to a particular virtue & character strength which is capable of explaining and promoting pro-social behavior at work. Based on the above discussions it is hypothesized that Virtue and strength of an individual is related positively to behavioural intentions.

Openness to Change and Behavioural Intention: In the present study, the focus is on the degree to which individual is ready to accept the intervention and the belief that it will be good to him, in other words, the characteristics which are shared across the multiple factors. Accordingly, the term used is openness to change. Based on the above discussions it is hypothesized that Openness to change is positively correlated to Behavioural intentions.

The link between Attitude-Intention-Behaviour: The extant literature reveals that, various models encompass diverse terminology in explicating the attitude – behaviour relationship, however the majority of the models suggest the causative links from attitude to intention and in turn the required behaviour. Since attitude leads to behaviour through intention, comprehending behavioural intent is essential to predict the actual behaviour.

Conscientiousness : Conscientiousness can be defined as individuals' personality characteristic like diligent and careful in the five-factor model. It is proposed that conscientiousness of individuals positively affects sustainability oriented attitude and intention of the community people where the organization is operating.

7. DISCUSSIONS & CONCLUSION

In the conceptual framework mentioned above in point 5, thirteenhypotheseshave been derived, wherein seven hypotheses are directly connected with positive psychological climate. Positive psychological climate is a contextual factor which is affected by Organizational behavior and affects human traits. Perception of corporate social responsibility, perception of organizational support and perception of organizational fairness plays an important role in creating Positive Psychological Climate. Positive psychological climate stimulates various traits of human such as Felt Obligation, Virtues and Strength, openness to change and attitude. All these seven hypothesized relationships have been conceptualized to be positively related and, in fact, the statistical results of the study supported these assertions. Individuals' conscientiousness and their impact on sustainability-oriented attitude of the community impact positively to the sustainability-oriented Behavioral intentions. Further, human traits such as Felt obligation, Virtues and Strength, openness to change and attitude have a greater impact on Behavioral intentions to contribute towards sustainable development of an organization.

The result of the study revealed that Perception of Organizational Support found is the most influential factor for Positive psychological climate followed by Perception of Corporate social responsibility and Perception of Organizational Fairness. This may be because, it depends on individual's attribution concerning the organization's intent behind their receipt of favorable or unfavorable treatment. So, when an individual accepted the positive treatment of others, there is a natural tendency that a psychological pressure and sense of obligation is generated to pay off, and as such generate an attitude or behavior of giving positive response to the one given. Corporate social responsibility (CSR) is context-specific organizational actions and policies which take into account stakeholders' expectations and the triple bottom line of economic, social, and environmental performance.

The study further showed that positive psychological climate has strong influence on felt obligation as Felt obligation which is related to norm of reciprocity. Thus, felt obligation mediates the relationship between perceived organizational support and affective organizational commitment, organizational spontaneity, and in-role job performance in such a way that it benefits the organization. The second most influence of positive psychological climate is on Virtues and Strength. Virtues and strength are associated with improved well-being of individuals and better functioning of organization that leads to sustainable behavior of the individual.

Results of this study showed that Felt Obligation, Virtues and Strength, Openness to Change & Attitude played a crucial role and impact positively on Behavioral Intension to contribute for the organization. Among these factors Attitude turn out to be the most influential factors which shows the greater impact on Behavioral Intension followed by Openness to Change, Felt Obligation & Virtues and Strength. Since, Attitude has behavioral component that influence whether and how to react. Hence, this leads towards the Behavioral Intention. As per result, Openness to Change is the second most influential factor for Behavioral Intention. Since, Openness to Change referred to general willingness to engage into new stimuli. So, it creates positive impact on Behavioral Intention. Felt obligation relates to the norm of reciprocity, which suggests that employee's feel compelled to help the organization in reaction to perceived beneficial treatment from the organization. Result of this study showed that Felt Obligation impact positively on Behavioral Intention. Behavioral Intention covers the larger domain of psychological antecedents like altruistic, equitable actions etc. These characteristics can be categorized as Virtues and Strength.

7.1 Practical Implications:

Sustainability of Coal Sector and its growth is heavily dependent on inclusive growth of the community living nearby. Mindset of the community and acceptance of mining projects depends on the aspirations of the people in terms of economic benefits as well as their sentimental mindset for the land which may be taken out from their possession. Social and economic factors are always taken into consideration while formulating project proposals, however behavioral aspects lag a lot. This study has attempted to find out the role of organizational behavior which plays a significant role in generating positive psychological climate in the community which is a contextual factor. The factors of organizational behavior taken in the study were Perception of Corporate social responsibility, Perception of Organizational Fairness & Perception of Organizational Support. Considering perception of organizational support which plays a major role in creation of positive psychological climate, there is a need for policy makers to give priority while setting policies & strategies for the organization to set positive psychological climate around the coal mining industries. Though perception of corporate social responsibility is not rated as the main factor, but a number of organizational supports to community come from the schemes of corporate social responsibility. Policy makers need to understand and try to covert the scheme in developing better perception of organizational support.

The other part of the model was to find out impact of positive psychological climate on the behavioral traits of individuals living in the community nearby. From the data analysis (Kumar Peeyush 2023), it has been found that the Attitude of the people is greatly affected due to positive climate created by the organization through their good perception in the mind of people. The research and data analysis has also shown that the positive psychological climate affect positively to all the traits of individuals identifying and studied in this research such as Felt Obligation, Virtues and Strength, Openness to Change & Attitude. Openness to change in the mind of local community is very important since the rehabilitation process even if giving better life needs to be accepted in the mind of people. This is one of the important traits which need to be influenced by policy makers by developing suitable organizational strategy ensuring necessary positive psychological climate. Sustainable development of coal sector is need of hour and can be achieved by making suitable policies in terms of organizational behaviour so as to generate positive psychological climate. A study on behavioural traits of the community has shown positive connection due to positive psychological climate. Behavioural traits of the community can then be molded into intention of the community to contribute for the organization. The conception of the study will definitely help policy makers to develop a quality relationship with the people nearby the industry that will leads to a sustainable environment.

8. LIMITATION & FUTURE DIRECTION :

There has been limited research focusing impact of psychological parameters on sustainable development. This study is one of empirical studies to identify the rationale of positive psychological climate & how this impact on human traits and mold them to ensure positive intention to contribute for the organization. However, the same size is limited to Jharkhand and West Bengal. The model needs to be tested with samples drawn from other States. As this study has showed some interesting results, a number of limitations may be inherent in it. A number of studies have concluded that gender differences play a moderating role in the relationship between perceptions, psychology and behavioural intention. This study showed that approximately 87.1% and 12.9% of the respondents were male and female, respectively. The findings may not properly reflect the population distribution of gender and cause a bias against the current results. However, no systematic non-response bias was stated among the sample respondents in gender regards. In this study, judgmental sampling technique was adopted to collect the data. Hence, collected response may reflect some bias.

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KEY THRUST AREAS FOR SUSTAINABLE COAL MINING

By Prof. Binay Dayal

SUSTAINABLE DEVELOPMENT

In the last three decades the terms "Sustainable Development" and "Sustainability" have been in use by government and policy makers worldwide. It is commonly agreed that sustainable development defined in 1987 by the Brundtland Commission ("Our Common Future" The World Commission on Environment and Development- United Nations) as a "System of development that meets the basic needs of all people without compromising the ability of future generation to meet their own life sustaining needs"is the basic definition. Since then, a rich discussion had ensued about what this means in practical terms. So many other sets of words have been suggested for defining the sustainable development. In mining world these words where possibly first utilisedutilized in early 1990s in the Rio Summit (1992).

In recent years the word sustainability has also found its way into common use. The ideas of sustainable development and sustainability are different but synchronous. Sustainability is in more general terms is the one that captures the idea that we need to maintain certain important aspects of the world over the long term.

It is based on three fundamental pillars :

- **Planet (Environmental),**
- **People (Socio-cultural), and**
- **Profit (Economic).**

It involves the overlapping of different domains (Environmental, Public Policy, Socio-cultural, Economic, Technological) including the three pillars of sustainability. If one is missing, then a sustainable community will not be achieved. Therefore, no community can be sustainable, if one of the domains is missing.

At the base of the interlinked ideas of Sustainability and Sustainable development is the easy perception that the human activities (obviously including coal mining) should be carried out in such a way that the activity itself and the product originated, together, afford a net positive contribution to the human and ecosystem's, well-being over the long term.

IIT ISM Dhanbad, Former Director(Technical),CIL

Sustainable Development Goals

The policy of sustainable development of coal mining is being adopted by United Nations, Government as well as Mining industry players.United Nations has defined 17 Sustainable Goals as follows :

GOAL 1 : No Poverty

GOAL 2 : Zero Hunger

GOAL 3 : Good Health and Well-being

GOAL 4 : Quality Education

GOAL 5 : Gender Equality

GOAL 6 : Clean Water and Sanitation

GOAL 7 : Affordable and Clean Energy

GOAL 8 : Decent Work and Economic Growth

GOAL 9 : Industry, Innovation and Infrastructure

GOAL 10: Reduced Inequality

GOAL 11: Sustainable Cities and Communities

GOAL12:Responsible Consumption and Production

GOAL 13: Climate Action

GOAL 14: Life Below Water

GOAL 15: Life on Land

GOAL 16: Peace and Justice Strong Institutions

GOAL 17: Partnerships to achieve the Goal

Goal 7 & Goal 13 : The basic understanding of Sustainable Coal mining according to environment activist is Oxymoron because :

a) the The potential implication of coal mining activities and its use as fuel in power sector is significant;

b) Many interests (communities and local populace) are touched by mining and role of many of these interests in decision making, is growing;

c) The nature of contemporary communication has brought the often dramatic nature of coal mining operation (terming coal as a dirty Fuelfuel) in the public eye.

d) Industry, Government, Civil society organizations and the public in general are all eager to ensureto ensure that coal mining makes a positive continuation that is fairly shared.

However, the focus is not on how coal mining can be sustainable, identifying the coal mining operation which has a finite useful life but on how coal mining industry can help to Sustainable Development. This is a conceptual change from a singular analysis and mitigation of impacts to a more complete study. In this sense financial aspects are essential to meet this the sustainable development objectives (the equator principles). Financial institutions have adopted the EP which ensures the projects are developed in a manner that is socially responsible and reflects sound environmental management practices.

Present status of Coal Sector (Some Basics) :

Global Steam coal production is about 6 billion Tonnestonnes. The leading coal producer is China-producing more than 50% of the world coal production followed by India , USA, Australia and Indonesia. The coking coal production is about one billion tonnes and Lignite is 0.6 million tonnes. Consumption wise the biggest consumers are China, India, USA, Germany, Russia, and Japan.

Worldwide coal is still having about 25% share in primary commercial energy consumption. It is turning to be precise one out of every 4 unit of energy in the world comes from coal. In India about 55% of commercial energy requirement is made by coal and lignite with almost 70% of the total electricity generation is through Coal. Worldwide 40% of the electricity is produced through coal fired boilers.

International Energy Agency IEA has noted that this share has actually edged up in the past 4 decades. For the first time ever in 2018 global coal fuel generating capacity topped 2000 gigawatt. This is enormous 62% increase since the year 2003., some 300 gigawatt of new coal fueled generation is under construction in the Asia alone, more than the entire existing USA coal fleet. more than 40 Nations have added coal fuel generation since 2010. In India too this uprising trend is to continue seeing the per capita electricity consumption is almost 1/3rd of the world average.

Coal remains worldwide cheap and reliable energy source. Nearly 1 billion people (15% of the world population) lacks access to electricity. Around 3 billion people still rely on primitive biomass which would be some 1000 times cleaner using Coal by electrification.

The transport sector moving towards EV with coal again returning as major fuel of transportation in places such as China with high speed trains electric versus cars and scooters.

This simply puts the world plans and needs to use coal for the foreseeable feature.

Mitigating adverse effect of coal mining :

Sustainable development model in which coal production goes hand in hand with environmental protection, resource conservation, care for society and measures to protect our forests and biodiversity should encompass . The key metrics for environmental sustainability in mining relate relating to : -

- ➤ Efficiencies in Resource Consumption
- ➤ Minimizing Land Disturbance
- ➤ Pollution Reduction
- ➤ Closure and Reclamation of exhausted mine lands.
- ➤ Dealing with Green House Gas emission in coal utilisationutilization side

China, which is the largest coal producer and with 90% of the coal production is coming from underground. In India it is just reverse, coal production is mainly through open cast mining. Open cast affects the land use pattern and land degradation are is widely associated with coal mining. On an average 20% to 25% of land involved in the case of coal mining is forest, affecting flora and fauna. This demands creation of enough green cover against broken forest land. This necessitates making a scientifically planned progressive mine closure and final mine closure plans. Very good example has been set in Singrauli coalfield of NCL where the green cover has increased compared to what it used to be before mining, which has been established through satellite imagery.

Coal being site specific, it has resulted in displacement of human settlements, requiring handling massive Rehabilitation & Resettlement issues. Strictly adhering to RFCTLAAR conditionality and many cases like that in MCL giving more than the provisions, has resulted in positive community impact.

Mine Voids acting as water reservoir for the local populace, land restoration by development of Eco Park and special plantation drive in coal sector are now part of coal mining activities. Massive efforts for first mile connectivity, eliminating road transport, have been taken for reducing dust emission.

Key Thrust Areas:

1. Responsible Coal mining -: Paradigm shift from old coal culture to 21st Century culture at Global level :

   In India approximately 2,550 sq. km are a is under different coal mines and there are also plans to bring more areas under it as coal production will increase to meet the rising coal demand. Major thrust areas would involve :

   - Good Rehabilitation & Resettlement practices and engagement with community for their grievance redressal
   - Land reclamation & eco-restoration in reclaimed land.
   - Plantation & afforestation
   - Involving State Government agencies in utilization of mine water for community use through MoU route or similar arrangement.
   - Focus on safety & health aspect

2. Implementation of New technologies/Machines for ensuring minimal environment foot print due to coal mining operation. Ensuring Energy Security by World Class Technology.

3. Digitalization of mining operation & Implementation of artificial Intelligence & Drone Technology (Cyber Physical system) in Mines for making operations efficient and effective. Entering MoUs with IITs/IIMs and World Class Co's/agencies which have proven track Records in this regard.

4. Exploring productive repurposing of reclaimed land such as integrated Modern Township, agriculture, horticulture, FCA compensatory land, renewable energy farms etc. Planning for creation of eco parks in reclaimed areas, which will also include water bodies etc., for recreation activities and tourism purpose. Inclusion of eco-parks with local tourism circuit and inclusion of underground mines developedment of underground mines as tourism spot.

5. Environmental audit of mines and conducting specific studies for establishing a robust knowledge base by engaging expert agencies. Use of Satellite imagery & Drone technology for monitoring.

6. Encourage Advanced Technologies to continually reduce emissions:

India's INDC (Intended Nationally Determined Contribution) goals) are well set out:

- ✓ *to reduce the emissions intensity of its GDP by 33 to 35 per cent by 2030 from 2005 level
- ✓ *to achieve about 40 per cent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030 with the help of transfer of technology and low-cost international finance including from Green Climate Fund (GCF).
- ✓ * to create an additional carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent through additional forest and tree cover by 2030.

The question remains how to drive down CO_2 emission with coal at helm of providing energy security. Technology has been the proven answer.

Source-wise analysis of Greenhouse Gas (GHG) emission : Thermal power sector using coal as a fuel is responsible for 33% emission, followed by Industry (24%), Agriculture (18%), and Transport sector (12-13%). About 2.6 gigatonnes of CO_2 is emitted in India per Annum.

To mitigate the emission issue concept of Just Transition to switch over to renewable from fossil fuel, is also gaining momentum and time bound program is on anvil. Steps need to be taken for improving emission from existing fossil fuel generation through low emission technologies. Since 1970, in US,where emission from coal have been reduced by 82%, even though coal consumption has risen by 146%. To be more specific, Globally globally, the average efficiency of coal fuelledfueled plant today is 35%. Raising this average by 5 points to 40%, would reduce the global emission by 2 Giga Tonnes or equivalent of India's Annual annual total CO_2 emission. Many of the major coal consuming countries in are going for advanced coal technology as a part of their Nationally Determined Contributions under Paris Agreement and they continue to see a role for coal in carbon constrained world.

7. Wide spread deployment of Advanced Coal Technologies in Carbon Capture Use & Storage (CCUS) :

Intergovernmental Panel on climate change has advocated widespread deployment of CCUS technology, a greater regularity clarity around CO_2 storage and greater deployment at power plant. Technology exists today and that, needs to be optimised to deploy at scale. There are transformational technologies in the innovation pipeline which will reduce the cost further with continued research and development.

Conclusion

To summarise, the coal Industry faces multiple Challenges but within these challenges there lies embedded opportunities. Those opportunities demand us for putting thrust on to manage well, to insist on responsible mining and to encourage advanced technologies to continually reduce emissions.

"In India coal will remain viable for far longer time than many would like, --but for far greater good of multiple stakeholders".

DIGITIZATION OF MINING INDUSTRY

Dr. D.P. Tripathy

Abstract

With the beginning of Industry 4.0, many mining companies have started taking important steps towards the digitalization of mines. Digitization can help mine operators improve the productivity, optimizes output, minimize costs and enables real-time data collection and analysis, to take better decisions besides remote monitoring and control of mining operations, that can improve safety and efficiency. The mining companies must include digital thinking and processes throughout their organization in order to realize the benefits of digitalization and thrive for digital future by developing the right digital strategy, automate operations and digitization of assets, implement data-driven planning and decision making. The present paper comprehensively discusses the trends in digitization of mining industry, potential benefits and bottlenecks in implementation of the technology. It also elaborates some of the digital transformational technologies in brief. It is expected that the adoption of digital technologies, artificial intelligence and analytics in the mining industry will be accelerated in a big way. In the article, the author has comprehensively discussed some of the digital technologies like artificial intelligence and machine learning, digital twinning, internet of things, virtual reality etc. and their potential areas of applications in the mining industry.

Keywords : Digitization, Mining, Artificial Intelligence and Machine learning, Digital Twinning, Internet of Things

1. INTRODUCTION

The mining industry has been at the forefront of digitization in recent years. Many companies have embraced the digital technology to increase productivity and efficiency in mines while reducing costs, optimizing output, improving safety and sustainability. It is rapidly transforming the mining industry as new technologies and digital tools are changing the way mining operations are optimized and managed.

Digitalizing in the mining industry needs significant change in the way the entire value network comprehends and adopts innovative technology. It helps in streamlining the work processes and provide data insights to drive strategic decisions thereby reduce costs and improve profits. Mining 4.0 involves the using digital technologies for flow and control of data which are analyzed, summarized and classified for the end users.

Many mining companies have started investing in digital technologies. In World Economic Forum Report (2017), it was reported that by 2025, digitalization in the mining and metals industry has potential of adding significant value for the industry, customers, society, and environment worth: USD 425 billion; USD 320 billion – for the industry ;USD 190 billion –for the mining sector; USD 130 billion – for the metals sector; 610 million tons – reduction in CO_2 emission;1,000 lives – being saved and 44,000 injuries – can be avoided.

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2. DIGITALIZATION OF MINING INDUSTRY - ROAD AHEAD

Many mining companies have realized the benefits of digitalization and have taken number of steps to implement them. The World Economic Forum has outlined four major mining digitalization trends and themes namely : (i) Automation and operational hardware tools to automate and optimize inefficient, manual and risky operational activities and processes that may include sensors, robots and 3D printing solutions. (ii) Digitally-skilled workforce to perform better (iii) Integrated enterprise, platforms and ecosystems to improve operational efficiencies, logistics and financing using information technology (IT) and operational technology (OT), cyber-security and use of block chain technology and (iv) Next-generation analytics and decision support - including advanced analytics, simulation modelling and artificial intelligence. Digital maturity is an important indicator of success of a company's digital transformation. Fig 1 gives comparison of digital maturity of mining vis-à-vis other sectors (Calusen et al., 2020).

Boston Consulting Group (BCG)'s Digital Acceleration Index (DAI) is a powerful diagnostic tool to assess and compare digital performance ofcompanies. It is reported as per BCG's Digital Acceleration Index (DAI) that the metals and mining industry is 30-40% less digitally mature than the other industries. In the mining industry there exists wide gap between strategy and execution of the digital strategies, lack of customized solutions, besides not considering sustainability of the solutions (https://www.bcg.com). Digital technologies are increasingly being used to automate mining processes, from exploration to extraction. Automation can be used to optimize processes, reduce downtime, and improve safety and efficiency.

2.1. Benefits of digital transformation for the mining industry

Digitization in the mining industry can improve productivity of the operators, optimizes output, reduces expenses and manage resources like time, materials and manpower efficiently.

The other benefits of digitization for mining companies include :

- Improves planning, scheduling, and managing production across all business functions,
- Improves better collaboration with suppliers,
- Enables efficient use of resources,
- Enhances operational efficiency,
- Minimize costs through ensuring processes more efficient and waste reduction,
- Improves discovery and exploration of new sources,
- Reduces human risks,and,
- Better communication with their workers, supervisors and operators.

2.2 Challenges in Mining Digitalization

Digitalization in the mining industry requires a comprehensive change of thought and adoption of technology. Digitalizing involves not just implementing new technology, but also adapting management processes so that they can fully exploit opportunities offered by digitization. The potential challenges are:

- The high initial cost of new technology which many companies may not have enough fund.
- New technologies need additional staff training or support services.

2.3 The Risks of Not Implementing a Digital Strategy

- May result in non-adapting to new regulatory compliance. It may result in operation disruptions due to government pressures and non-compliance.

- May not be able to adapt to changes in operational processes. It may result insignificant increases or decreases in production rates.
- May face inability to meet demand.

2.4 Key Strategies for Successful Digital Transformation

i. Expansion of Technology Platform and Network Capabilities

It is required to improve interconnectivity for providing safe and secure environment for storage and processing data.

ii. Emphasis on Remote Monitoring and Automation

It is necessary so that mines can be more productive and safer in future.

iii. Implementation of Simple, Cost-effective and Sustainable Solutions

Full-fledged digital transformation can be costly and need major shifts in company culture and operational procedures. Mining activities should focus on simple and sustainable technology for customize solutions for each facility at lower costs.

iv. Enhance Employee Training and Good Company Culture

Companies should provide existing workforce with the needed training for successfully deploying and embracing digital technology.

v. Expansion of digital transformation Beyond Mine Operations

The mining leadership should consider providing technology and digital tools to other parts of the organization. beyond mine operations by following proper digital roadmap.

3. DIGITAL TECHNOLOGIES AND THEIR APPLICA TIONS IN THE MINING INDUSTRY

3.1 Artificial Intelligence and Neural Networks in Mining

Recently, the mining industry is increasingly adopting the use of artificial intelligence (AI) to enhance efficiency, profitability and safety of mining operations. Using advanced machine learning algorithms and data analysis techniques, mining companies are able to achieve optimization of operations, reduce costs, and provide safety for the workers. The technique has made it feasible to gather and analyze big data in real time, does faster and accurate decision-making. AI has made it possible for the mining companies to increase their efficiency and productivity and reduce risk and environmental impacts. AI-powered drones find applications for mapping and monitoring environmental impacts, monitoring mine sites and enhancing safety.

Artificial intelligence recognition systems based on support vector machines and wavelet scattering enables create seismic event recognition model in intensive mining clusters, by considering petrographic and geological conditions, methods, and parameters associated with mining. Application of neural networks in rock blasting design in both underground and surface mines is highly successful as it enhances the blast efficiency and optimizes all drilling and blasting parameters(Zhironkin and Ezdina,2023).

3.1.1 Key Applications of Artificial Intelligence in Mining

i. Autonomous vehicles

Autonomous vehicles and equipment, can operate in dangerous and remote environmental situations and make working conditions safer in mining as well as maximize productions.

ii. Decision support systems

AI is being used to support decision making, provides better worker safety, improvement of work processes and reduction of cost.

iii. Ore sorting

AI-based ore sorting systems can identify in real-time valuable minerals from associated waste rocks and thus improve mineral recovery and minimize processing costs.

iv. Robotics

Autonomous robots are used in surveying both in the surface and underground environments, performing excavations, hauling and processing materials, improving safety and manless mining. Robots can be used underground to deploy for stabilizing roof after blasting and deploy in inaccessible places.

v. Safety and risk assessments

AI has the ability to assess and issue alert against risks at a mine site and hence creates efficient and safer environment for human beings.

vi. Predictive maintenance

AI predictive maintenance models make predictions based on usage trends and predicts in advance potential equipment failures, ensuring greater on-site safety for workers. AI algorithms are used to analyze data on equipment, predict maintenance needs, reduce downtime and costs. It allows fast repairs and removes unwanted maintenance.

vii. Exploration

AI can help in mining exploration by analyzing huge data, identifying on-site targets and providing insights.

AI algorithms have been used to process geological and geophysical data and identify potential mining locations and optimization of drilling operations.

viii. Environmental data

AI can reduce environmental impacts and risks on location by analyzing environmental parameters quickly and efficiently.

ix. Energy optimization

The use of AI can optimize energy use and improve efficiency.

x. Predicting supply chain disruptions

AI models can be used to predict future supply chain information and identify disruptions in the supply chain and helps in streamlining the processes (Jackson, 2023).

3.2. Digital Twins

A digital twin refers to virtual representation of an object or system that spans its lifecycle. It is updated using real-time data, simulation, machine learning and reasoning to make decision making. It involves virtual representation of a physical asset, process or system, which does real-time performance monitoring, analysis and optimization. They integrate data from sensors, IoT devices and historical dataetc and develop comprehensive, accurate physical object model. In the mining world, there are two types of digital twin namely asset twins and process twins. Because of digital replica, organizations have opportunity to have valuable insights into the performance and efficiency of the assets, identify areas for improvement and even predict potential failures before they take place (Foster, 2023).

Few key benefits of digital twining can be:

(i) digital twins can integrate advanced analytics and machine learning algorithms to forecast wear and tear and give accurate estimation of the remaining useful life of components. It helps operators to take proper decisions regarding repair, maintenance, or replacement of assets and ensure operations' continued efficiency and sustainability.

(ii) They facilitate hotspot identification and predictive maintenance and detect potential issues before costly failures. It reduces downtime, minimizes repair costs as well asenhances the life of critical assets.

(iii) reduce downtime and extend asset life.

(iv) enhance safety and reduce risk by identifying potential hazards and suggest preventive measures thereby providing safer work environment and reduction of accidents.

(v) Facilitate the energy transition.(https://akselos.com/5-benefits-of-digital-twins-in-mining).

3.3. Internet of Things (IoT) in Mining

IoT stands for the Internet of Things and is defined as "expanding connectivity of the internet on physical devices". It is the extension of internet connectivity with physical devices and objects. In the mining industry, IoT is used for achieving cost and productivity optimization, improving safety and streamlining different operations.

Flowchart of IoT in Mining: Internet of things is based on four simple building blocks also called IoT architecture layers namely: (i) sensors (ii) Internet of Things (IoT) framework and gateway (iii) cloud server and (iv) mobile app/PC as shown in Fig 2.

IoT helps in implementing artificial intelligence making mines more efficient and able. AI and IoT both can improve metal extracting processes, make the process more accurate and produce less waste.

It supports sensors for accumulating critical data, analyze them in real-time and share for appropriate decision/ action and enhances worker productivity and makes performance better.

3.3.1 Applications of IoT in Mining Industry

i. Autonomous mining equipment

IoT-enabled autonomous equipment and vehicles have made mining safer and cost-efficient. The machines save workers from getting harmed e.g. self-driven trucks remotely through a high-bandwidth internet connection from miles away.

ii. Use of proximity sensors

IoT sensors help avoid accidents by detecting the proximity of heavy equipment or vehicles in a mine by using modern technologies like GPS, radar, RF-locating technologies etc. Miners can use this information to protect themselves and fellow miners from accidents.

iii. Effective ventilation systems

IoT-based efficient ventilation system, can adjust the ventilation and estimate the quantity of contamination at suitable locations. The ventilators are managed remotely.

iv. Sensors for predicting Equipment maintenance

IoT sensors provide data regarding the machinery status and operational conditions and identify predictive maintenance needed. They ensure worker safety and save the cost in repairs.

v. Fleet management and tracking of equipment

IoT improves control over equipment fleet and companies can track and manage their equipment from a central office. Micro-tracking with 5G transmission technology checks and monitors the fleet's location with precision.

vi. 3D mapping

IoT technologies often use innovative and accurate tools like GPS and sensors. IoT-enabled software is used to create 3D map of the mine, understanding of layout, navigation, operations management, and troubleshooting etc. during emergencies. Strategic planning with real-time and accurate data and 3D maps can result in making the mining operations safer and cost-efficient (Kamal,2021)

3.3.2 Drawbacks in use of IoT in the Mining Industry

Data Privacy and Security: It is a great challenge to keep the gathered data transmitted by the IoT devices safe. Cybersecurity is very important priority for the mining companies and devices must be protected from physical tampering, hardware and internet-based attacks. Data privacy is also a concern.

Technical complexity : The technology is very complex.

Requires regular electrification : Most of the devices depend on continuous power or internet connectivity to function properly. As power goes down, then the devices also goes down and affect anything which is connected to it.

Integration : There's no consensus regarding the protocols of industrial Internet of Things and their standards since the devices produced by the different manufacturers require different type of configuration and hardware connection hence making difficult to deploy efficiently.

Time consuming : Industrial Internet of Things(IIoT) is very time consuming; require huge investment.

3.4 Machine Vision and Learning in Mining 4.0

Machine vision and learning are unique digital technology emerging from the transition from Mining 3.0 to 4.0. It provides opportunities for the robotization of mining processes and help taking judicious engineering decisions. The expansion of deep machine learning (ML) is involving algorithms that improve over time through exposure to large data. AI and ML are helping mining companies, to rely on machine-made decisions and real-time collection and analysis of data.

Machine vision has potential for the identification of cracks and disturbances in the rock array, using a convolutional neural network (CNN) with an accuracy of prediction model > 85%. Random forest model has been used for detection of coal dust explosions. Hyperspectral analysis of coal preparation processes can automate the process of identifying the host rock deformation with a self-control module.

3.5. Big Data in Smart Mining (Mining 4.0)

Smart mining uses artificial intelligence and is capable of solving complex operational problems and faster processing of data (Majstorovic et al., 2022). It does analysis of big data which provides new knowledge, integrate logistic, engineering, and economic information of managing the business of mineral based industries (Sishi andTelukdarie, 2020).

Analysis of big data helps in intelligent geological exploration and minimizes the loss of minerals because of improved geological mapping (Li et al., 2022). Big data in 3D modeling implementation is done based on point clouds obtained from ground penetrating radars, LiDAR scanners for underground mine working design etc. Use of laser scanning technologies, big data analysis, and 3D modeling can control unmanned vehicles in underground mine workings and effectively prevent accidents and collisions (Rozmus et al., 2021).

3.6 Cloud Mining as a Path Digital Technology from Mining 4.0 to 5.0

Cloud mining, uses artificial intelligence for integrating digital data, technologies, talents and cloud computing parameters of the companies. Use of multi-criteria decision-making permits combining the financial and marketing strategies of enterprises, with aid of fuzzy cognitive map ensuring advance planning of activities. By combining cloud computing and machine learning algorithms help effectively doing in-depth analysis of good number of factors of accidents in mining (Bi *et al.*, 2022; Poormirzaee *et al.*, 2022).

3.7 Drones

Aerial drone inspectors have shown promise in monitoring drilling and blasting operations in quarries, conduct of preliminary and post-blast monitoring (Bamford et al., 2020). They also help monitoring of the state of coal storages, dumps and tailings (Shahmoradi *et al.*, 2020; Porras *et el.*, 2021)and survey. Drones are used for underground mining operations in monitoring mine atmosphere, mine pillars and operation of equipment (Russell *et al.*,2023; Martinez et al., 2023).

- Drone or unmanned aerial vehicle carry-out survey in an open-pit mine: for mine exploration, mine monitoring, stockpile management, operation planning, onsite inspections and detailed analysis of slopes, etc.
- Drones and 3D laser scanners are useful in for mine mapping underground with accuracy in short time.

3.8 Autonomous Vehicles Combined with Lidar and Image Processing

Autonomous vehicles solutions are enabling a vehicle to perceive its environment, navigate routes to destination, and drive it.

Unmanned (fully robotic) equipment is an unique innovation in mining (Radchenko and Bondarenko, 2023). It integrates data from LiDAR sensors and machine vision for processing and uses geometric matching algorithm that is capable of identifying the traffic signs in underground mines properly with unmanned robotic transport. It ensures accident-free movement along the designated route (Kim and Choi,2021). LiDAR (light identification detection and ranging) systems can be integrated with GPS and help in creating 3D cloud for prediction of sudden movements of rock mass.

Robo-inspectors independently collect and analyze diversified information on mine mechanical systems using machine vision (Szrek et al., 2022).

3.9 Block-Chain Technology

This technology has enabled mining companies to record, track and certify both the origin of minerals and the life-cycle record of minerals. It is promoting transparency, trackability and security with incorruptible data sharing.This can prevent fake/fraud transactionsas any transaction added to the block chain after being validated. This creates complete transparency, as anyone using a block chain (centralized or decentralized) can see exactly what transfers have occurred, between whom (the digital address) and when. It enables the secure exchange of critical trade documents. Since it is immutable, users can feel comfortable for assessing the validity of the information provided. It allows importers to track the life cycle record of minerals. The drawback is that it is unable to replace industry standards and to ensure the data uploaded is correct and accurately reflects the minerals being advertised or sold(Fasken, 2022).

4. CONCLUSIONS

In future, digital technologies will be used extensively by mining companies to optimize their assets for enhancing operating efficiency, improving mining decisions, increase profits and improve business performance.

Digital technologies help mining companies become competitive as make operations safer, sustainable and smarter with use of modern tools and processes. Digital technologies like artificial intelligence and neuralnet works, machine learning, Internet of Things, smartsensors, drones and autonomousrobots, digitalt wins, block-chain technology, bigdata analytics, and 3D visualization etc will be used in a big way in the mining industry.

The future of AI and machine learning in mining holds significant potential for further advancement. AI-powered mining equipment and sensors are expected to be more sophisticated and may provide increased accuracy and predictive capabilities. AI-powered devices and systems will help in better real-time data analysis and quicker decision-making with the advent of 5G networks. There are concerns about the potential job loss for human workers in mining companies. Chances of data privacy and security issueswill be prevailing besidesincreasingly relying on autonomous equipment and vehicles and need to be addressed. Digital twin technology is expected to drastically change the mining industry by optimizing operational optimization, minimizing costs, and enhancing safety and realizing the global energy transition. As mining companies will innovate and be competitive, adoption of digital twin technology will be essential to for achieving sustainable growth and success.

The Internet of Things technology is highly disruptive. It uses advanced sensor technologies, different interconnected networks, edge computing, big data analytics, processing of raw data and interactive visualization. Real-time tracking and visualization ensures workers' safety and security, and helps in real-time data analysis, and provide informed decision.

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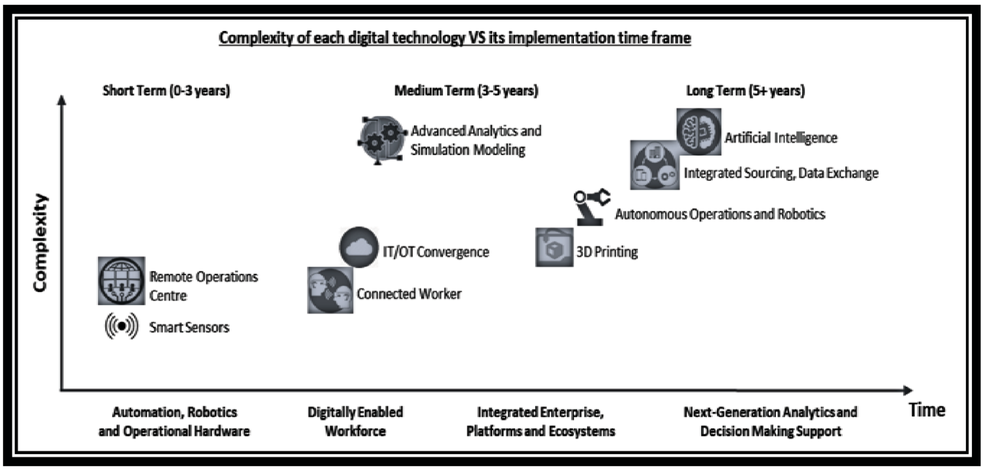

Fig1 Comparison of digital maturity of mining vis-à-vis other sectors (Clausen et al., 2020)

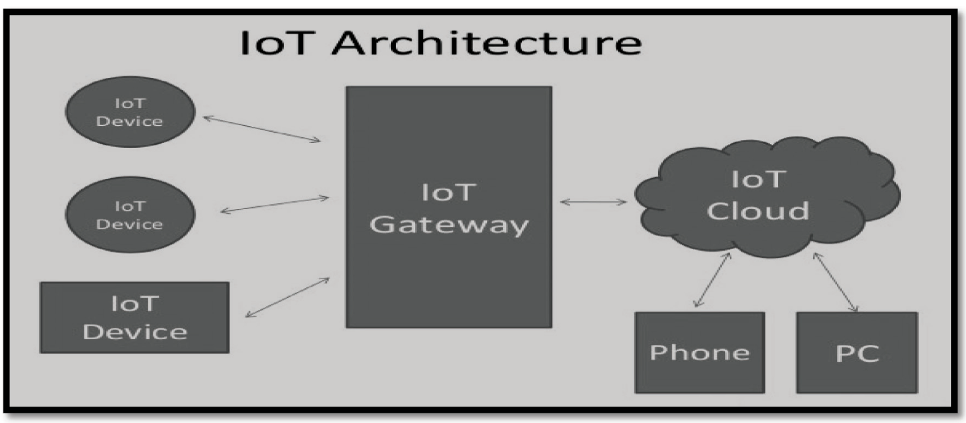

Fig 2. IoT architecture

OPTIMUM COMBINATION OF SAFE AND ECONOMICAL INTERNAL DUMP PROFILE OF DRAGLINE MINES.

Mani Mohana, and Dr. Ashish Patnaikb, Prof. Indrajit Royc

Abstract

In the Indian opencast mining scenario, dragline-operated opencast mining with a share of 45% of total opencast coal production is considered to be one of the efficient ways of winning coal for opencast mines linked to power plants. In dragline-operated opencast mines, the O.B. dump comprises both dragline dump and shovel-dumper dump. The dragline dump comes from parting between the bottom-most seam and just above to bottom-most seam. Whereas the shovel-dump dump comes from parting between intermediate seams and top overburden above upper seams. This complex process of dump formation by both dragline and shovel-dumper combination creates the stability problem of combined shovel-dumper dump above dragline dump. This paper discusses the problem of accommodating the maximum amount of waste rock withina combined shovel dumper and dragline dumpi.e. internal dump so that minimum land is required for external dumping.

Keywords : *Opencast mining, Dragline dump, Stability analysis*

1.0 PROBLEMS OF DRAGLINE DUMP

The challenges related to the positioning of a shovel-dumper dump above a dragline dump are outlined below. The dragline dump often lacks cohesive strength and is placed without compaction, resulting in loose dump material accumulating at its natural angle of repose, representing a state of limiting equilibrium. Placing the shovel-dumper dump directly above a fresh, uncompacted dragline dump with a Factor of Safety ranging from 1.0 to 1.05 will lead to the failure of both the dragline and shovel-dumper dumps positioned either above or in proximity to the dragline dump. Alternatively, depositing the shovel-dumper dump at a considerable distance from the fresh dragline dump allows for consolidation over time, enabling the development of cohesion and the angle of internal friction within the mass of the dragline dump.

However, this increased distance for dumping comes at the cost of reduced space for internal dumping. As a consequence of this diminished space, the height of internal dump and the external dump increases, posing a threat to the overall stability ofboth the external and internal dumps. Beyond these challenges, the presence of a flowing water table within the dump material presents a significant problem for the stability of the internal dump. The water table exerts upward water pressure and generates seepage forces that affect the base of the internal dump, significantly impacting the stability of both the dragline and shovel-dumper dumps.

Addressing the challenge of dragline and shovel-dumper dump stability requires a focused approach targeting the most influential factors: angle of internal friction (F2) and cohesion (C2) of the (dump & interface material) , mine floor inclination (I), height of the water table within the

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internal dump, and ground accelerations generated within the dump mass due to blast vibrations. The challenge revolves around the formulation of comprehensive guidelines specifically tailored for dump design in opencast coal mines utilizing both dragline and shovel-dumper operations. The main objective is to establish a set of recommendations that delineate optimal dump heights, slope angles, and other pertinent parameters while emphasizing stability considerations. These guidelines must encompass the multifaceted factors influencing stability while accommodating the inherent variability in geological, geo-technical , hydrogeological and blast vibration conditions across diverse mining sites.

In the content of this paper, a study has been embarked upon to craft tailor-made guidelines that enhance the geometry of shovel-dumper dumps positioned above dragline dumps. The ultimate objective of this undertaking is to prioritize stability and safety as the primary focal points within the dump design process. This study extensively investigates the stability analysis of notable mines such as Nigahi OCP, Sasti OCP, Sonepur-Bazari OCP, and Amali OCP, all with the aim of extracting practical insights to refine and optimize dump geometry.

2.0 STABILITY ANALYSIS FOR OPTIMIZING INTERNAL DUMP GEOMETRY

The systematic evaluation of optimal geometry for positioning a shovel-dumper dump over a dragline dump involves a structured sequence of stability analysis. This process, pivotal in ensuring the safety and stability of mining operations, is detailed below :

Step 1 - Characterization of Geotechnical Parameters :

In this initial phase, essential geotechnical parameters including cohesion, angle of internal friction, and bulk unit weight are determined for both the dragline dump and the prospective shovel-dumper dump. The assessment extends beyond purely geotechnical factors, incorporating hydro-geological, geo-mining, and dynamic parameters arising from blast vibrations.

Step 2 - Establishing Regulatory Factor of Safety:

Aligned with the contemporary regulatory norms set forth by the Directorate General of Mines Safety (DGMS), a stipulated Factor of Safety ranging between 1.30 and 1.35 is adopted. This range serves as the benchmark against which the stability analysis outcomes will be evaluated.

Step 3 - Site-Specific Factor of Safety Calculation:

A crucial phase involves calculating the site-specific Factor of Safety. This entails applying sophisticated stability analysis techniques to ascertain the Factor of Safety for various positions of the shovel-dumper dump relative to the dragline dump.

STABILITY ANALYSIS STEPS :

- Determination of Initial Factor of Safety (1st trial surface ABDCF- Figure 1):
  Utilize Fellenius method to calculate the Factor of Safety for an initial circular-cum-planar failure surface (ABDCF).

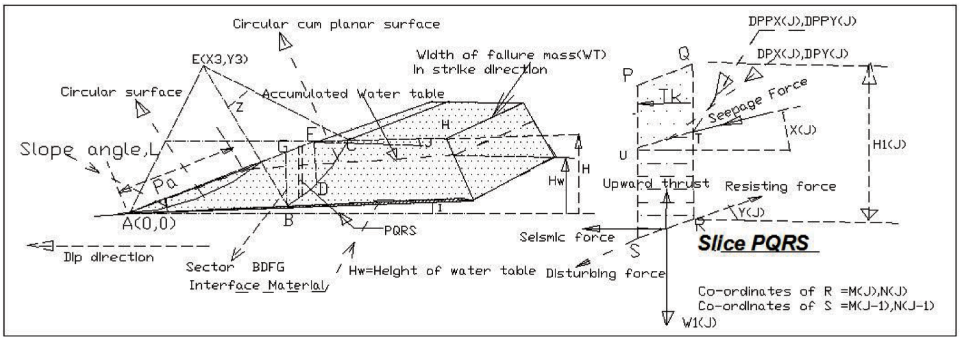

Figure 1 : Free body diagram for slope stability.

- Iteration for Critical Failure Surface (Figure 2).:

Employ an iterative process to identify the most critical failure surface that corresponds to the absolute minimum Factor of Safety. This is achieved through the Fellenius method.

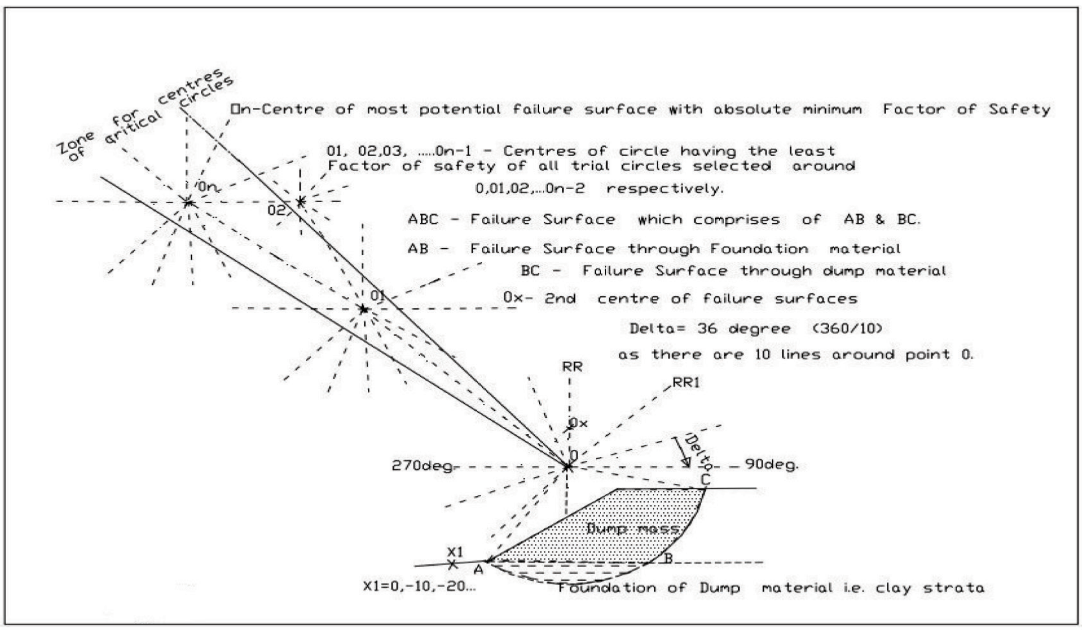

Figure 2 : An iteration method to locate the most critical failure surface.

- Modification via Bishop's Simplified Method:
  Modify the absolute minimum Factor of Safety obtained from the Fellenius method using Bishop's simplified method.
- Comparison and Validation:
  Compare the Factor of Safety calculated using Bishop's simplified method for both the shovel-dumper dump and the dragline dump with the stipulated value (1.30- 1.35).If the calculated Factor of Safety aligns with the stipulated value, select the geometric position of the shovel-dumper dump above the dragline dump as the optimal configuration.

3.0. INTERNAL DUMP PROFILES

The optimal balance between safety and economic considerations for the internal dump profile of Nigahi OCM, Sasti OCM, Amlai OCM, and Sonepur-Bazari OCM, as previously discussed, is outlined below.

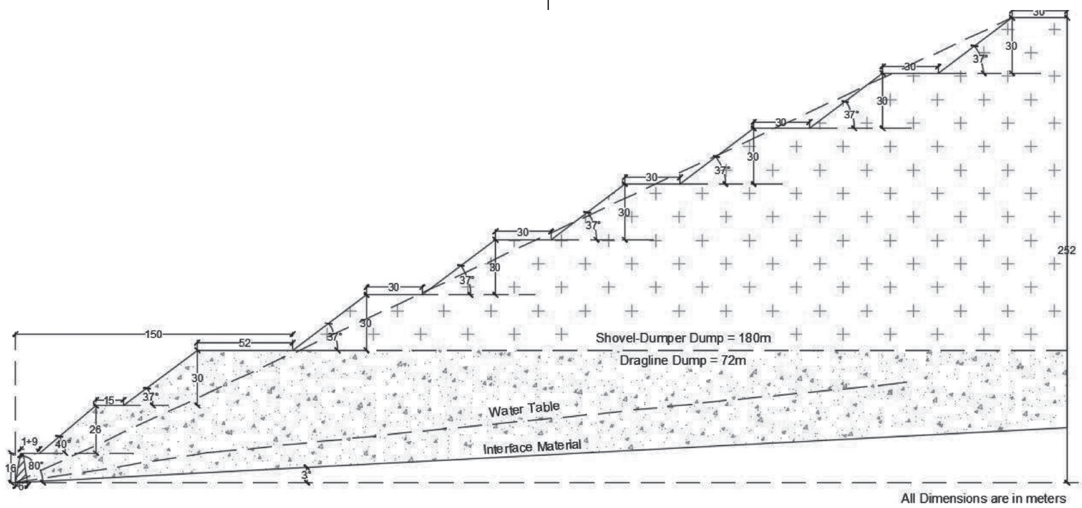

Figure 3: Shovel-Dumper Dump Profile above Dragline Dump Profile, Nigahiocp (NCL)

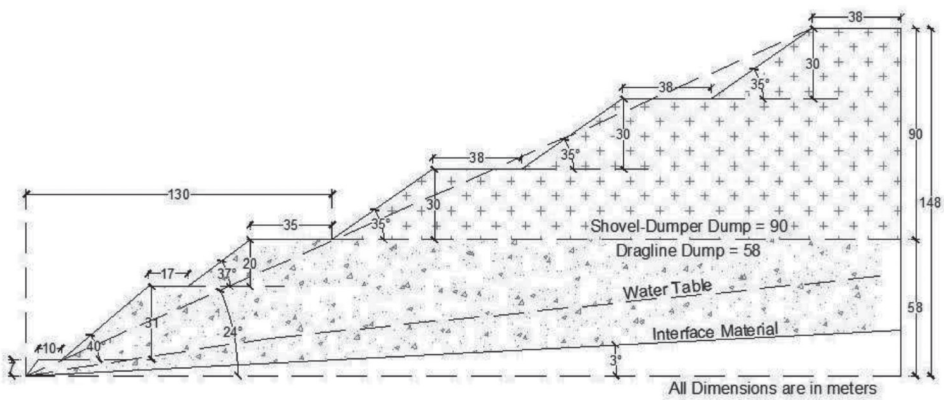

Figure 4: Shovel-Dumper Dump Profile above Dragline Dump Profile, Sastiocp (WCL)

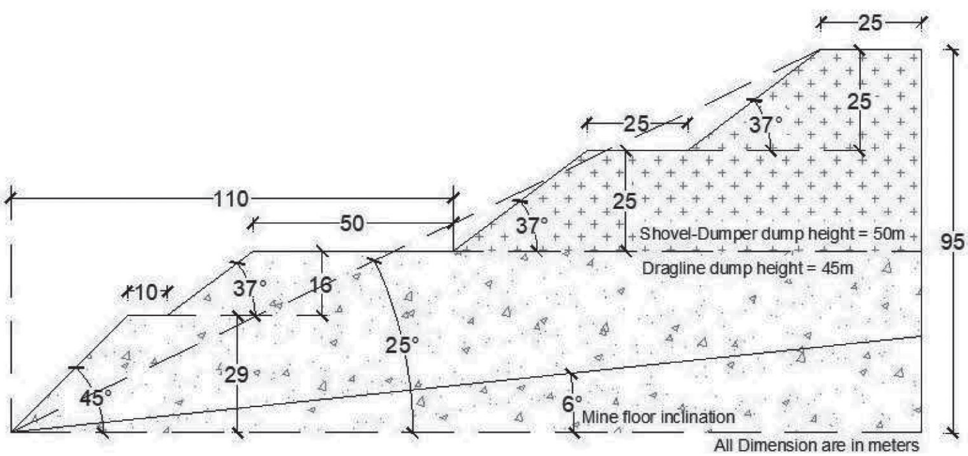

Figure 5: Shovel-Dumper Dump Profile above Dragline Dump Profile, Amali ocp (SECL)

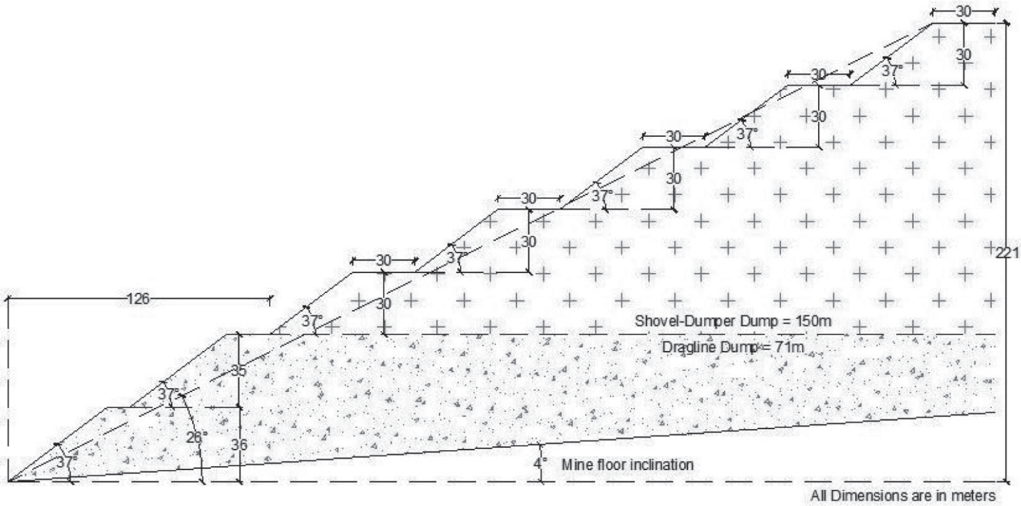

Figure 6 : Shovel-Dumper Dump Profile above Dragline Dump Profile, Sonepur-Bazariocp (ECL)

4.0 TABLE SHOWING GUIDELINES

The following table outlines the general guidelines developed based on a study of individual dragline-operated opencast coal mines. These guidelines pertain to the overall height and slope of both dragline and shovel-dumper dumps. The following notations are used in the table :

H: Represents the overall height of the dragline and shovel-dumper dump above a horizontal plane passing through the dump toe.

L: Denotes the overall slope angle of the dragline and shovel-dumper dump concerning the inclined mine floor.

I: Signifies the inclination of the mine floor.

C^2: Represents the cohesion of the dump material.

ø2: Indicates the angle of internal friction of the dump material.

C3,ø3: Represent the cohesion and angle of internal friction of the interface material. This interface material is a layer composed of crushed coal and crushed rock mixed with water, located at the mine floor.

T2: Denotes the bulk unit weight of the dump material.

D: Signifies the height of the water table located 20 meters behind the toe of the dump.

C4, ø4: Represent the cohesive and frictional resistance between the coal rib (coal seam) and its floor.

Ag: Represents the ground acceleration generated within the dump mass due to blast vibrations.

L+I: Indicates the combined angle of overall slope and mine floor inclination.

H: Represents the overall height of the dump.

The table provides specific ranges and values for these parameters, which have been derived based on the study of various mines. These guidelines aim to ensure the safe and stable design of dragline and shovel-dumper dumps while considering all the geo-engineering factors such as geotechnical, geological, hydrogeological and dynamic factors due to blast vibration. Adhering to these guidelines is crucial for maintaining the desired level of stability and safety in the dump design process.

Table : General guidelines

C_2	Φ_2	C_3	Φ_3	Γ_2	I	D	A_g	L+I	H	Stipulated Factor of Safety
kN/m^2	(deg)	kN/m^2	(deg)	kN/m^3	(deg)	(m)	m/sec^2	(deg)	(m)	
68-78	25-30	40-60	21-29	20-22	2-4	15-20	0.01	21+3	250-275	1.30-1.35
68-78	25-30	40-60	21-29	20-22	2-4	15-20	0.01	21+3	250-275	
68-78	40-42	50-60	30-35	20-22	2-4	15-20	0.01	21+3	250-275	
68-78	40-42	50-60	30-35	20-22	2-4	15-20	0.01	21+3	250-275	
68-78	40-42	50-60	30-35	20-22	6-8	15-20	0.01	21+3	250-275	
68-78	40-42	50-60	30-35	20-22	6-8	15-20	0.01	21+3	250-275	
48-53	21-29	50-60	18-23	20-22	3-4	15-20	0.01	21+4	175-195	
48-53	17-19	30-35	18-20	20-22	3-4	15-20	0.01	22+4	70-90	
48-53	21-29	50-60	18-23	20-22	3-4	15-20	0.01	18+8	70-90	

5.0 CONCLUSION

The investigation spanned a diverse array of conditions and scenarios pivotal for evaluating the design and stability of dragline and shovel-dumper dumps in opencast coal mines. Parameters including cohesion (C2), angle of internal friction (F2) of dump materials, characteristics of interface materials (C3, F3), bulk unit weight (G2), mine floor inclination (I), water table height (D), ground acceleration (Ag), combined slope angle (L+I), and overall dump height (H) collectively govern the structural integrity and safety of these dumps. The stipulated Factor of Safety range (1.30-1.35) emerges as a pivotal standard, strongly ensuring stability. The introduced table now assumes a role of paramount importance, offering indispensable guidance to engineering practitioners, and facilitating prudent decision-making tailored to the distinctive conditions of each mine. This comprehensive guide strongly emphasizes the utmost importance of focusing on safety while improving dump designs in the world of opencast coal mining.

6.0 ACKNOWLEDGEMENT

The authors extend their gratitude to the Coal India management for their unwavering support throughout the research and development study. They also acknowledge the support and permission provided by the management of Birla Institute of Technology, Mesra, in conducting this investigation and sharing its outcomes. It's important to note that the expressed opinions solely belong to the authors and do not represent the views of Coal India or BIT Mesra.

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STABILITY ASSESSMENT OF OVERBURDEN DUMP ON BLACK COTTON SOIL BENCH : A NUMERICAL MODELLING APPROACH

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Abstract

In recent times, large-scale opencast mining has generated huge overburden (OB) dump material and this is stored in the form of internal or external dumps. The preparation and management of these OB dumps, particularly when they are placed on soft black cotton (BC) soil, present significant challenges for mine management. This issue is particularly prevalent in some of the opencast mines, where bench slopes need to be designed under these circumstances. In this paper, an effort has been made to assess the stability of OB dumps situated on BC soil benches within the mine slopes. Numerical modelling was conducted to assess the impact of various factors such as dump height, BC soil thickness, and bench width on OB dump stability. The study focuses on assessing the stability of OB dumps considered as single bench OB dumps (i.e., 60 m OB dumps height) and Double bench OB dumps (i.e., 30 m & 30 m heights). The dump is placed on the BC soil layer, which has varying thicknesses of up to 30 m. The Kamthi series sandstone is also situated beneath the layer of BC soil. The study results indicated that the OB dump's stability is significantly influenced by its height. Moreover, the factor of safety (FoS) experiences a sudden decrease as the thickness of the BC soil increases, particularly up to 5 m. However, it was perceived that with an increase in bench width, the stability of OB dumps improves in such given conditions.

Keywords : - *Overburden dump material, Factor of safety, Black cotton soil, Waste dump, Stability, Numerical modelling*

1.0 INTRODUCTION

The adverse repercussions of thermal coal on climatic conditions and greenhouse gasses have drawn attention to renewable sources of energy for a long back. However, to meet the energy requirements of the current globalisation, the dependence on coal is there to stay for decades to come. Opencast mining is one of the predominant coal extraction methods worldwide, other than underground mining. Nearly 199 underground, 212 opencast and 21 mixed coal mines have been operating in India, where opencast mines produce nearly 95% of the country's coal (1). With 101 BT of known reserves, India produces the second-most thermal coal worldwide (2). The demand-supply gap for coal in India is continually growing, and 20% to 30% of the nation's annual coal production is insufficient to meet domestic demands. The only way to close the gap between supply and demand is to increase output from opencast mining. Opencast mining, however, has inherent drawbacks and is hampered by serious challenges like socio-political and management-technical difficulties. The life of opencast mining and coal extraction depends on the steepness and stability of 'slopes' (3). The slopes are usually designed in level and steep directions. The level slopes are suggested to provide the desired safety and stability, whereas steep slopes result in avoiding surplus removal of waste rock (4), (5). The key ele-

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ments that determine the design and stability of slopes are lithology, geological discontinuities, water conditions, mining technique, cohesion, and friction angle (6). The removal of OB dump material increases with an increase in the depth, size and stripping ratio of the mine. In India, the overall OB removal and coal production for the year 2021-22 is 2048.9 M. Cum and 745 MT respectively (7). Fig. 1. shows the overall OB removal and coal production in Indian coal mines from 2019 to 2022. Opencast mining generates an enormous quantity of dump material, which is dumped as either internal or exterior dumps. For the mine management, setting up and maintaining these OB dumps is quite challenging. Earlier, researchers have postulated the design guidelines for the stability of slopes based on the field, laboratory and numerical modelling analysis. To assess the stability of slopes in rock mass, Wei etal. (8) utilized the generalized Hoek-Brown and strength reduction methods. Sakellariou and Ferentinou (9) created an ANN (Artificial Neural Network) model based on database tests that used geometrical and geotechnical criteria for predicting the FoS. Oztekin et al. (10) conducted a stability analysis of cut slopes in limestone by considering the high angle of inclination of cut slopes ranging between 71° to 84° and observed the FoS lies in the range of 1.19 to 3.83. Bui et al. (11) reported the forecasting of slope stability with the help of a hybrid artificial intelligence model developed based on FoS of 450 slope observations of Vietnam.

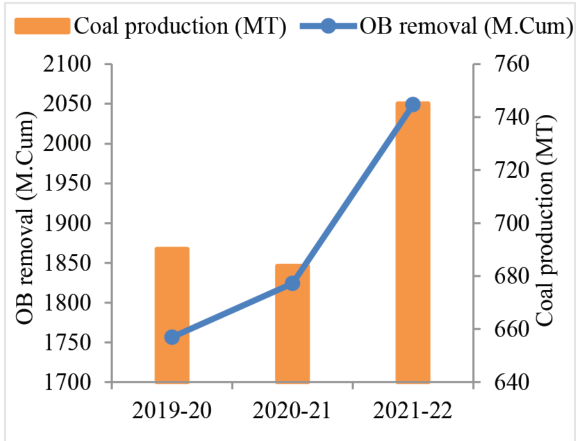


Fig. 1: Quantity of OB removal and coal production from Indian mines during the period from 2019 to 2022 (7).

BC soil is a very poor type of clay soil having a black colour with very fine grains. The name is derived from Deccan traps commonly known as "Kali". It has a low shrinkage limit and high optimum moisture content (12). When OB is placed on soft material like BC soil, the failure of such dump slopes increases. Notable research work has been done since long back on the stability of slopes over BC soil. Kainthola et al. (13) highlighted the ground water as a responsible factor for the failure of earth slopes over BC soil as it has a higher bearing capacity of water. Kainthola et al (13) affirmed from the finite element method that the FoS of bench slope on BC soil was found 0.81 for the saturated condition while for the dry conditions, the FoS attained 1.09 which is critically stable for the progressive slope. Poulsen et al. (14) identified the presence of BC soil as a key reason for the failure of dump slopes in their case study. According to Noolu et al. (15), adding calcium carbide residue, an industrial waste, could lessen fluidity and boost BC soil's strength. The stability as well as the reduction of ground settlement and heaving might be achieved by replacing BC soil with competent material near toe and pitting vertical column (16). In this research paper an attempt was made to understand the stability of OB dump material on BC soil by varying the dump height, BC soil thickness and bench width. Extensive results were presented based on 2D numerical models developed with FLAC3D (18). This study helps the research to design the OB dump over the BC soil in a safe and efficient manner.

2.0 WARDHA VALLEY COALFIELDS (WVC) WVC COMES

under Western Coal Fields Limited a subsidiary of Coal India Limited (CIL). It covers an area of about 4,130 km^2 and extends in a North West- South East direction as shown in Fig. 2. The coalfields are very well connected by roads and rail. It is surrounded by Nagpur in the north and Wardha towards the north-west and Kazipet in the south. The coalfields include 40 opencast mines, each producing between 0.5 and 1.5 MT of coal every year at depths between 70 and 150 m (17). The coalfields consist of varied types of rock formations and the major geological formations include Kamtee series, Alluvium and BC soil (12). The lithology of one of the

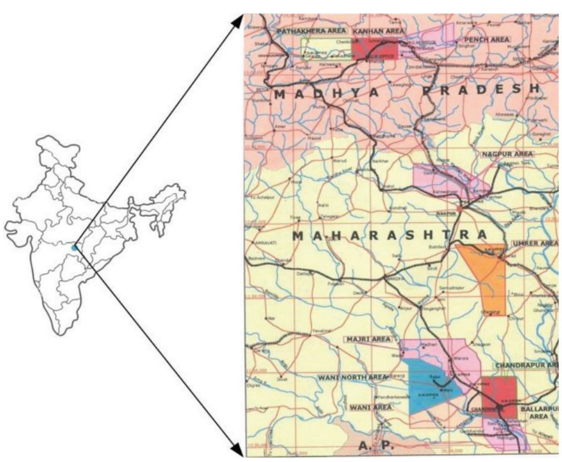


Fig. 2 : Location map showed the WVC areas (20).

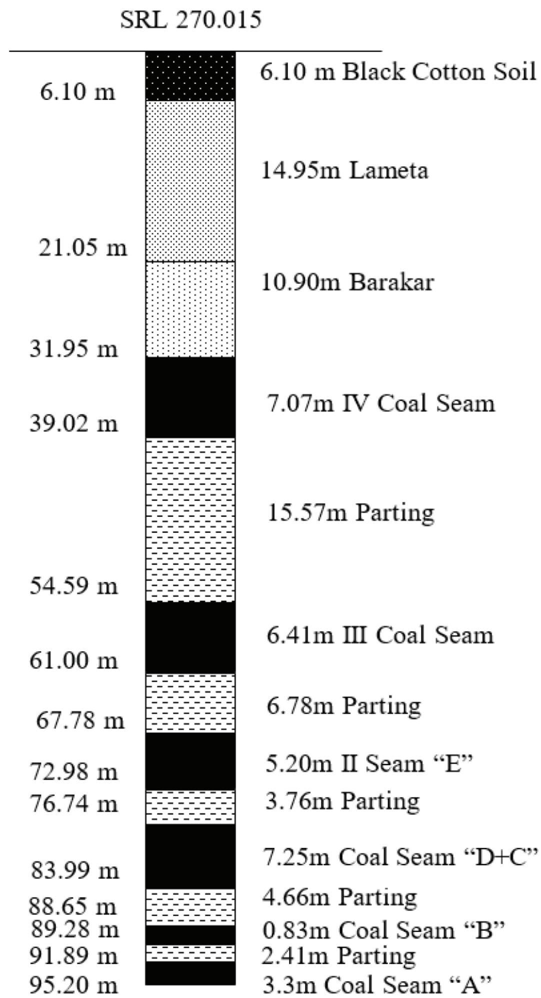


Fig. 3: Lithology of one of mine sites from WVC (12).

3.0. NUMERICAL MODELLING

FLAC^{3D} is a numerical modelling tool for the sign, and analysis of complex structures in the field of Geomechanics, Hydrogeology and Micro seismicity (18). It is widely used in geotechnical engineering and mining. In this paper, 2D numerical models were developed by FLAC^{3D} by considering the lithology as shown in Fig. 4.

The procedure for modelling involves the following steps :

i. Generation of grid (Fig. 5 (a), 5(b)).

ii. Discretization of the model.

iii. Suitable constitutive material behaviour model selection.

iv. Taking into account the characteristics of the material, gravity, in-situ stresses, and boundary conditions.

v. A solution to the equilibrium of the elastic model that produces the in-situ stresses in the model.

vi. Assessing the model behaviour like maximum shear strain, FoS, etc.

The grid developed in plain-strain condition has a maximum length of 500 m in the X-direction, 200 m in the Zdirection and unit dimension in the Ydirection. A total of 42 models are prepared which include 21 "Single bench OB dump models" and 21 "Double bench OB dump models" by varying the BC soil thickness from 0 m to 30 m and BC soil bench width from 0 m to 100 m. The slope angle of OB dump is 40^0 and the overall pit slope angle is 22^0 to 40^0. The BC soil is placed on a 30 m thick Kamthi series sandstone and the coal seam has a 15 m thickness. The bottom of the model was fixed such that there was no movement in the X, Y, or Z axes and the sides were assigned roller type boundaries.

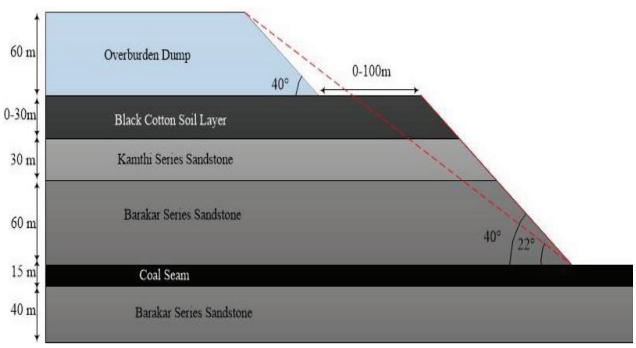


Fig. 4: Generalized bench geometry used for modelling.

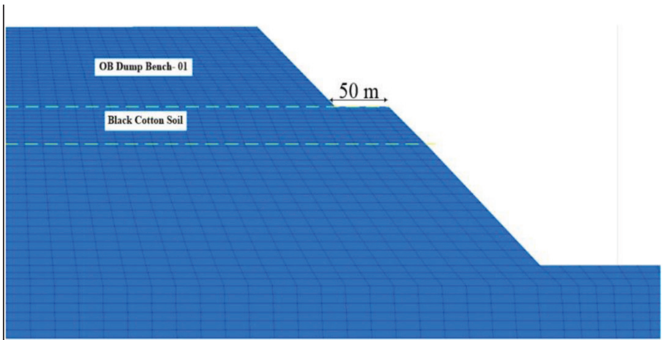


Fig. 5 (a) : Grid shows the single bench OB dump with a 50 m width of BC bench.

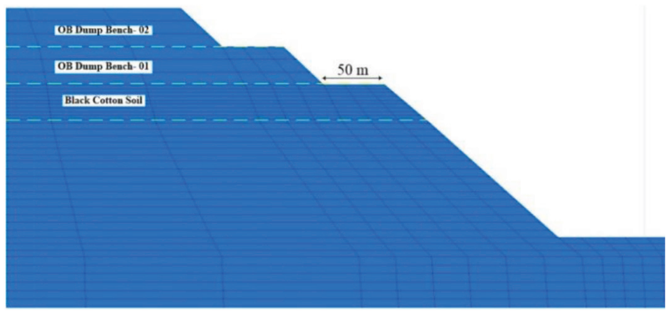


Fig. 5 (b): Grid shows double bench OB dump with a 50 m width of BC bench.

3.1. Properties of rock mass utilised for modelling.

The scaling of intact rock properties (Table 1) was done by considering Sheorey's failure criterion (19) which is defined as follows;

$$\sigma_{1m} = \sigma_{cm}\left(1+\frac{\sigma_{3m}}{\sigma_{tm}}\right)^{b_m} \quad \text{(i)}$$

$$\left.\begin{aligned} \sigma_{cm} &= \sigma_{ci} e^{\left(\frac{RMR-100}{20}\right)} \\ \sigma_{tm} &= \sigma_{ti} e^{\frac{(RMR-100)}{27}} \\ b_m &= b^{\frac{RMR}{100}} \end{aligned}\right\} \quad \text{(ii)}$$

where σ1m is the triaxial strength of the rock mass (MPa); σ3m is the confining stress of the rock (MPa) mass; σci and σti are the compressive and tensile strengths of the intact rock (MPa) respectively; b=0.51 is the exponent in the failure criterion, which regulates the curvature of the triaxial curve; σ_{cm} and σ_{tm} are the compressive and tensile strengths of the rock mass (MPa); and RMR is the Bieniawski's Rock Mass Rating. The abbreviations i and m, respectively, stand for the intact rock and the rock mass. The equation (iii) can be used to express the intact rock strength τ(MPa). where μsm (MPa) is the rock mass shear strength, μ0m is the cohesion of the rock mass, and Ø0m is the co-efficients of internal friction angle of the rock mass respectively.

$$\tau = \tau_{sm}\left(1+\frac{\sigma}{\sigma_{tm}}\right)^{c_m} \quad \text{(iii)}$$

Where, $$\tau_{sm} = \left\{\left(\sigma_{cm}\sigma_{tm}\frac{b_m^{b_m}}{(1+b_m)^{1+b_m}}\right)^{1/2}\right\} \quad \text{(iv)}$$

$$\mu_{om} = \frac{\tau_{sm}^2(1+b_m)^2-\sigma_{tm}^2}{2\tau_{sm}\sigma_{tm}(1+b_m)} \quad \text{(v)}$$

$$c_m = \mu_{0m}^{0.9}\frac{\sigma_{tm}}{\tau_{sm}} \quad \text{(vi)}$$
$$\mu_{0m} = \tan\phi_{0m}$$

3.2 In-situ stresses used in the numerical modelling According to Sheorey (1994), the in-situ stresses taken into account for numerical modelling are as follows:

$$\left.\begin{aligned} S_H = S_h &= 2.4 + 0.01\,H \\ S_v &= 0.025\,H \end{aligned}\right\} \quad \text{(vii)}$$

where Sv is the vertical stress, S_h is the minor horizontal stress, and S_H is the major horizontal stress in MPa and H is the depth of cover (m).

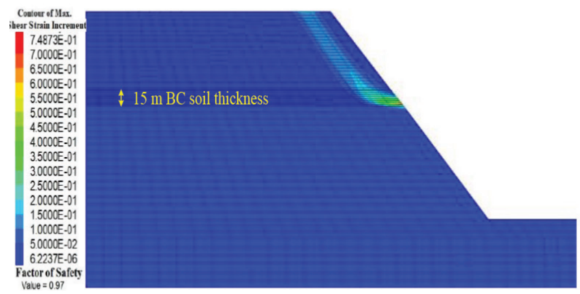
Table 1 : Intact rock properties for numerical modelling.

Parameters	ρ	UCS	TS	RMR	C	ø
OB Dump	1800	5	0.95	-	0.04	31
BC Soil	1970	4	0.8	-	0.02	18
Kamthi Sandstone	2170	22	2.02	45	0.37	36.54
Barakar Sandstone	2300	32.5	2.49	45	0.5	40.31
Coal Seam	1600	15	2.84	45	0.36	19.24

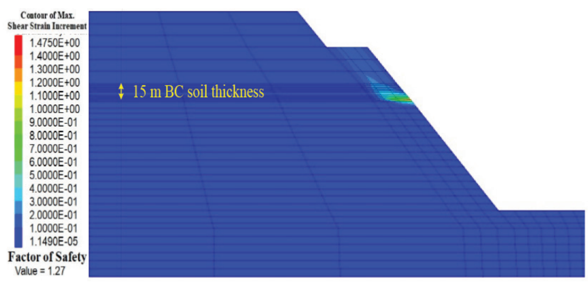
ρ = Density in Kg/m³; UCS= Uniaxial Compressive strength; TS= Tensile strength and C= Cohesion are in MPa; ø = Friction angle; RMR=Rock Mass Rating.

4.0. RESULTS AND DISCUSSIONS

The numerical modelling was performed by varying the parameters of BC soil thickness, Single Bench OB Dump and Double Bench OB Dump, and the width of BC soil bench. A total of 42 no. of models were prepared and analysed by changing the BC soil thickness from 0 m to 30 m with 5 m intervals; widths of BC soil bench as 0 m, 50 m and 100 m; and single OB dump bench and double OB dump bench. Fig. 6 (a) & (b) shows the FoS of a Single Bench OB Dump and Double Bench OB Dump when the BC soil bench width is 0.0 m. The corresponding analysis of stability for all dump slope models is shown in Table 2.

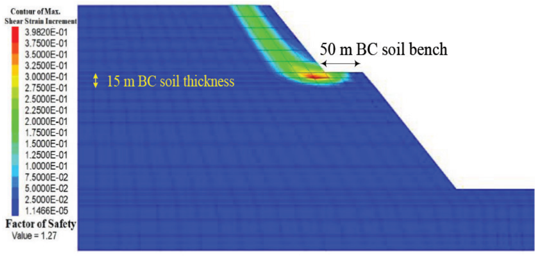


(a) Single bench OB dump.

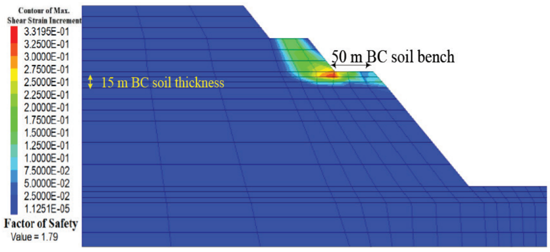


(b) Double bench OB dump.

***Fig. 6 :** Contours of maximum shear strain rate with FoS when BC soil bench width 0 m.*

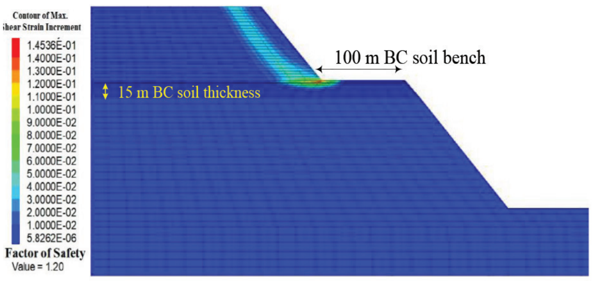


(a) Single bench OB dump.

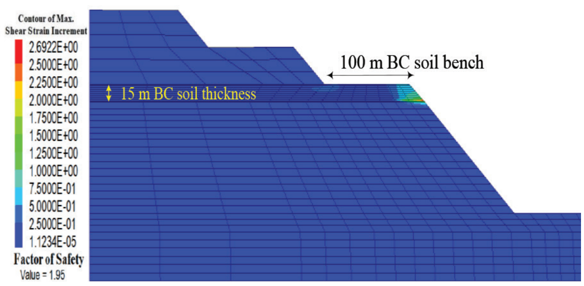


(b) Double bench OB dump.

Fig. 7: *Contours of maximum shear strain rate with FoS when BC soil bench width 50 m.*



(a) Single bench OB dump.



(b) Double bench OB dump.

Fig. 8: *Contours of maximum shear strain rate with fos when BC soil bench width 100 m.*

The results revealed that the BC soil thickness has a greater effect on the stability of OB dumps. As shown in Fig. 7 (a) & (b) and Fig. 8 (a) & (b) when OB dumps are placed on the Kamthi series sandstone i.e., BC soil thickness zero, the dumps have a FoS of more than 1.5 in Single bench OB dump and more than 2.0 in double bench OB dump, which indicates the improved stability. With the increase in BC soil thickness from 5m to 30m, the FoS decreased gradually. In the case of a single bench OB dump, the lowest FoS observed was 0.83 at 30m thick BC soil, which indicated the failure of dumps. Whereas in double bench OB dumps, the least FoS noticed was 0.99. It is here to mention that with an increase in OB bench width from 0m to 100m the FoS increased to 0.83 to 1.2 in single bench OB dumps and 0.99 to 1.49 in double bench OB dumps at 30m thick BC soil as shown in Fig. 9, 10 and 11. The OB dump above the BC soil should be designed in such a way that the dump has a FoS of more than 1.3. Additionally, the double bench OB dumps consistently exhibited higher FoS values compared to the single bench OB dumps for similar bench widths. This suggested that the double OB dumps provided better stability in the presence of BC soil.

Table 2 : FoS obtained and the corresponding analysis of stability for dump slope models.

BC Soil (m)	Single bench OB dump			Double bench OB dump		
	BC soil bench widths			BC soil bench widths		
	0m	50m	100m	0m	50m	100m
5	1.19	1.26	1.2	1.93	2.01	2.15
10	1.06	1.26	1.22	1.45	1.93	2.18
15	0.97	1.26	1.19	1.27	1.79	1.94
20	0.91	1.2	1.21	1.15	1.60	1.89
25	0.87	1.18	1.2	1.05	1.66	1.82
30	0.83	1.14	1.2	0.99	1.39	1.49

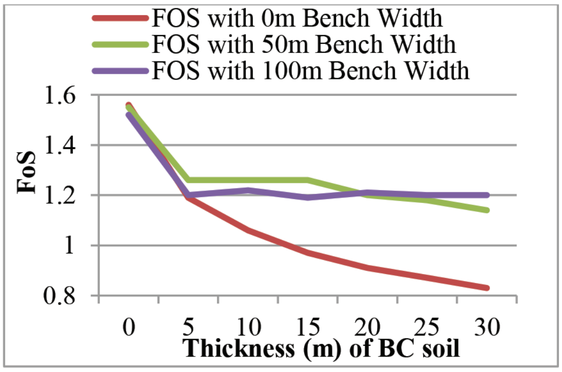


Fig. 9 : *FoS variation in single bench OB dumps with regard to BC soil thickness*

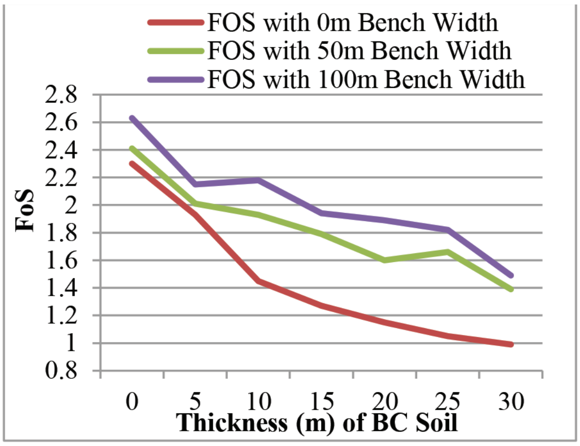


Fig. 10 : *FoS variation in double bench OB dumps with regard to BC soil thickness.*

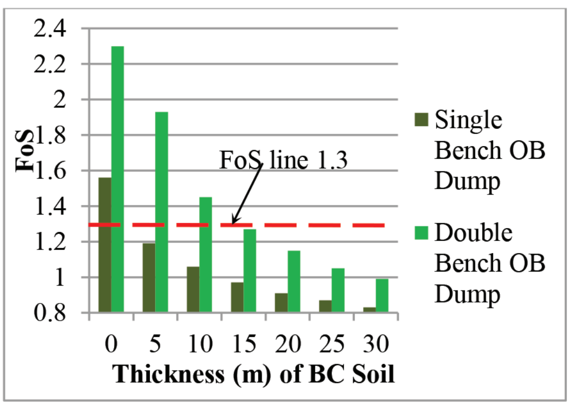


Fig. 11: *FoS variation in single bench and double bench OB dumps with regard to BC soil thickness for a 0 m bench width.*

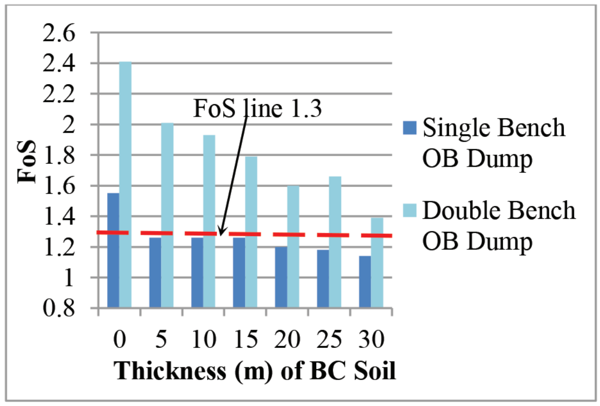


Fig. 12 : *FoS variation in single bench and double bench OB dumps with regard to BC soil thickness for a 50 m bench width.*

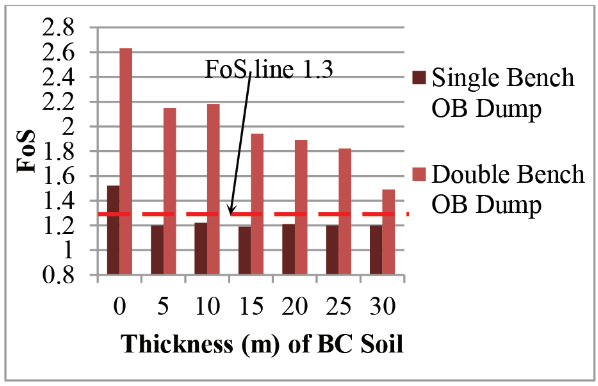


Fig. 13 : *FoS variation in single bench and double bench OB dumps with regard to BC soil thickness for a 100 m bench width.*

5.0. CONCLUSIONS

Design and analysis of OB dumps have a vital role in the safety and productivity of opencast mines. In this paper, an extensive numerical modelling study was conducted to understand the stability of single bench OB dumps and double bench OB dumps. The results indicate that the BC soil has a significant effect on the stability of OB dumps. Overall, the FoS of the OB dumps decreases with the increased BC soil thickness and it is proposed to design the OB dumps in a composed number of slope OB dumps rather than single bench OB dumps. When the OB is dumped over the BC soil, it was found that the increased bench width of BC soil improves the stability of dumps. The specific design and safety criteria might vary based on the nature of the dump, soil properties, and other site-specific factors. The conclusions drawn from this study can provide valuable insights into designing OB dumps on BC soil benches, considering the trade-offs between single bench OB dump and composed number of OB dumps bench widths. The results of this study contribute to the understanding of OB dump stability over BC soil and can inform decision-making in designing and managing OB dumps under such conditions.

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RISK TO RESILIENCE IN CYBERSECURITY ON THE WAY OF DIGITAL TRANSFORMATION IN MINING INDUSTRY – KEY APPROACHES

Dr R N Patra

Abstract :

In the digital era, the transformation from legacy system towards automation and digital transformation has become the new trend for sustainability of industry. To cope with the digital world, the mining and metal industries are emerging towards massive digital transformation. From exploration to extraction, advance technologies like controlled blasting, deep automation, supply chain optimization, robotics, Artificial Intelligence (AI), Machine Learning (ML) are some of the deployed technologies for improving operational efficiency, enhancing capability, reducing costs and increasing value at all stages of the mining lifecycle to gain a competitive advantage. In addition, mining companies are seeking to drive operational and safety improvements into their production systems and assets through convergence and digitization by leveraging new paradigms introduced by the Industrial Internet of Things (IIoT).

In this digital transformation scenario, deployment of adequate security for IT+OT (IIoT) in a structured manner is of utmost importance from day one. Not only AI has to be the part of automation, AI also required to be deployed in cybersecurity of sensitive data generated in the process, which needs proper planning along with digital transformation. Otherwise, the anticipated benefit out of digital transformation will become outlying and the company, its assets, people, entire community and nation will be at risk.

This paper focuses and highlights the importance of cybersecurity of OT + IT and key approaches towards formation of security capsules to create a secured environment with cyber-resilient framework from pit to port operation for optimum profitability & sustainability of mining sector.

INTRODUCTION :

The mining sector plays a significant role in metals, minerals, and energy production of a country. Globally, Mining companies contribute significantly in economic growth of a nation. The mining industry in India plays a vital role in economic activity, which contributes significantly to the economy of India. The gross domestic product (GDP) contribution of the mining and quarrying sector is around 2.5% only but going by the GDP of the total industrial sector, mining sector contributes around 10% to 11%. Over the past couple of years, the mining and metals industry has undergone a massive digital transformation. From exploration to extraction, advanced technologies like deep automation, robotics and artificial intelligence are being deployed for improving operational efficiency, enhancing capability, reducing costs and increasing value at all stages of the mining lifecycle to gain a competitive advantage. Mining companies are seeking to drive operational and safety improvements into their production systems and assets through convergence and digitization by leveraging new paradigms introduced by the Industrial Internet of Things (IIoT).

Such initiatives require the secure connection of process environments via standard networking technologies, which will allow mining companies and their key partner's access to a rich stream of new data, real-time visibility. Optimized production systems, secure remote access to the systems

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as & when needed and assets in the operational environments while maintaining operational efficiency, product quality, sustainability and most importantly safety of the mine and its personnel are some of the focus areas in mine digitalization.

Mining industries are adopting several solution to overcome the barriers for digitization including security concerns, inflexible legacy networks, and complexity. Industry may carefully opt for the right solution, which can provide a proven and validated blueprint for Industrial Automation and Control Systems, production assets, improving industrial security, and improving plant data access and reliable operations. Some of the verticals of digitization with the use of emerging technologies are Fleet management along with Fuel monitoring & Pilferage tracking in both GNSS (Global Navigation Satellite System) and GPS (Global Positioning System) denied environment through Private 5G, Mine mapping, Stock pile calculations and compliance, monitoring through Drones and AI enabled cameras.

Mine operations monitoring including real time mine activity monitoring through intelligent cameras, situational alerts etc through drones and intelligent cameras, Video surveillance and Mission Critical Voice/Video Communication for personnel communication are included in the digitization. Global adoption of 5G technology has paved the way for deployment of above technologies by providing high-speed low latency network infrastructure.

In the process of such automation, huge sensitive data are transported over a network to control system / server / cloud infrastructure depending upon the architecture of the deployment. These sensitive data are required to be kept safe to obtain optimum operational efficiency. However, this technology revolution is also exposing companies to new risks that can severely disrupt operations. Here, the most concern is cybersecurity of OT + IT i.e IIoT system. Cybersecurity must support the mining and metals sector's technology revolution. This objective should be prioritized and governed by the needs of resilience. Companies must understand how much risk they can safely take on, coupled with a dedicated team to keep the organization up to date with compliance and regulatory requirements and support the cybersecurity professionals to put them in place.

Smooth, reliable and consistent operations is vital to mining companies, countries and world economics alike. The key objectives and complexities of transformation are digitizing mining production environments from extraction to transportation and all the steps in between. Additionally, Mining operation is performed in remote areas and requires the development of a local ecosystem comprising of infrastructure and services to support the operation.

In an age when threats are being unearthed every day, mining companies should account for five imperatives like identity, protect, detect, respond & recover, when thinking about cybersecurity in their operations to build a cyber-risk based approach that improves business resilience and unlocks the true value of transformation.

Cybersecurity is a critical aspect of digital transformation projects as it protects organisations' digital assets, intellectual property and customer data. The rapid development of digital technologies has significantly changed security perspectives and increased the risk of cyber threats.

The rapid development of information technology has prompted many industries to depend on network connections for sensitive business operations. However, these networks have become more vulnerable than ever to cyber attacks. According to "Cybercrime Magazine", the cost of global cybercrime was expected to hit $6 trillion by the end of 2021. This figure is predicted to grow by 15% every year, reaching $10.5 trillion by 2025. In India it is revealed that a total of 13,91,457 cybersecurity incidents were reported to the Computer Emergency Response Team (CERT-In) in 2022. Clearly, the cyber-attack surface in the modern world is massive and continues to grow rapidly.

As per "TXOne Networks" global survey report-2022 on OT/ICS (Industrial Control System) cybersecurity in the manufacturing industry states that 94% of IT security incidents have also affected the OT environment as IT and OT become more integrated. 93% of organizations have deployed at least one OT cybersecurity solution and 85% of organizations still plan to increase their OT security capabilities next year. Despite increased investment in OT security, 70% of organizations are still considering adopting IT security solutions for the OT environment.

The above report highlights the importance of the reliable, cost effective cybersecurity solutions for Industrial Internet of Things (IIoT) for enhancing organizational resilience in the face of catastrophic events. As such, in mining sector attacks can disrupt production operations & productivity, which may require hours or days to recover. Therefore, it is also important for mining industry to deploy OT cybersecurity solutions while transforming to new digital platform. The use of data mining, artificial intelligence and machine learning in cybersecurity can develop robust models for intrusion detection and execution of malware. However, achieving this goal needs an in-depth understanding and amalgamation of data mining and artificial intelligence with other computing technologies. Moreover the cost of cyber security solution and its benefits over the investment of digital mining is required an in-depth analysis based on the business activity of the company.

This article may become a revelation for mining industry to pay equal importance to cybersecurity on the way of their digital transformation and may adopt AI in cybersecurity to safeguard their business operations.

Key Approaches :

Considering new threats and new strategies adopted by cyber attackers, there are many ready-made solutions are available like Firewall, EDR (Endpoint Detection & Response), XDR (Extended Detection & Response), NDR (Network Detection & Response), SIEM (Security Information & Event Management), SOAR (Security Orchestration, Automation & Response), SOC (Security Operations Centre), etc. If any mining company will opt for a high reliable security solution, huge cost involvement and their RoI (Return of Investment) may supersede the cost of digitization. Therefore, prior analysis for required cybersecurity solution to cover the risk and resilience is very much essential along with the digitization project. An approach towards deployment of a AI enabled security capsule is the main focus area of this article. The main idea is to develop a security capsule driven by Artificial Intelligence (AI) with low cost, easy to deploy and easy to manage and scalable for legacy & modern system like plug & play. The AI based solution should be manageable without skilled cybersecurity personnel. Two different models are placed below in Figure-1 & Figure-2 showing basic scenario of deployment of security capsules in mining industry.

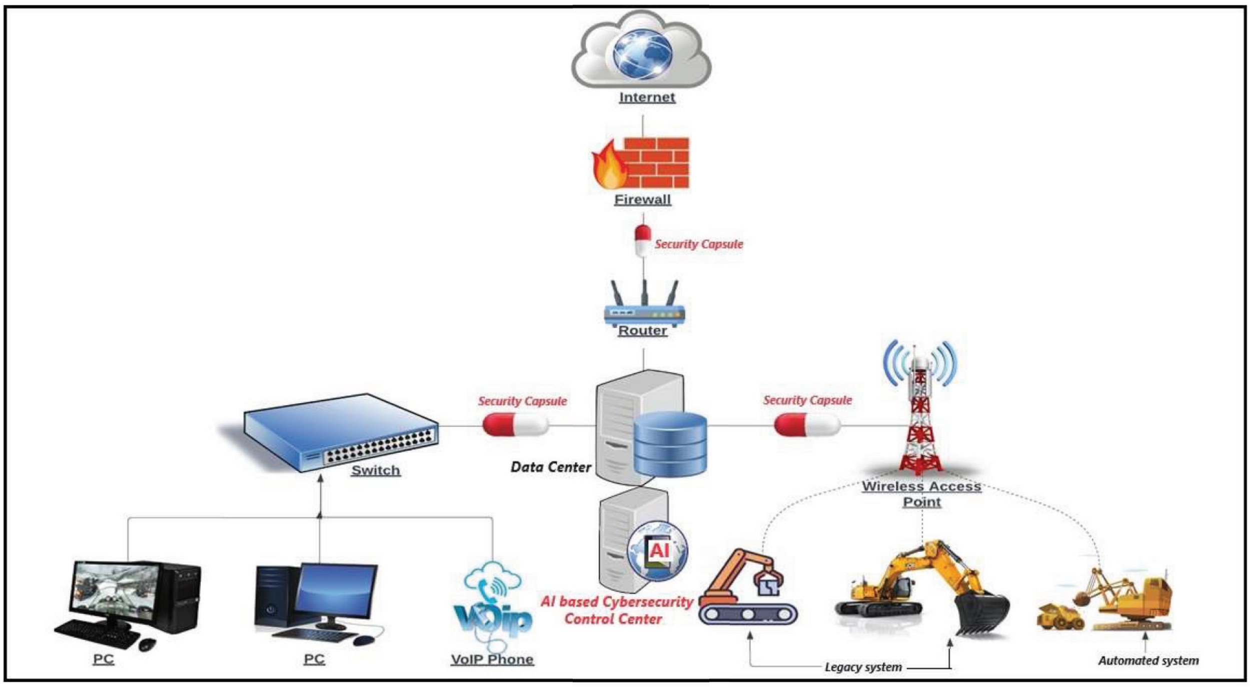

Figure-1 : AI Cybersecurity solution for private network environment of digital mining.

In the above simple model (Figure-1), the digitization of equipment is adopted using a private network, where data generated from the machines are transmitted to server zone at Data centre over private network. In this model, security solution requirement is minimum due to the secure private zone. Therefore, the security capsule is placed in the backhaul of the data network to minimize the cost. Moreover, AI driven security centre deployed in premises for protection monitors the capsules. In addition, data diodes (optional) may be deployed for the legacy machines where sensor data are being transmitted one way from machine to server/storage so that cyberattack shall not disrupt the operation of the machine. Moreover, the design of the capsule should be such that it can be universally fitted at any zone and can cater protection for legacy as well as modern equipment. The central AI based cybersecurity centre shall monitor, control the capsules based on the security postures of the machine & behaviour to automatically deploy the required security. This will also anticipate or predict the attacks by analysing the log data and intelligently apply the solutions to provide zero day protection.

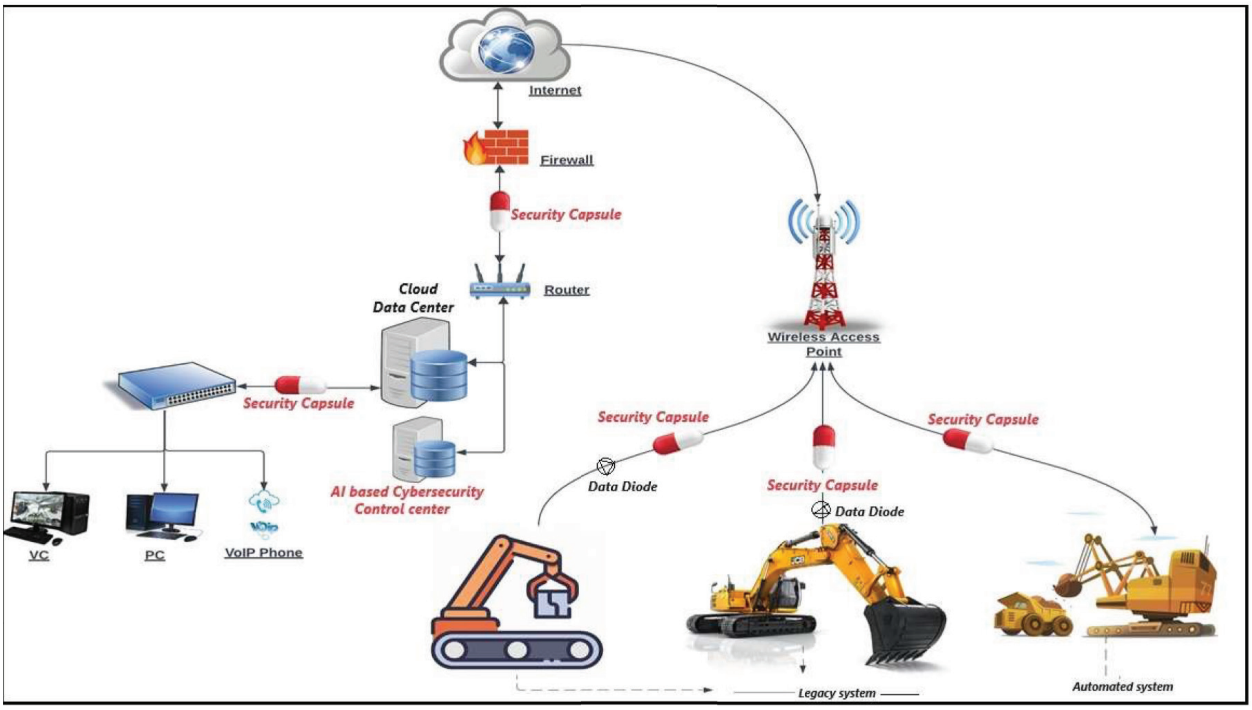

Figure-2 : AI Cybersecurity solution for cloud environment of digital mining.

In the above model (Figure-2), the digitization of equipment are deployed with cloud environment using high speed public network, where data generated from the machines are transmitted to server zone through internet. In this model, security solution requirement is high. Therefore, every zone before entering to a public network need adequate security solutions. The security capsules are placed for each machine whether a legacy system or a modern system. In addition, security solutions are to be deployed at cloud data centre. Moreover, the capsules are driven by AI based security solutions deployed in cloud for protection of data. Further, optional data diodes may be deployed for the legacy machines where sensor data is being transmitted one way from machine to cloud server/storage so that cyber attach shall not disrupt the operation of the machine. Further, security capsules should be intelligently deployed as one machine may have n number of sensors / IoT devices. All the data from the sensor / IoT devices of the machine should be transmitted over a single

backbone connectivity. Therefore, the security capsule should be deployed in the data stream. All configuration, control, policy shall be deployed from the central AI based cybersecurity solution centre.

CONCLUSIONS :

In the process of digitization in mining industries, new Industrial Internet of Things (IoT) architecture gains momentum. Traditional centralized system & communication methods are shifting. In this process, many sensors are now using IoT protocols to connect industrial sensors directly to the cloud. Thus mining sector becoming vulnerable to attacks, which can disrupt production operations & productivity. The intensity and frequency of cybercrime attacks continue to evolve rapidly with each coming year. Depending on the size of the organization, there are millions of data generated, which need to be analysed to predict risk accurately. The process of analysis and improvement of cybersecurity is no longer a humanscale problem. Data mining and AI in cybersecurity are fast-emerging trends that enhance the performance of IT security teams. AI give the much-needed threat identification and analysis that security teams can use to minimize breaches and strengthen security posture.

The author emphasizes for designing cybersecurity capsules driven by AI. These AI based capsules will automatically decide the deployment of rules/policies based on the behaviour & security postures analysis of the machine and IoT sensors fitted. The sensor data may be categorized as low, medium or high based on the company activity and operational technology deployed. AI at centre will monitor and control the capsules to deploy adequate cyber security protections with prediction and mitigation with zero day protection. The entire cybersecurity solution will provide a cost effective, easy deployment and less human intervention solution. Author invites companies and experts to design and develop such capsules for easy deployment and early mitigation to provide complete cyber security solutions for mining industries on the way of digital transformation.

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A FRAMEWORK FOR DIGITAL TRANSFORMATION IN THE MINING AND METALS INDUSTRY

Michalis Katapotis[1], Samuel Olmos Betin[2], Martin Efferoth[3]

Although digitalization is widely regarded as enabling the mining and metals industry to address its current challenges (depleting resources, low productivity, safety concerns, financing and increasingly stricter ESG regulations), digital mine transformation programs tend to fall short of expectations. Indeed, as shown in a 2021 report by BCG, the gap between digital strategy and execution in metals and mining is significant, especially in relation to other industries. This paper reviews information from recent studies on technology adoption in the mining & metals industry, corporate reports and market information in order to shed light on the diverse reasons behind this gap and articulate a framework for successful digital transformation programs. We look at financial, technical and cultural/organizational barriers to innovation, specific to the mining and metals industry, and propose ways to overcome them in order to unlock the full potential of new digital technologies for optimization across the value chain.

Keywords : Mining, metals, digital transformation, digital mine, mine 4.0, innovation

1. INTRODUCTION

Within the mining and metals sector, technological progress and market dynamics havebrought to the fore the transformative phenomenon of digitalization. Aligned with the principles of Industry 4.0, this trend involves the integration of intelligent technologies, data-driven decision-making, and heightened connectivity to revolutionize conventional mining practices. The new paradigm gained pace with the decline of the commodity boom, a period during which escalating demand had obscured the need for structural changes shifting the focus instead on increased production volumes. In recent years, however, the sectorhas been facing a wide array of challenges.The legacy of the commodity boom has been a steep decline in productivity (further exacerbated by the depletion of rich, near-surface deposits shifting exploitation to more remote, deeper, and more complex deposits of declining ore grades) from which mining is still struggling to recover (Humphreys 2020). Furthermore, the raw materials market has been characterized by extreme volatilitydriven by geopolitical tensions, resource nationalism, demand and supply disruptions (the most recent example being the covid-19 pandemic), raw material substitutions due to technological change,and pressures by circular economies. Finally,rising social, legislative and financial pressures to mining companies to demonstrate commitment to environmental, social and governance obligations have brought to the forefront the issues of sustainability and transparency.It is in this context that digital transformation has claimed a strategic role in the mining and metal sector. The advent of new technologies, such as the industrial IoT, IT/OT convergence, big data analytics, artificial intelligence, automation, augmented and virtual reality, 3D printing, and the cloud,has offered organizations novel ways to boost operational efficiency, improve safety and workspace quality, and create value in a sustainable way (see Ganeriwallaet al

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2021 for a list of potential KPI improvements).It is indicative that mentions of digitalization in corporate reports in the mining industry have increased by no less than 448% since 2016 (Mining Technology 2022).

Despite this strong presence of digitalization in corporate strategy, however, its transformative potential remains largely unexploited. Indeed, although the pace of implementation of digital solutionsvaries among regions, company-sizes,and different technologies (GlobalData 2022), the mining and metals sectordemonstrates overall a considerable lag in digital maturitycompared to other industries. According to BCG's Digital Acceleration Index, metals and mining are 30-40% less mature than industries like chemicals and automotive (Ganeriwallaet al 2021). Similarly, according to the Industry 4.0 Maturity Index by ABI and Nokia (2022), mining ranks very low in terms of both investments in IT infrastructure and deployment of actual OT use cases (Figure 1).

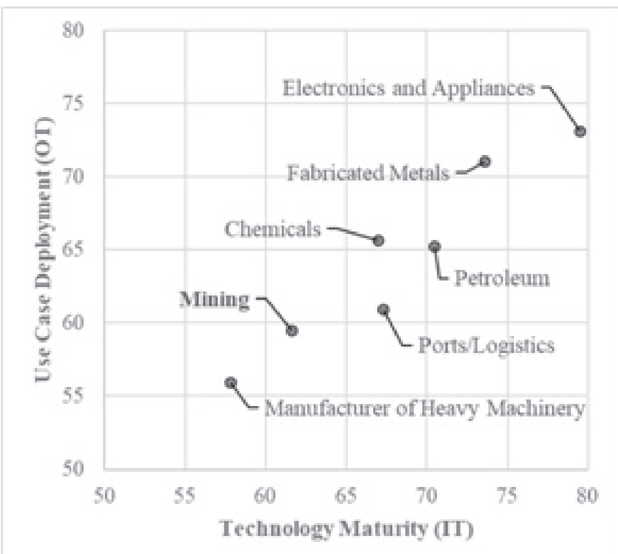

Figure 1 Industry 4.0 Maturity Index by Vertical (data from ABI and Nokia 2022).

This strategy-execution gap in the digital transformation of the metals and mining industry, which is substantial in relation to other industries (Table 1),indicates that digitalstrategies are developed but are rarely implemented, which,in turn, means that transformation programs have a low rate of completion. Asurvey by Rockwell Automation (2019) serves to demonstrate the point: in contrast to other industries, most mining companies have not yet engaged in digital transformation, 32% are still exploring the opportunities of digitalization but only 10 % have implemented at least one digital solution.

Industry	Gap
Metals and Mining	30%
Engineering Products and Solutions	18%
Pharma and Biotech	11%
Chemicals	9%
Automotive	9%
Logistics	8%
Technology	7%

Table1 The strategy-execution gap in metals and mining (data from Ganeriwallaet al 2021).

This paper reviews information from recent studies on technology adoption in the mining & metals industry, corporate reports and market information in order to shed light on the diverse reasons behind the strategy-execution gap and articulate a framework for successful digital transformation programs. We look at financial, technical and cultural/organizational barriers to innovation, specific to the mining and metals industry, and propose ways to overcome them in order to unlock the full potential of new digital technologies for optimization across the value chain.

2 BARRIERS TO DIGITALIZATION IN MINING

Mining companies havea reputation of being conservative and reluctant to fully embrace new technologies, which is to a large extent relatedto distinctive attributes of the industry.Factors like high capital-intensity, orebodyuncertainty, commodity and equity price volatility, high safety and environmental risks, and remote operating environments, discourage investments in innovation favoring, instead, sustained use of mature, reliable technologies (Ediriweera and Wiewiora 2021, Shook 2015).

Furthermore, since the de-verticalization of large firms in the 1990s, the role of mining companies in innovation has changed dramatically.Focusing on their core business,companies downsized their in-house R&D capabilitiesbecomingincreasingly reliant oninnovations developed by a rapidly growing Mining Equipment, Technology, and Services (METS) sector (Sturbin 2017).It is indicative that the average R&D spending of five of the largest mining companies during the 2011-2018 period was less than 0.5% of their revenue as opposed, for example, to the pharmaceuticals and ICT industrieswhere R&D spending was 25% in 2015 (Sánchez and Hartlieb 2020).Presently, only few of the major mining companies maintain in-house R&D groups which mostly work on highly specialized technological solutions (Calzada Olvera 2022).

With the advent of digitalization, the mining innovation ecosystem has become broader, more diverse and more entangled. On the one hand, ICTs (majors and startups) have entered the market with a wide range of software and hardware solutions for the entire value chain from the pit to the client. On the other, major OEMs have complemented their equipment portfolio with digital systems to optimize and automate its operation and boost its performance (Sánchez and Hartlieb 2020). It is within this intricate landscape of multiple, diverse suppliers and products of different levels of maturity, that mining companiesas net consumers of innovation(Steen et al 2018) must chart their course towards digital transformation.

Interviews with members of the mining and metals industry have revealed a wide array of organizational, cultural and technological barriers that companies encounter when embarking on digital transformation programs (ABI and Nokia 2022, Gao et al 2019, Ganeriwallaet al 2021).Although responses may vary among different company and site profiles, certain themes emerge as prevalent.

2.1 Strategy and Leadership

Mining is a technologically and organizationally complex system.Interconnected processes, each with its own challenges and objectives, take place at different locations and different time horizons, from exploration to mine closure and from the pit to the client (Usher and Dover 2018). At the same time, the traditional structure of mining companies as portfolios of independent, geographically dispersed and isolated mines (Steen et al 2018) often leads to a decentralized and fragmented decision-making hierarchy.

As a result, it is not uncommon for digitalization in mining companies to occur in episodes of small, disjoinedad hocprojects, which may address specificproblems but fail to drive transformation across the organization.Not only does thisshort-sighted perspective disregard the potential consequences that any technical modification may have on downstream processes, often resulting in sub-optimal outcomes; entrenched digitalization also humpers the enterprise-wide data integration and increases implementation and maintenance costs. Finally,without anoverarching digital strategy in alignment with corporate strategy and financial plans, it is difficult for digital transformation programs to secure the long-term management commitment andfunding required for their successful implementatio**n** (Abdellah et al 2022).

At the same time, a lack of commitment across the enterprise to a shared digital vision allows divergent views and interests within the firm to act as barriers to change (Gao et al 2019). Tensions among stakeholdersmay emerge through conflicts between long-term objectives of continuous improvement and short-term expectations of performance and productivity, compromising project management efficiency(Ediriweera and Wiewiora 2021). Similarly, from the workers' perspective, digital technologies may appear as threats to their jobs, their privacy, and the prospects of their local communities (Lööw etl al 2019, Storey 2023). Such concerns are frequently manifested asresistance to technology adoption either formally, through unions, or in practice (Gruenhagen and Parker 2020).

2.2 Digital capabilities

Digital transformation requires a wide range of capabilities that most mining firms have beentraditionally lacking (Abdellah et al 2022). They include expertise not only on technical domains such as data analytics, IoT, artificial intelligence and machine learning, cybersecurity, data privacy and compliance but also on innovation management, agile methodology, data-driven decision-making, and ecosystem thinking. Unfortunately, within the highly competitive environment of the global skills shortage, attracting talents is handicapped by current perceptions of mining as a labor intensive, male-dominated, dangerous, and polluting industry. Digitalization will definitely contribute to reshaping that image, transforming the workplace though remote operations, automation, and sustainable practices (Lööw etl al 2019). In the short run, however, it is a challenge that remains to be addressed.

2.3 Business case development

Investments to digital technologies are often considered unjustifiable due to expectations of low returns, often corroborated byprevious experience with projects where considerable differences emerged between anticipated and actual costs and benefits (Gao et al 2019).Such problems arise when projects are mostly orientated towards solving technical problems rather than on creating business value (Abdellah et al 2022, Deloitte 2017). Without a structured business case, project feasibility, potential benefits, and associated costs cannot be properly evaluated, impeding the establishment of realistic project goals, proper allocation of resources, and accurate risk assessment. In essence, the omission of business case development deprives the organization of a critical tool for informed decision-making, strategic alignment, and value-driven digitalization.

2.4 Technological maturity

Innovation in mining is always associated with risk. Any disruptions to daily operations, due to delays or failures in commissioning, have a negative effect on cash-flows and, more importantly, may compromise employee health and safety, which is a critical issue for the industry (Ediriweera and Wiewiora 2021, Gao et al 2019). Due to the fast pace of innovations by a very active and expanding METS sector, and the inherent difficulties of testing and experimentation in a mining context, operational managers are not always willing to take the risk of adopting a new technology, due to concerns about its robustness, reliability, and safety (Gao et al 2019).Further concerns arise from the lack of interoperability standards, with many products relying of proprietary data formats, interfaces, and platforms (indicative of less mature ecosystems),which complicates integration (GMG 2021).

3 A DIGITAL TRANSFORMATION FRAMEWORK

Although there are no fit-for-all solutions to the challenges described above, there are lessons to be learned from success stories. In the following sections, we outline certain dominant themes underpinning the digital transformation programs of leading companies in the industry.

3.1 Digital strategy

A digital transformation program begins with the development of a strategy, a plan that aligns digital initiatives with the company's overarching business goals. This strategy empowers stakeholders to delineate clear objectives, prioritize initiatives, and allocate resources accordingly(EY 2018). Additionally, it facilitates the identification of potential bottlenecks, risks, and opportunities, allowing for proactive mitigation and exploitation. By fostering collaboration between technical experts and operational teams, a robust digital strategy enhances stakeholder buy-in and engenders a shared vision for transformation. Such a vision can steer companies away from a short-term returns mentality towards fostering a long-term perspective of continuous improvement, supported by sustained investments that cut through price cycles(ABI 2021).In essence, the development of a digital strategy catalyzes innovation, maximizing operational efficiency, sustainable growth, and competitive advantage (Amadi-Echendu et al 2011: 24).

3.2 Data-driven innovation

Digital initiatives should be assessed and prioritized based on well-constructed business cases (Abdellah et al 2022, EY 2018). By rigorously evaluating potential benefits, costs, and alignment with strategic goals, companies can ensure that their digital endeavors are not only technologically feasible but also contribute meaningfully to value creation and sustainable growth.In the case of a condition monitoring system for belt conveyors, for example, opting directly for a solution that detects all types of failure would involve high capital expendituresand operational expenses, as well as high risks due to the increased complexity of the system. Instead, by first conducting a Pareto analysis to identify the failure types that occur more frequently and induce higher costs (labor, spare parts, inventory, and downtime), it is possible to select the solution thatmaximizes ROI (for an example of belt conveyor failure analysis see Zimroz and Król 2009).At first, decisions will be driven by informationprovided by legacy systems.However, as more assets are connected, more data will become available enabling the company to better understand its processes and identify further opportunities for improvement (Shook 2015).

3.3 Integration

The highest form of digital integration in mining is the Remote Operations Center (or Mine Operations Center). A single room connected to mines and plants, with a capacity to collect, analyze, and visualize diverse sets of real-time data from the trackingand monitoring of people, materials,equipment and processes, enabling informed decision-making and remote operations to drive optimization across value-chains (WEF 2017). This construct relies, in turn, on an equally complex and integrated IT/OT infrastructure, with thousandsof sensors, devices, automations, wired and wireless communication technologies, interoperable protocols, data platforms, servers andsoftware applications. The real foundation of integration, however, is the concept of the mining enterprise as system of interdependent people, technologies and processes cooperating towards a set of shared objectives (Ganeriwallaet al 2021).

Digital transformation is, therefore, less about deploying hardware and software solutions; it is about building a culture of integration with a holistic approach to decision-making (Deloitte 2021). To do so, companies need to adopt practices that break away from traditional compartmentalized organizational motifs :

- Early engagement of all stakeholders in cross-function teams breaks down silos and drives collaboration across the organization.

- Focusingon KPIs that measure performance at the system level instead of the process level, promotes collaboration and a broader perspective on value creation. In this respect, digital transformation programs could also benefit from integrating concepts, such as mine-to-mill, geometallurgy and total cost of ownership (Lishchuk and Pettersson 2020; Nadolski et al 2015, Steen et al 2018).
- Even when digital transformation is taking place incrementally, the design of the data and IT/OT architecture should be, from the onset, oriented towards systemwide integration. Interoperability and scalability should therefore be critical design criteria.

3.4 Collaborative ecosystem of competence

Digital transformation is about leveraging diverse skills and capabilities to create value across value chains. Mining companies need therefore to adopt new innovation paradigms, focusing not only on building internal digital capabilities but also on developingcollaborative ecosystems of competencewhich extend beyond their organizational boundaries.Leading mining companies demonstrate how to pursue this dual agenda though development and collaboration initiatives :

- Training plans should become integralto the company's digital strategy based on a gap analysis of skills and competencies required to deliver long-term value. The scope of the training plan should not, however, be limited to digital skills; instead, it should also foster a culture of adaptability, collaboration, communication, creativity, and problem-solving mentality(Ediriweera and Wiewiora 2021).
- Attracting talentrequires significant progress to be made by the mining industry in relation to working conditions, health and safety, gender equality and ESG transparency and compliance.
- Collaborations with local Universities, such as the Siemensdigital mining incubator' at the Wits University in South Africa (Wits University 2018), enable the development of the next generation of digital mining experts.
- Strategic co-creation partnerships with technology providersestablish relations of trust by mitigating risks involved in technology adoption (Ediriweera and Wiewiora 2021). Examples of such partnerships are those between Rio Tinto, BHP and other mining firms,and Komatsu to develop zero-emission mining equipment and infrastructure (Mining Technology 2021); and between Goldcorp and IBM to develop the IBM Exploration with Watson platform which uses AI on exploration datasets to identify new gold prospects (NMA 2019)
- Local supplier development initiatives not only facilitate local innovation (a potential source of solutions customized to local conditions); they also strengthen the local economy and therefore the company's bonds with the local community (Sturbin 2017). BHP has pioneered such initiatives with its World Class Supplier Program in Chile (Navarro 2018), the Supplier Innovation Program in Australia (Minerals Council of Australia 2022) and the Core innovation hub in Australia (BHP 2022).
- Industry-level collaboration, for the development of innovative solutions, could yield significant cost savings. An excellent example is Canada Mining Innovation Council's digital transformation initiative 'Rethink mining' which hosts the'Sensor-based ore sorting' project with the participation of 9 mining and technology companies (Weatherell 2020).
- Testing centers, such as NORCAT in Canada, provide the ground for testing new technologies therefore mitigating risks of new technology adoption (ABI 2021).

4. CONCLUSIONS

This paper discussed the significant gap between digitalization as a key component of corporate strategy and its effective execution within the mining and metals sector. It was argued that the low digital maturity of mining should be associated not only with inherent attributes of the industry that discourage innovation but also with specific barriers to digital transformation, such as siloed decision-making structures, shortage of digital capabilities, poor business case development and low technological maturity. To address those challenges, a digital transformation framework has been proposed that is based on a solid digital strategy, data-driven innovation and the development of a collaborative ecosystem of competence.

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ENVIRONMENTAL AND SOCIAL IMPACT ASSESSMENT OF AN INDIAN IRON ORE MINE USING FOLCHI MATHEMATICAL MODEL

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Abstract

Mining plays an indispensable role in societal growth and human development, fuelling various aspects of modern life. However, its negative impact on the environment and surrounding areas is a concern that cannot be ignored. This paper employs the well-known Folchi method to measure the environmental effects of an Iron ore mine situated in a biodiverse forest, providing a detailed analysis of the consequences on different environmental components. Among several indicators, the paper finds that the use of territory and the alteration of the landscape are highly impacted by mining activities, marking a primary concern. Additionally, the social disturbance caused by increased traffic in mining areas is noted as a significant issue. Despite these negative aspects, the paper also highlights some positive impacts, such job opportunities to local communities and an improvement in living conditions. The study suggests for an integrated approach to mining that takes into account both the need for responsible environmental management and the necessity of considering both positive and negative repercussions. The study finishes with suggestions for environmentally responsible mining methods that might balance the needs of growth and those of ecological responsibility.

Keywords : *Environmental Impact, Social Impact, Sustainable Mining, Folchi Method, Impact Assessment Tool*

1.0 INTRODUCTION

Mining is undoubtedly at the heart of modern civilization, providing essential minerals and metals that fuel various aspects of human life. Historically, the role of mining has been monumental in shaping economies and fostering growth, as detailed by Allan (1995) and Azapagic (2004). However, as important as mining is, it does not come without costs, especially to the environment and society at large. The ever-growing global population, coupled with an insatiable demand for goods and services, has led to an intensified reliance on mining. This increased dependence is likely to accelerate the depletion of minerals and amplify the waste produced in mineral processing plants. Osanloo (2012) particularly emphasizes this aspect, warning of the long-term consequences of a single mining operation, which could alter an area's developmental course for centuries, a notion supported by scholars like Kirsch (2010). The mining sector's concern is not just restricted to the extraction of minerals but extends to a broader responsibility towards the production of goods, services, and infrastructure. As noted by Mayes et al. (2009) and Jordan (2009), some forms of mining, such as surface mining, are particularly damaging, causing significant land degradation and environmental harm.

Modern mining is beginning to evolve, recognizing the urgent need for responsible practices.

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Companies are now focusing on issues like waste reduction, radioactivity management, and emission control. They are aligning themselves with global goals that promote job growth, social development, partnerships with governments, and improved quality of life. At the core of this transformation is the concept of 'sustainable mining' or 'responsible mining.' The concept of sustainable development (SD), which was first discussed at the United Nations Earth Summit in 1992, aims to balance the requirements of the present without sacrificing the capacity of future generations to meet their own needs (Hustrulid et al., 2013; Asr et al., 2019). Since its introduction, countless studies have delved into the intricate relationship between mining operations and SD, exploring environmental, societal, and economic aspects (Azapagic, 2004; Phillips, 2013;Syahrir et al., 2020). The Sustainable Development Goals (SDGs), also known as the Global Goals, were created by the United Nations General Assembly in 2015 (Pouresmaieli et al., 2023), and the mining industry is committed to accomplishing them. These 17 interconnected goals serve as a blueprint for global peace, prosperity, and planetary health. Embracing the SDGs, the mining sector has started to realign its objectives. Notable contributions in this area include Folchi's (2003) 2D matrix for assessing environmental impacts, Rahmanpour et al. (2017)'s system for sustainable mine pit limit selection, and Azapagic (2004)'s sustainability development framework. Recent studies have emphasized mining's complex and multifaceted impacts, including its potential positive environmental influence and sustainable development criteria (Mobtaker et al., 2014; Moradi et al., 2015). Research by Alves et al. (2018), and Amirshenava et al. (2019) shed light on mining's local community impacts, encompassing both socio-economic benefits and environmental drawbacks.

India is one of the world's largest producers of iron ore, with abundant reserves primarily located in the states of Odisha, Chhattisgarh, and Karnataka. Iron mining in India has played a vital role in the country's industrial growth, contributing significantly to the GDP. However, the extraction and processing of iron ore have raised substantial environmental concerns. Mining activities, particularly in biodiversity-rich forests, have led to the degradation of landscapes and the loss of habitat for various flora and fauna (Lamare, 2017). Deforestation, soil erosion, and alteration of landforms are common, often causing long-term ecological imbalances (Sahoo et al., 2013). Air quality is another significant concern, as dust emissions from mining and transportation activities contribute to air pollution, affecting both the environment and human health. The energy-intensive nature of iron ore extraction and processing also leads to considerable carbon emissions, contributing to climate change (Chakravorty, 2001). Despite the challenges, initiatives are underway in India to promote sustainable iron mining practices. Implementation of stricter regulations, technological advancements, and community engagement are among the efforts to mitigate environmental impacts. Collaborative approaches involving governmental agencies, mining companies, and local communities can lead to a more balanced coexistence of mining activities and environmental preservation (Bose-O'Reilly et al., 2010). These considerations illustrate the multifaceted nature of iron mining in India and the pressing need for responsible practices that align with global sustainability standards. The experience of India serves as an essential reference point for other nations grappling with similar challenges, highlighting the importance of sound policy, technology, and collaboration in achieving sustainable mining practices.

In this study, we examined an Indian iron ore mine located in a biodiversity-rich forest, paying particular attention to its environmental impact. We employed the Folchi method (2003) to measure the mine's influence on various environmental parameters, such as air and water quality, soil health, and biodiversity, etc. We also used Phillips' semi-quantitative evaluation approach to estimate the mine's sustainability, weighing its long-term viability against environmental and social costs. This research emphasizes the need for responsible mining practices that prioritize environmental conservation and sustainability.

2.0 METHODOLOGY

2.1. The Folchi Method

The Folchi method, introduced by Folchi in 2003, is recognized as a highly effective way for carrying out environmental impact analyses. It combines adaptability, comprehensiveness, repeatability, efficiency, and efficacy to address difficult EIA challenges. Folchi used this method for the first time in Sardinia's mining operations in Italy to quantify the environmental impact caused by mining activities such as drilling and blasting. The outcome of the data analysis demonstrated high levels of accuracy and reliability. However, it was observed that the precision of the results improved significantly when the Folchi method data was gathered by skilled personnel for analysis (Monjeziet al., 2009; Phillips, 2009). The procedure is comprised of seven key stages, as outlined below:

- Understanding the existing environmental setting, taking into account factors such as geology, geo-technics, hydrology, climate, economy, and more.
- Identifying potential impact factors, or those elements that could alter the existing environmental conditions during mining operations.
- Establishing the potential scope of change caused by each identified impact factor.
- Determining the environmental components that could be altered due to the mining activities.
- Forming correlations between each impact factor and each affected environmental component.
- Predicting the specific intensity of each impact factor based on the pre-established ranges.
- Computing the cumulative weighted impact of the identified impact factors on each affected environmental component.

2.1.1 Weightage of Mining Environmental Factors

The Folchi method calculates environmental factors based on the degree to which pre-existing conditions have an impact (from zero to maximum). All components associated with mining are normalized to a total of 10. Table 3 illustrates the weighting elements and the degree of concern associated with environmental component effect factors.

2.1.2 Scoring Impact and Folchi Method Challenges

Each environmental component's impact is calculated by selecting a magnitude from Table 2 and multiplying it by the corresponding values in Table 3. The real weightage of each component represents its distinct impact on environmental sustainability. The maximum score awarded to each component is supposed to be 100 in accordance with Folchi's technique.

The effectiveness of this model is determined on the quantity and kind of classes or parameters (described in Table 2) available for assessing the environmental and human aspects of mining activities. The Folchi technique has eight and three parameters, respectively, and is organized around two basic categories: environmental conditions and human wants and interests.

The model offers a way to identify potential areas for sustainability enhancement through a combined human-environment approach. Moreover, it aids in continuously monitoring, mitigating, or enhancing environmental and anthropogenic factors, thereby potentially augmenting the sustainability dimensions of mining operations over time. Despite its utility, the Folchi method does have inherent limitations. According to Phillips (2013), it includes rigid categories that might not sufficiently account for the complex human-environment system. Since the component magnitudes are predetermined, the correctness of the results depends heavily on the assessor's discretion. According to Monjezi et al. (2009), the Folchi technique, which was first developed for evaluating mining processes and environmental sustainability, might be modified to fit various operations.

Table 1 : The factors influencing the impact and the categories of the mining environment within the Folchi Method (2003).

Impacting factors		Environmental components
1. Alteration of the area's potential resources	1.	Human health and safety
2. Exposition, visibility of the pit	2.	Social relationship
3. Interference with above-ground water	3.	Water quality
4. Interference with underground water	4.	Air quality
5. Increase in vehicular traffic	5.	Use of territory
6. Atmospheric release of gas and dust	6.	Flora and fauna
7. Fly-rock	7.	Above ground
8. Noise	8.	Underground
9. Ground vibration	9.	Landscape
10. Employment of local work force	10.	Noise
	11.	Economy

Table 2 : Impacting factor's magnitude ranges within the Folchi Method (2003)

	IMPACTING FACTORS	SCENARIO		MAGNITUDE
1.	Alteration of area's potential resources	Parks, protected areas		8-10
		Urban area		6-8
		Agricultural area,		3-6
		Wood Industrial area		1-3
2.	Exposition, visibility of the pit	Can be seen from inhabited areas		6-10
		Can be seen from main roads		2-6
		Not visible		1-2
3.	Interference with above-ground water	Interference with lakes and rivers		6-10
		Interferences with non-relevant water system		3-6
		No interference		1-3
4.	Interference with underground water	Water table superficial and permeable grounds		5-10
		Water table deep and permeable grounds		2-5
		Water table deep and un-permeable grounds		1-2
5.	Increase in vehicular traffic	Increase of 200%		6-10
		Increase of 100%		3-6
		No interference		1-3
6.	Atmospheric release of gas and dust	Free emissions in the atmosphere		7-10
		Emission around the given reference values		2-7
		Emission well below the given reference values		1-2
7.	Fly-rock	No blast design and no clearance procedures		9-10
		Blast design and no clearance procedures		4-9
		Blast design and clearance procedures		1-4
8.	Noise	<141db		8-10
		Peak air overpressure at 1 km distance	<131db	4-8
		<121db		1-4
9.	Ground vibration		Above threshold	7-10
		Cosmetic damage,	Tolerability threshold	3-7
			Under tolerability threshold	1-3
10.	Employment of local work force		High	7-10
		Job opportunities	Medium	3-6
			Low	1-2

Table 3:The correlation matrix of impacting factors and component magnitude provided by Folchi (2003).

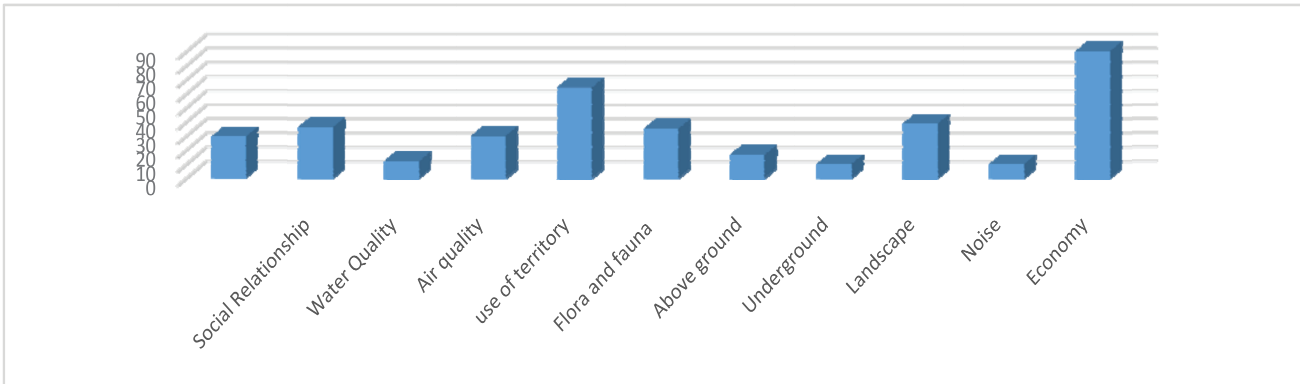
Impacting factors	Environmental components										
	Human health and Safety	Social relationship	Water Quality	Air Quality	Use of territory	Flora and Fauna	Above ground	underground	Landscape	Noise	Economy
1. Alteration of area's potential resources	Med 0.80	Min 0.77	Nil 0	Nil 0	Max 5.71	Min 0.63	Nil 0	Nil 0	Max 2.86	Nil 0	Nil 0
2. Exposition, visibility of the pit	Nil 0	Min 0.77	Nil 0	Nil 0	Med 2.86	Nil 0	Nil 0	Nil 0	Max 2.86	Min 2.00	Nil 0
3. Interference with above-ground water	Max 1.60	Nil 0	Max 4.44	Nil 0	Nil 0	Max 2.50	Med 6.67	Nil 0	Max 2.86	Nil 0	Nil 0
4. Interference with underground water	Min 0.40	Nil 0	Max 4.44	Nil 0	Nil 0	Nil 0	Nil 0	Med 6.67	Nil 0	Nil 0	Nil 0
5. Increase in vehicular traffic	Max 1.60	Max 3.08	Nil 0	Nil 0	Min 1.43	Max 2.50	Nil 0	Nil 0	Min 0.71	Nil 0	Nil 0
6. Atmospheric release of gas and dust	Max 1.60	Min 0.77	Min 1.11	Max 10.00	Nil 0	Max 2.50	Min 3.33	Nil 0	Min 0.71	Nil 0	Nil 0
7. Fly-rock	Max 1.60	Nil 0	Nil 0	Nil 0	Nil 0	Med 1.25	Nil 0	Nil 0	Nil 0	Nil 0	Nil 0
8. Noise	Med 0.80	Max 3.08	Nil 0	Nil 0	Nil 0	Min 0.63	Nil 0	Nil 0	Nil 0	Max 8.00	Nil 0
9. Ground vibration	Max 1.60	Med 1.54	Nil 0	Nil 0	Nil 0	Nil 0	Nil 0	Min 3.33	Nil 0	Nil 0	Nil 0
10. Employment of local work force	Nil 0	Nil 0	Nil 0	Nil 0	Nil 0	Nil 0	Nil 0	Nil 0	Nil 0	Nil 0	Max 10.00
Total	10	10	10	10	10	10	10	10	10	10	10

Table 4:Impact score associated with mining impacting factors from data collection

Impacting factors	Alteration of area's potential resources	Exposition, visibility of the pit	Interference with above groundwater	Interference with underground water	Increase in vehicular traffic	Atmospheric release of gas and dust	Fly rock	Noise	Ground vibration	Employment of local work force
Score	9	2	1	1	9	3	1	1	1	9

Table 5: weighted impact score for environmental components

Sr. No.	Impacting factors	Environmental components										
		Human health and safety	Social Relationship	water quality	Air quality	use of territory	Flora and fauna	Above ground	Underground	Landscape	noise	economy
1	Alteration of area's potential resources	7.2	6.93	0	0	51.39	5.67	0	0	25.74	0	0
2	Exposition, visibility of the pit	0	0.77	0	0	2.86	0	0	0	2.86	2	0
3	Interference with above groundwater	1.6	0	4.44	0	0	2.5	6.67	0	2.86	0	0
4	Interference with underground water	0.4	0	4.44	0	0	0	0	6.67	0	0	0
5	Increase in vehicular traffic	11.2	21.56	0	0	10.01	17.5	0	0	4.97	0	0
6	Atmospheric release of gas and dust	4.8	2.31	3.36	30	0	7.5	9.99	0	2.13	0	0
7	Fly rock	1.6	0	0	0	0	1.24	0	0	0	0	0
8	Noise	0.8	3.08	0	0	0	0.63	0	0	0	8	0
9	Ground vibration	1.6	1.53	0	0	0	0	0	3.33	0	0	0
10	Employment of local work force	0	0	0	0	0	0	0	0	0	0	90
	Total	29.2	36.18	12.24	30	64.26	35.04	16.66	10	38.56	10	90



3.0. RESULTS AND DISCUSSION :

3.1 Iron Ore Mine and its Environmental Impact

Nestled within the West Singhbhum district of Jharkhand, India, lies a prominent iron ore mine. Situated deep within a protected Forest, a biodiversity hotspot sprawling across 820 square kilometres, the mine is a vital source of high-quality hematite ore. Managed by a state-owned leading steel corporation, the mine contributes about 4.25 million tons of iron ore annually to India's booming steel industry. To assess the environmental impact of the mine's operation, data collection was conducted through site visits to the mine, utilizing questionnaires and evaluating Environmental Impact Assessment (EIA) reports.

To measure the environmental impact of the mine's operation, we utilized the Folchi method. The analysis exposed diverse levels of impact on varying environmental components (Table 4 and Table 5). Human health and safety are moderately impacted, with the alteration of potential resources having a relative impact score of 7.2 and an increase in vehicular traffic scoring 11.2. These concerns can be alleviated through effective traffic management and resource utilization monitoring. Social relationships within the mining community are lightly impacted mainly by vehicular traffic and noise. Engaging the community continuously and launching noise reduction initiatives is recommended. Water quality, with interference scores for above-ground and underground water at 4.44 each, has a relatively low impact, signifying the importance of water conservation and quality control measures. Air quality, impacted by the release of gas and dust, registers an impact score of 30, that can be summarised as a moderate impact. This necessitates the prioritization of implementing advanced emission control technologies. The use of territory, i.e. area utilized by mining and auxiliary activities, records a high relative impact score of 51.39. This emphasizes the significance of strategic land management and reforestation. Flora and fauna, with a moderate relative impact, accentuate the importance of biodiversity conservation and habitat restoration. Landscape preservation, affected by various factors including the alteration of potential resources, has a significant relative impact score of 25.74, highlighting the need for coordinated efforts to maintain the natural landscape's integrity and aesthetics. Noise, primarily from the pit's exposition and visibility, possesses a relatively low impact value. Nevertheless, noise control measures are advised for community comfort. Lastly, the employment of the local workforce scores a substantial 90 in relative impact, signifying an extremely positive influence on the local economy. This contributes to community development and economic stability.

4.0. CONCLUSIONS

Our study, using the Folchi method analysis, provides a complex overview of mining operations and their intricate environmental relationships. It emphasizes the necessity for an approach that recognizes the mining process's challenges and opportunities, focusing on responsible practices to align growth with sustainability goals. Targeted planning and interventions are vital in this regard. While highlighting areas that need immediate attention, the study also recognizes positive aspects, like community development through local employment. It represents a pivotal move towards sustainable mining, balancing industrial growth with environmental care and social equity. The analysis of the iron ore mine's impact also sheds light on sensitive areas in both environmental and social aspects. Utilizing these nuanced findings enables the refining of strategies for mining planning, sustainability enhancement, and community alignment. Key to this process is the creation of strategic plans for the holistic improvement of mining, which includes fostering robust communication with locals and proactive environmental initiatives. Special emphasis must be on regulating air pollution and unwavering adherence to environmental management plans for both environmental sustainability and human well-being.

However, the limitations of this study must also be acknowledged, including the specific methods applied, potential biases in the selected assessment areas, and the descriptive and semi-quantitative nature of the analysis. These factors may constrain the generalizability of the findings. Nevertheless, this study provides valuable insights and a comprehensive framework for responsible mine planning and operation, with an emphasis on integrated management practices that prioritize both ecological preservation and social harmony.

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SAFETY IN UNDERGROUND MINES USING FLAMEPROOF LIGHT FITTING

Bishwajit Modak[1]*, Amit Kumar[1], Rakesh Kumar Mishra[1], Manoj Kumar Vishwakarma[1] and Awanindra Pratap Singh[1]

Abstract:

Mining in underground mines is always been a difficult task due to the presence of explosive gases like methane. Miners often encounter methane gas during mining. Due to the explosive nature of the methane gas, normal light fitting cannot be used in underground coal mines. To prevent the explosion, flameproof light fitting is used in underground mines. Flameproof light fitting is a special type of light fitting which allows to occur the explosion inside it, developed by means of any arc or spark, but is prevents the flame to transmit into outside atmosphere. This paper deals with the mechanical integrity of flameproof light fitting. In this context mechanical integrity of the light fitting is checked by performing different types of tests like; Impact test, Thermal Shock test, Temperature rise test, Reference pressure test, Overpressure test and Non-transmission internal ignition test as per the standard IS/IEC 60079-0 and IS/IEC 60079-1. By performing these vital tests, it will be easy to know the strength of the equipment. Flameproof light fitting is useful for illumination in underground mines and it helps in production as well as miner's safety.

Keyword : *Light Fitting; Flameproof; Explosive gas*

INTRODUCTION

Safety in underground mines is a very difficult task due to the presence of hazardous gases. When coal is extracted from underground coal mines, methane emission takes place. Since Methane is of explosive and hazardous in nature hence it is very much necessary to use flameproof certified equipment in the underground coal mines. Flameproof light fitting is one of them. Flameproof light fitting is used for illumination in underground mines. It is used in underground mines as well as surface industries for lighting up the surrounding in various industries. Flameproof Light fitting comprises of one or more flameproof enclosure. The toughened type glass of the light fitting should be internally supported by a backing. The main aim of a flameproof light fitting is to provide the illumination after the electric supply of control panel. Low pressure sodium lamp shall not be used in the explosive area. Only toughened types glass isallowed and shall be used.

The light fitting consists various types of component like glass cover, enclosure, terminal box, baking plate, wire guard cover, LEDs and different size of bolts. High tensile strength bolts should be properly fastened and tightened during installation and maintenance of the light fixture. The terminal box is fixed with enclosure cable must be passed through terminal box to supply power of LEDs. The various types of tests are done to confirm the overall integrity of flameproof light fitting. Flameproof equipment or enclosure is a special type of equipment which allow to occur the explosion inside the enclosure but it prevents the flame to transmit into outside atmosphere.

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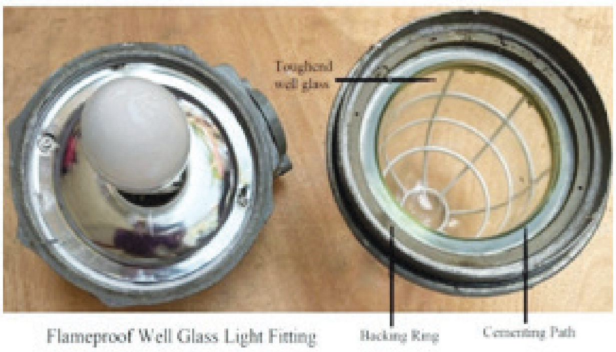
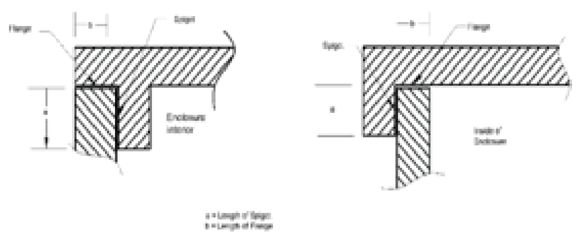


Flameproof Joint

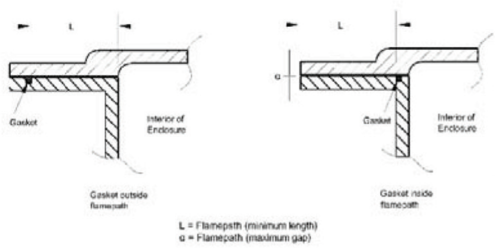
There are mainly three types of joints.

Spigot Joint, Flange Joint and Threaded Joint

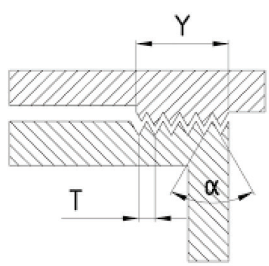
Spigot



Flange



Threaded



Y = Axial threaded length (Threaded Flame path)

T = Pitch

a = Thread Angle

Design and Construction

Encloser

Height: - 80mm

Thickness: - 7mm

Diameter: - 205mm

Flamepath: -15mm

Type of joint: - Spigot joint

Number of bolts: - Four

Size of bolt: - m6x20mm

Glass cover

Height: -150mm

Inner diameter: - 136mm

Type of glass: - Toughened type

Cementing material: - Calcium Sulphate

(COT: -20 oC to +120 oC)

Material of construction: - Cast Iron

Terminal Box

Average height: - 57.5mm

Internal diameter: - 77mm

Flamepath: - 15mm

Types of joint: - Spigot joint

Number of bolts: - Two

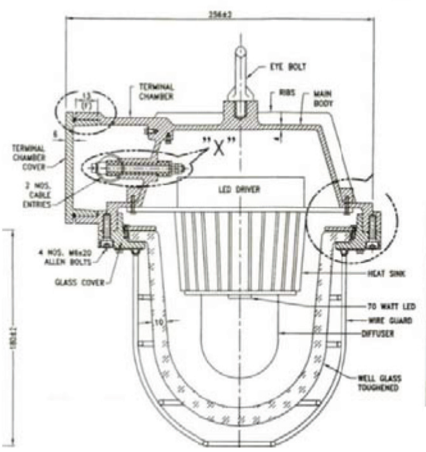
Size of bolt: -M6x20mm

Special fasteners: -

Flameproof protection requires a special type of fastener which conform the basic criteria like,

Only NPT or metric threadof coarse pitch are allowed.

Diagram



METHODOLOGY

There are mainly four (4) no. of tests to confirm the mechanical integrity of a flameproof Light fitting.

- Impact test.
- Reference pressure test.
- Over pressure test.
- Non-transmission of internal ignition test

Impact test :

One kg of hardened steel mass having hemisphere of 25mm diameter approx. is fallen vertically on the surface of the test object as specified in the IS/IEC 60079-0.

The equipment or test object shall be fully assembled and ready for use condition.However, in case of light transmitting part, the impact test is performed by removing the relevant part but fixing it into an equivalent frame. If the test is done for an empty enclosure, it should be permitted with proper justification and documentation.

The test should be performed on at least two samples. In case of light transmitting parts, two separate points on the sample is section, one is on the glass part and another is on the body part.

Generally, the impact point shall be considered the weakest part of the enclosure or equipment and shall be on the external part and exposed to impact. If the light fixture is protected by wire guardthen the impact test shall be done on external parts of the light fixture.

If the test surface is flat, the direction of the impact test shall be perpendicular to the test surface and if the surface is not flat, the direction of impact test shall bevertical to the tangent of the test surface.

Tests parameters for resistance to impact as per IS/IEC 60079-0

	Impact height			
Group	I		II	
Level	High	Low	High	Low
Equipment and external parts of equipment (excluding light fitting)	2	0.7	0.7	0.4
Wire Guard and protected cover	2	0.7	0.7	0.4
Light fixture (No wire guard)	0.7	0.4	0.4	0.2
Light fixture (having wire guards)	0.4	0.2	0.2	0.1

Impact energy can be measured by a relationship, falling from different heights.

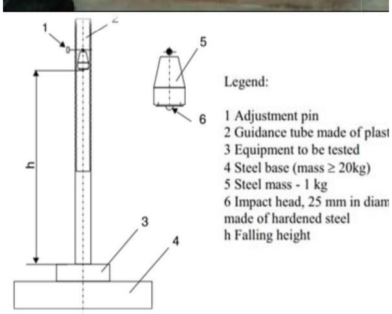
$h = \overline{mg}$

(h= Height,

E= Impact energy,

m=Mass,

g = acceleration due to gravity)

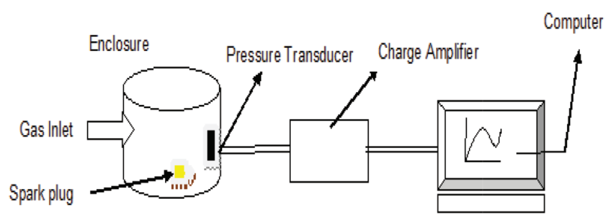


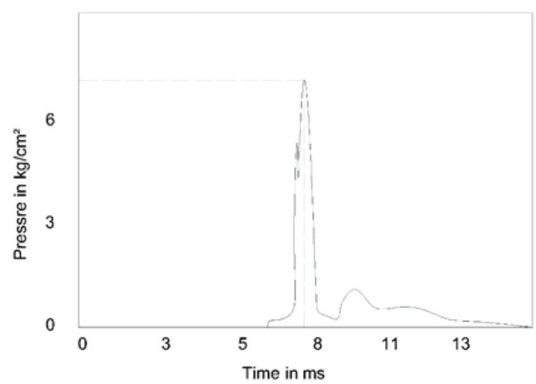
Reference pressure test :

Reference pressure test is one of the important tests for flameproof equipment. It is mainly a test to get the maximum pressure developed into the enclosure during explosion. This test setup consists of pressure transducer, charge amplifier and computer system. During this test explosive gas, as per the gas group classification, is filled into the enclosure and with the help of spark plug an explosion has been done inside the enclosure.

The pressure is sensed with the help of pressure transducer inside the enclosure. There is a piezo electric crystal inside the pressure transducer which helps the transducer to sense the pressure. Now this pressure energy is converted into voltage with the help of charge amplifier and gives a graph between pressure and time in the computer system. Thus, we get the **o**ptimum reference pressure into the enclosure.

Block Diagram :



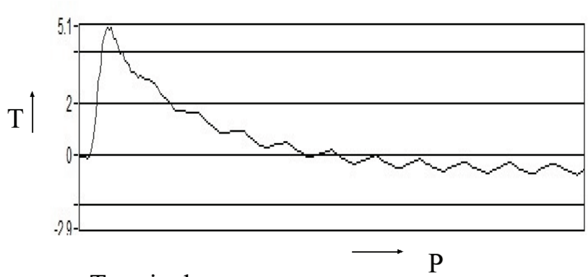


Graph

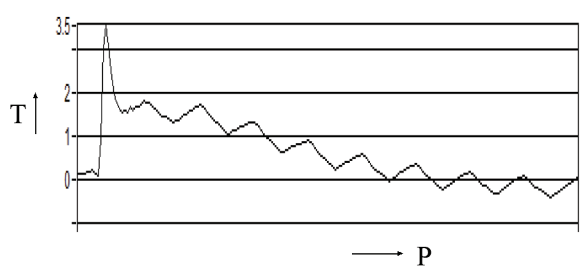
Test Data :

	Gas mixture: 10% CH4 in air. Test conducted as per IS/IEC 60079-1		
Group	Mixture % in Air		No. of Tests
I	10% CH4 in air		3
Test No.	Max. Pressure in Bar	Time(in ms) at which maximum pressure occurs	Observation
Main enclosure			
Test1	5.0	16.4	No evidence of distress
Test 2	5.1	18.6	-do-
Test 3	4.9	17.4	-do-
Terminal enclosure			
Test1	3.2	15.9	No evidence of distress
Test 2	3.3	18.4	-do-
Test 3	3.5	19.2	-do-

Graph :



Terminal



Main Enclosure

P (along x-axis) Vs **T** (along y-axis)

Overpressure Test (Static) :

It is nothing but 1.5 times of the maximum pressure observed into the equipment.

The enclosure gets a positive result only if is sustains an overpressure of 1.5 times of the optimum pressure for at least 10 seconds and none of the enclosure part is permanently damages or deformed.

Test conducted as per IS/IEC 60079-1 :

Enclosure	Ref no.	Pressure (kg/cm2) for 10 sec.	Observation
Main Enclosure	Test 1	8 kg/cm2	No damage or deformation
Terminal Enclosure	Test 2	6 kg/cm2	No damage or deformation

Overpressure test setup

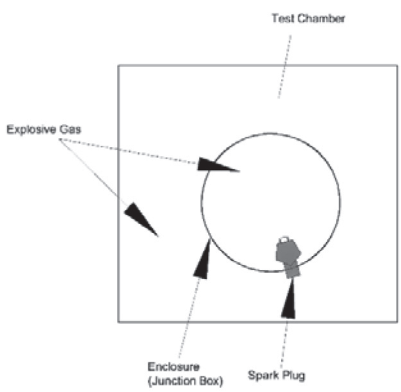
Non-transmission internal ignition test :

It is one of the vital tests for flameproof equipment. During this test, the enclosure allows to occur the explosion inside the enclosure but it prevents the flame to transmit into outside atmosphere. This test setup comprises of a test chamber where the enclosure is placed into the test chamber and a spark plug is fitted into the enclosure. After that explosive gas is filled into the enclosure as well as the test chamber. Now, with the help of the spark plug explosion is done inside the enclosure. If the mechanical integrity of the enclosure is good enough to bear the pressurethen it is pass.

One more important thing is the flamepath. The enclosure shall maintain the required flamepath and gap as per IS/ IEC standard 60079-1.

Gas Mixture : 12.5% CH_4/H_2 (58% CH_4 and 42% H_2) in air. No. of Tests: 5 Test conductedas per IS/IEC 60079-1 (No pre-compression required)				
Enclosure	Group	Mixture % in Air	No. of Test	Test Result
Main Enclosure	I	12.5% of (CH_4+H_2)	5	Pass
Terminal Enclosure	I	12.5% of (CH_4+H_2)	5	Pass

Non - transmission of internal ignition test setup



CONCLUSIONS

After performing the above-mentioned tests (i.e., Impact test, Reference pressure test, Overpressure test, non-transmission internal ignition test) following results has been observed.

1. After falling the mass of 1 Kg of hardened steel, perpendicular to the surface of the junction box to create impact energy, no crack & deformation is observed.
2. No evidence of distress is found after reference pressure test. It is performed five times according to standard IS/IEC 60079-1.
3. No damage or deformation is observed during Over Pressure test.
4. After performing the Non-transmission internal ignition test five times, as per the standard IS/ IEC 60079-1, no damage or deformation is observed and the test sample maintained its mechanical integrity.

Hence, Flameproof light fitting is useful for illumination in underground mines and it helps in production as well as miner's safety.

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A STUDY ON THE EFFECTS OF HORIZONTAL STRESS ANISOTROPY ON STABILITY OF GALLERIES IN DEEP UNDERGROUND COAL MINES

Nilabjendu Ghosh*, Subhashish Tewari, Rana Bhattacharjee, Arka Jyoti Das, Pankaj Kumar Mishra and Prabhat Kumar Mandal

Abstract

In-situ horizontal stress orientation plays a significant role in the stability of roof of galleries including bords, trunk roadways and gate roadways in underground coal mines. Higher obliquity between the major horizontal stress direction and the gallery drivage direction may cause cutter roof failure. Cutter roof or guttering is a type of failure that initiates at the upper corners of the galleries and propagates upwards, eventually reaching above the bolting horizon and can cause massive roof failures if left untreated. With increase in mining depths, the detrimental effects of high horizontal stress and its orientation assumes greater significance. Orientation of galleries, especially that of trunk roadways, and their support system should ideally be designed by considering the magnitude and direction of the in-situ major horizontal stress. This paper reviews the theoretical aspects of cutter roof failure and documents the ongoing studies on the effects of horizontal stress anisotropy at Indian underground coal mines in the form of field observations and attempts to replicate the experiences through numerical simulations.

Keywords : *Cutter roof failure, guttering, horizontal stress, longwall mining, deep underground coal mines*

1. INTRODUCTION

The stability of underground coal mine galleries is adversely affected by horizontal in-situ stresses working at higher angles to the direction of gallery drivage. The effect of high horizontal stresses assumes greater importance at deeper horizons and at geologically disturbed areas. Very high horizontal in-situ stresses may cause severe strata control problems in the form of cutter roof failure or roof guttering, especially if the stress anisotropy that is, the difference between the maximum and minimum horizontal in-situ stresses is also high. Instability of coal mine roof rock due to its horizontal compression and crushing is referred to as cutter roof failure. This type of failure most often originates at the intersection of roof and pillar and the damage is more pronounced in case of laminated roof rocks. Cutter failure is of progressive nature and can extend above the roof bolting horizon thereby causing a cantilevered roof and can finally result in a roof fall. While initiation of cutter failure disturbs the roof at the newly driven face, falls may occur after the guttering has progressed to a sufficient extent above the bolting horizon and severed the roof beam. Cutter roof also leads to increased convergence at the face, especially if the immediate roof layer is composed of laminations of friable rock. In such a situation the orientation of a roadway with reference to the major horizontal stress becomes important in ensuring its stability. Past studies, based on field observations and numerical modelling, concluded that the galleries oriented parallel to the major horizontal in-situ stress direction will enjoy maximum stability, while galleries oriented perpendicular to the major horizontal in-situ stresses will face severe strata control problems (1-11). A few studies on cutter roof failure have been conducted in the past in

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different countries. Investigations carried out by the United States Bureau of Mines were aimed at outlining the causes of cutter roof failure based on field investigations, analysis of numerical modelling results, and observations at underground mines. The report by Hill (1986) (8) also mentions a few methods of control such as yield pillars, reorientation of entries, and sacrifice entries. Additionally it advises that mining methods which reduce the amount of exposed roof that must be supported for long periods of time need to be adopted. Molinda and Mark (2010) (12) have defined cutter roof as instability of coal mine roof rock caused dueto horizontal compression and crushing of the rock which mostly takes place at the junction of roof and pillar. The damage is caused by horizontal stress acting to shorten and crush the roof. Ndlovu and Stacey (2007) (13) have used numerical modelling by FLAC 3D for analyzing cutter roof failure in South African coal mines. They have carried out comparative analysis using isotropic, transversely isotropic and Mohr-Coulomb constitutive models. Gao and Stead (2013) (14) have simulated cutter roof failure through discrete element models created in PFC3D and 3DEC software. They have suggested that longwall panels should be oriented at a small angle to the direction of the maximum horizontal stress to reduce fracturing of the rock mass and the likelihood of cutter roof failure.

Based on the above facts, in the present paper, authors have attempted to evaluate the stability of the gate roads and cross-cuts in the presence of stress anisotropy under weak laminated roof at AdriyalaLongwall Project, an underground Longwall coal mine belonging to Adriyala Project Area of Singareni Collieries Company Limited (SCCL), India (Figure 1). The Singareni Collieries Company Limited (SCCL) planned AdriyalaLongwall Project, a fully mechanized deep mine with a target production of 2.5 MTPA. Adriyala Shaft Block is the dip side extension of GDK 10A mine. The rise side property of this mine is mined out by RG OC-II. Seam no. I is exposed in high wall of RG OC-II from where punch entries (trunk roadways) are driven along the sandstone roof in 1 in 4.2 gradient for means of access to the deposit within the boundaries of project and to form longer Longwall panels.

In this mine, severe cutter roof failure or roof guttering was observed during widening of the installation chamber at the longwall face in comparison to the gate roads. In this paper, based on measured in-situ stress values and its direction as one of the input parameter in 3-D numerical modelling technique, best possible stable orientation of the gate-roads and cross-cuts have been established vis-à-vis the direction of the major horizontal stress.

2. GEOLOGY OF THE AREA

Ramagundam coal belt extends over a strike length of 25 km. The formations of Gondwana group are well represented and are deposited on the Archaean / Pre-Cambrian basement. Seven seams viz. IA, I, II, IIIB, IIIA, III & IV are present in descending order. The entire block area is covered by surface soil and Barren measures over most part of the block and Lower Kamthi along the dip side limits. The area is more or less free from any major faults except a fault in the North and North-east of the block. The general trend of the coal measures is North-Northwest to South-Southeast direction with slight swings at places with NEly dips.

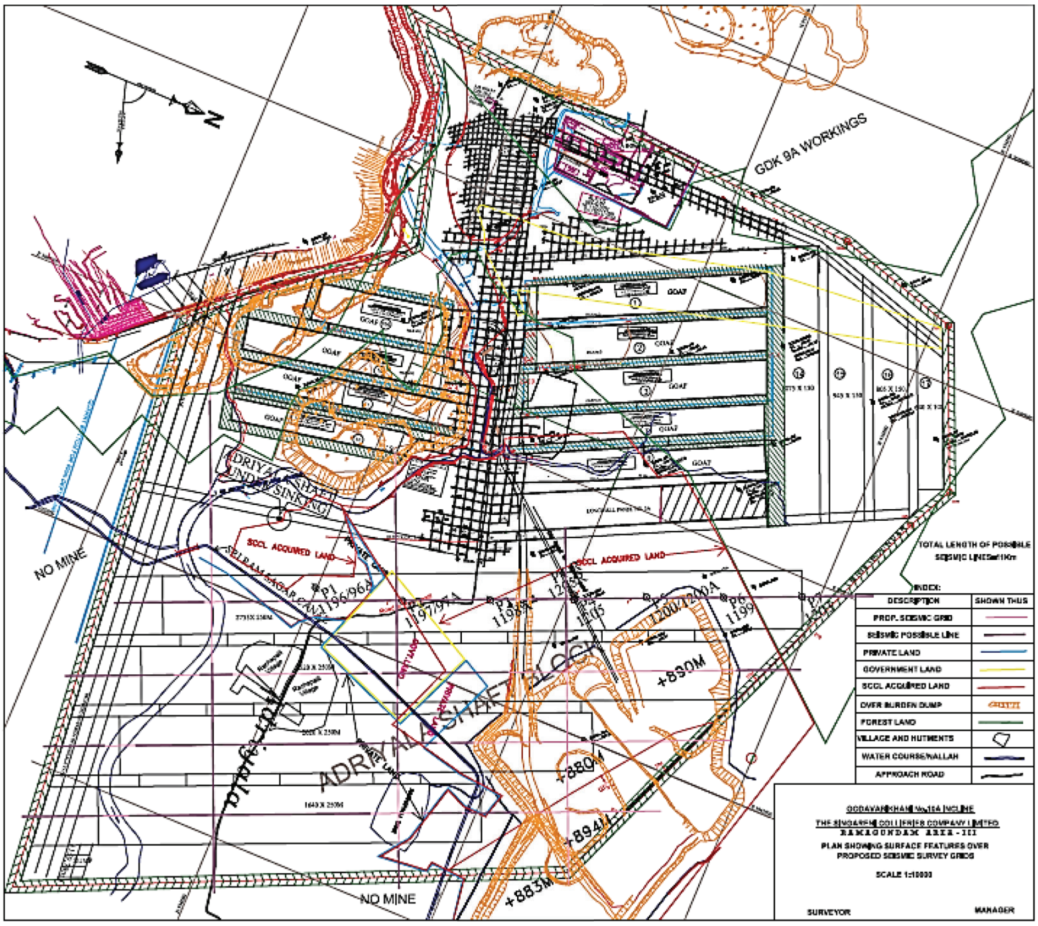

Figure 1 : Plan showing the Adriyala Shaft Block workings.

3. PROBLEMS EXPERIENCED DURING DEVELOPMENT

Adriyala shaft block is the dip side property of seam no. I of GDK 10A Incline mine which has been developed to introduce longwall system of working. The cover depth varies between 350m-550m. Gate roads have been developed along the floor in 6.7m thick seam no. I with dimension 5.2m width and 3.6m height. The immediate roof is composed of coal, overlain by clay and sandstone. Numerous cleats in different orientation and slips are observed in the coal roof. Slips are observed more or less across the gallery due N 230o. The unadjusted RMR of coal roof is determined as 46 and that of sandstone roof is 50.

During drivage of the face gallery, micro-cracking (Figure 2) are assumed to initiate in the region (face side edge) where the induced compressive stresses exceeds the crack initiation stress. During the deformation process, the rock stores strain energy. This continues until a point is reached where the rock cannot store any more strain energy. Further deformation causes the rock to fail in a violent crushing manner to form roof gutters with sudden release of strain energy (Figure3). The gutters occurring at the longwall face most probably because of shear failure near the pillar edge. And these will progresses gradually towards the centre of the face gallery.

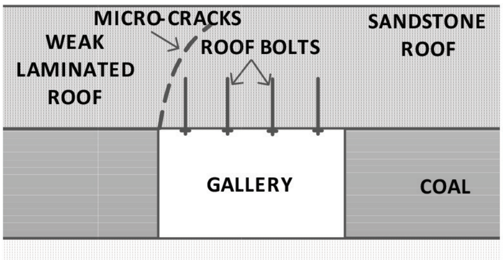

Figure 2 : Initiation of micro-cracks during initial drivage

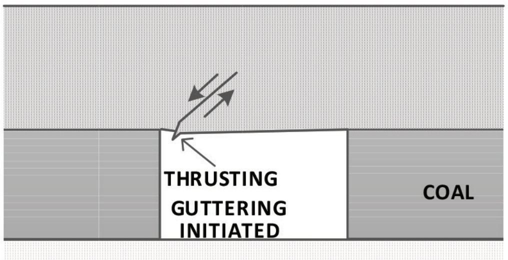

Figure 3 : Initiation of roof gutters due to shear failure at pillar edge

The likely causes of the guttering at the face:

- High horizontal stresses
- Weak laminated shale/coal roof: The presence of laminations in the immediate roofreduces-the overall strength of the roof rock. Under high horizontal stress,thin layers of weak roof crumples which is likely to fail in compression or in shear.
- Presence of clay bands in the coal roof: As seen in Figure 4, there are two clay bands present in the coal roof. The clay swells when it comes in contact with water and destabilizes the underlying coal band.

Development of gutter had stopped at the face (stable) after the face gallery was driven. This is due to the redistribution of stresses and establishment of a new state of stress equilibrium where growth of the roof gutters is stopped.

During widening of the face gallery having existing roof gutters, the bedding planes are exposed to air and moisture. Thus, the bedding planes of the roof rock are further weakened. Additionally, with the widening of the face, the redistributed stresses in the area exceed the crack initiation stress and hence, guttering progresses causing increasedlayer separation (Figure 5) and finally roof fall takes place (Figure 6).

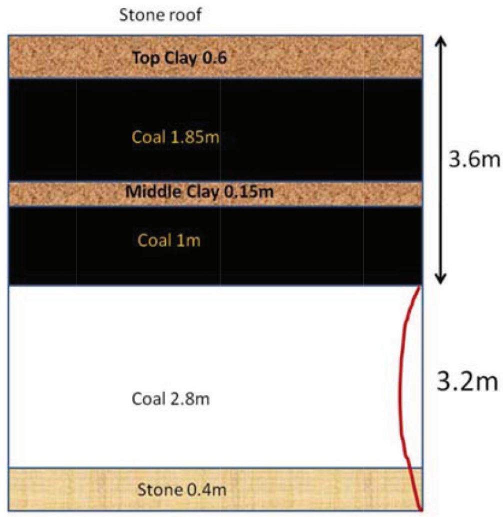

Figure 4 : Working section at installation chamber/ face gallery

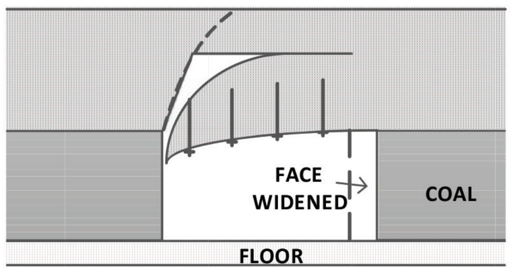

Figure 5 : Layer separation due to progression of roof gutters above bolted horizon

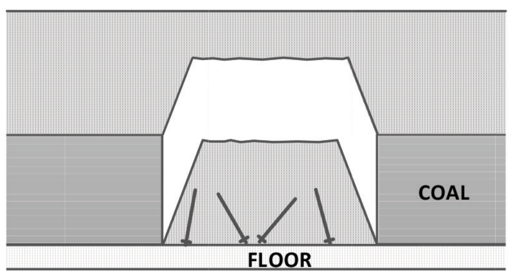

Figure 6 : Roof fall due to guttering

The support used for roof stability purpose for gate-roads and face gallery/installation chamber are shown in Figure 7a and 7b.

Figure 7a : Hydraulic props used for supporting gate roads and installation chamber

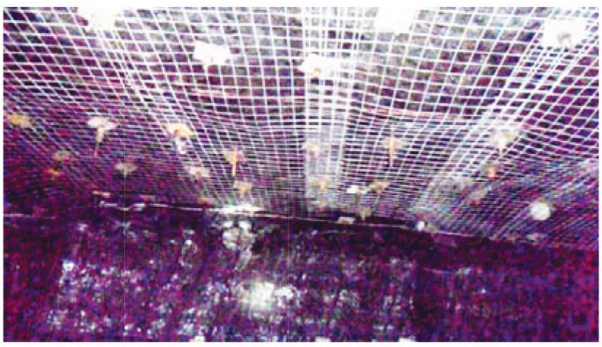

Figure 7b: Rigid wire mesh used along with bolting

4. STUDY APPROACH

An attempt has been made to study the effect of the horizontal stress anisotropy on the stability of the gate roads and cross-cuts by numerical modelling using FLAC3D software. Parametric study has been carried out by orienting the directions of the gate roads and perpendicular cross-cuts at different angles with the maximum horizontal stress direction. The results of the numerical modelling study in the form of the height of the disturbed zone above the perpendicularly oriented gate roads and cross-cuts have been analyzed to find the best conditions i.e. the optimum extent of the height of the disturbed zones in both the galleries.

5. FIELD AND LABORATORY INVESTIGATIONS

Rock Mass Rating (RMR) study of the immediate roof rock at GDK 10A mine of RG OC-II was estimated based on field investigations and rock samples tested in the laboratory by Regional Laboratory, Kothagudem (2). The rock mass parameters are used after strength reduction based on RMR in the numerical modelling studies, as given in Table 1.

Table 1: Estimated RMR of the immediate roof of seam no. I at GDK 10A mine of RG OC-II

Parameters	Layer 1, MCg. Sandstone		Layer 2, FMg. Sandstone	
	Value	Rating	Value	Rating
Layer thickness (cm)	77	30	123	30
Structural indices	4	21	4	21
Slake durability (%)	99	19	60	4
Rock strength (kg/cm2)	179.32	5	204	6
Ground water (ml/min)	4	9	4	9
Total Rating		84		70
Adjusted RMR		68		57

5.1. In-Situ stress

A total of 17 successful hydrofracturing tests were conducted by MeSy India at Adriyala Longwall Block. These tests yielded reliable determination of a stress-depth profile for the depth range from 77 m to 522 m. For all of the 17 hydrofracturing tests the orientation of induced fractures was determined by impression packer tests. The mean azimuth of the vertical fractures was determined as N (24 ± 14) degrees (NNE). The estimated mean stress-depth relations for the minor (Sh) and major (SH) horizontal stresses and the vertical stress (SV) are listed in Table 2.

Table 2 : In-situ stress condition

Depth range	77 m to 522 m
Sh (MPa)	2.05 + 0.0092 • (z, m - 77)
SH (MPa)	3.13 + 0.0142 • (z, m - 77)
SV (MPa)	0.0216 • z, m

The above-mentioned in situ stress conditions have been incorporated into the numerical model to simulate actual stress regime existing at the location under study.

5.2. Numerical Modelling procedure

A numerical model was prepared in FLAC3D software to observe the effect of horizontal stress anisotropy on the stability of two perpendicularly oriented galleries which may be considered as gate road and cross-cut (Section 4). The rock layers up to a height of 45 m above the coal seam were simulated (Figure 8) as Mohr-Coulomb material and a truncated load corresponding to a depth of 400 m was applied over the nodes as nodal forces. The physico-mechanical properties and other details of the rock layers and coal seam used for modelling as per Borehole no. 1119 are enumerated in Table 3.

Table 3 : Lithology and properties of rock layers overlying seam no. I as per Borehole no. 1119

Rock Type	Thickness, m	Depth, m		Density, kg/m^3	Compressive strength, MPa	Tensile strength, MPa	Young's Modulus, GPa
		From	To				
Seam I (Bottom Section)	3.00	387.25	384.25	1470	20.91	1.42	2.00
Seam I (Top Section)	3.00	384.25	381.25	1470	20.91	1.42	2.00
Coarse to Medium Grained Sandstone	4.20	381.25	377.05	2335	39.02	2.84	5.09
Coarse to Medium Grained Sandstone	14.9	377.05	362.15	2281	41.65	3.55	3.94
Clay/ Coal/ Shale	5.10	362.15	357.05	2302	39.21	3.78	7.00
Medium to Coarse Grained Sandstone	4.52	357.05	352.53	2198	31.56	2.42	8.00
Shale/ Coal	1.33	352.53	351.20	2276	31.70	4.47	6.92
Coarse Grained Sandstone	11.3	351.20	339.90	2207	41.34	3.59	7.37
Coal/ Clay	3.75	339.90	336.15	2276	31.70	4.47	6.92

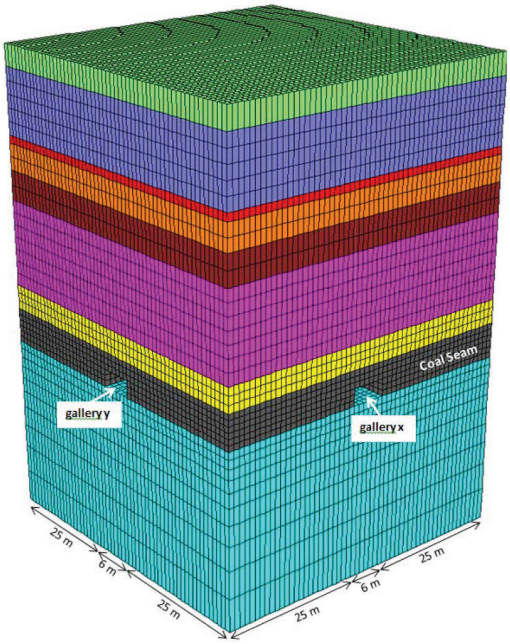

Figure 8 : The mesh of the numerical model

6. RESULTS AND DISCUSSIONS

The height of the disturbed zone above the galleries corresponding to the contour of Safety Factor = 2.0 (hSF=2.0) have been computed using the rock failure criterion introduced by Sheorey (1997) (15). The heights of the disturbed zones above the galleries (designated as gallery x and gallery y) have been found by varying the angle of orientation of the major horizontal stress direction (SH) with the gallery x. Initially, the angle of 43° was used which reflects the actual orientation of the gate roads with the measured direction of SH at Adriyala Longwall Project. The results obtained for angles ranging between 0° and 90° have been enumerated in Table 4 and graphically represented in Figure 9. As expected, it can be observed that the height of the disturbed zone above gallery x is the least when the angle is 0°, i.e., the gallery x is parallel to the major horizontal stress direction. At this orientation, the height of the disturbed zone above gallery y is the maximum, as in this case the gallery y is oriented perpendicular to the major horizontal stress direction. With the increase in the angle, the height of the disturbed zone above the gallery x increases and that above the gallery y decreases. The height of the disturbed zone above the gallery x attains the maximum value when the angle is 90°, i.e. when the gallery x is perpendicular to the major horizontal stress direction. At this orientation, the height of the disturbed zone above gallery y is the least.

Table 4 : Variation of height of disturbed zone with angle between SH and gallery x

Angle between SH and gallery x, degree	Height of disturbed zone above, m	
	gallery x	gallery y
0	3.24	4.97
10	3.37	4.88
20	3.61	4.82
30	3.85	4.58
40	4.03	4.34
43	4.15	4.21
50	4.34	4.03
60	4.64	3.79
70	4.82	3.61
80	5.00	3.43
90	5.06	3.25

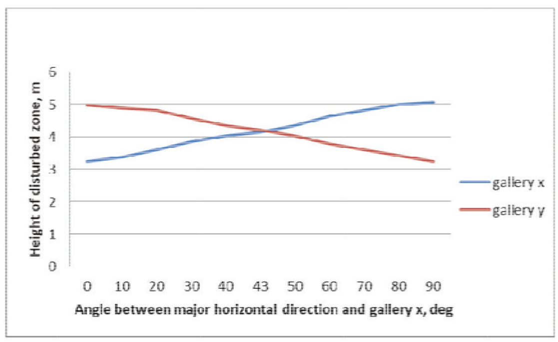

Figure 9 : The trends of variation of height of disturbed zone above gallery x and gallery y

From the results of the numerical modelling study it can be inferred that for Adriyala Longwall Project, the orientation of the gate roads with the direction of the major horizontal in situ stress i.e. 43° is ideal as the heights of the disturbed zones in the perpendicularly oriented galleries are optimum.

7. CONCLUSIONS

The purpose of the present study was to determine the effects of horizontal stress anisotropy on the stability of galleries in deep underground coal mines. The site selected for the study, i.e. Adriyala Longwall Project, is a deep mine having workings at depth greater than 400 m. The in-situ stresses had been measured at the site before planning of the longwall operations and design of the gate roads and the other galleries. Hence, the mine planners could take into account the direction of the major horizontal stress and oriented the gate roads in such a way that the adverse effects of horizontal stress anisotropy was negated to a large extent. Still, some guttering was encountered while driving the gate roads and while widening the installation chamber due to presence of layered strata clay bands in the immediate roof. However, the situation could have been much worse had the in-situ major horizontal stress direction was not known at the planning stage. Future mining projects involving large investments in the form of longwall face machinery or continuous miner packages should strive to carry out measurement of in-situ stresses at the planning stage itself to minimize the adverse effects of horizontal stress anisotropy on the stability of galleries in underground coal mines.

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ADOPTION OF BEST MINING PRACTICES WITH THE HELP OF SOFTWARE APPLICATIONS : A REVIEW

Preeti Kumari[1*], Vivek K Himanshu[2], Maneesh Vishvakarma[2], Saket kumar[2]

Abstract

Mining industries play important role in the economic growth of the country. It provides raw material for the steel, construction, power and other industries. With the rise in production demands from the industrial sectors, raw material need has also enhanced. The productivity pace from mining has to be enhanced accordingly. The best mining practices have been adopted all over the globe to enhance the productivity pace. Starting from production scheduling to ore modelling, planning etc. have played important role. The software application has provided ease to the practising engineers in overcoming challenges related to safety and productivity. The prediction methodology has been adopted using numerical simulation. The advanced data analysis tools have also been used to analyse big data. The machine learning algorithms have been developed using python or other programming codes. This paper presents a comprehensive review on the application of software in different operations related to mining. The utility of different tools in global context has also been showcased.

Keywords : *Software; Numerical Simulation; CFD; Big Data Analysis;Machine Learning.*

1.INTRODUCTION

Software are used widely as a means to provide ease in operation. Many Industries have automated and streamlined their operations using various software. The latest advancements have also enabled the user in the accurate predictions of outcomes through software application. Mining is also not untouched in software utility. It has been used in various sectors of mining to improve the quality of work in many aspects such as safety, production, planning, management, Ore modelling, etc.

Over the years' researchers have used software for the safety assessment, evaluation of stability of pillars, underground drivages, underground workings, designing operational parameters etc. (Himanshu et al., 2021; Himanshu et al., 2022a; Tewari *et al.*, 2020; Vishwakarma et al., 2023; Himanshu *et al.*, 2023a). In some of the leading industries, automation has also been adopted using software. The automatic drilling from a remote place are done at some of the mines viz. Kiruna underground iron ore mine. Additionally, software is also used for production planning and scheduling. The standard operating procedure (SOP) of any operation is being formulated and implemented with ease using the software. The latest advancements in the statistical analysis and machine learning have enabled the users to optimize the input parameters to get the desired outcomes (Gorai *et al.*, 2021; Roy et al., 2022; Himanshu et al., 2022b; Himanshu et al., 2018). Various aspects of such software and their utility in improving the ease of operation has been discussed in this paper.

2. PRINCIPLES AND PROCESSES OF VARIOUS MINING SOFTWARE

Based on Introductory discussions, it is clear that the major mining software are based on scientific formula or statistical data analysis. Scientific formula based software are used for numerical simulation, image analysis, scheduling and ore-body modelling etc. An overview of various models used in mining is given in Figure 1. The numerical simulation software is based on stress analysis.

The geometry of the model is developed to replicate the actual field condition. After that the geometry is discretized. Loading conditions and boundary conditions are defined thereafter in the modelled geometry. The desired outcomes from the numerical model is analyzed in terms of stress, strain, deformation, safety factor etc. The processes used in the numerical simulation models is depicted in Figure 2.

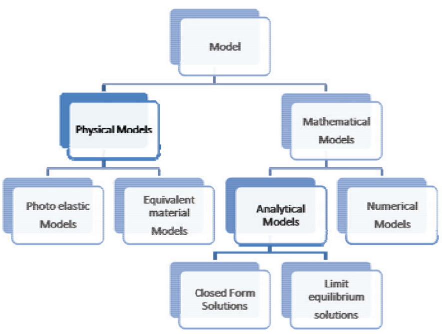

Figure 1. Diagrammatic layout of various models used in mining.

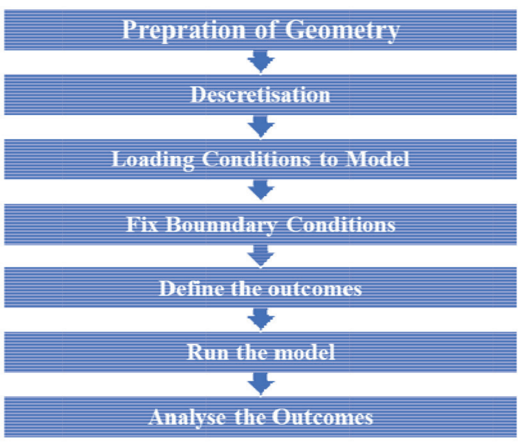

Figure 2. Steps of numerical modelling

The statistical data analysis based software predict outcomes of a problem through case histories. The data are feed to the statistical model. The model is being trained based on the data, and further the outcome is predicted from the trained model. The process followed by statistical models is given in Figure 3.

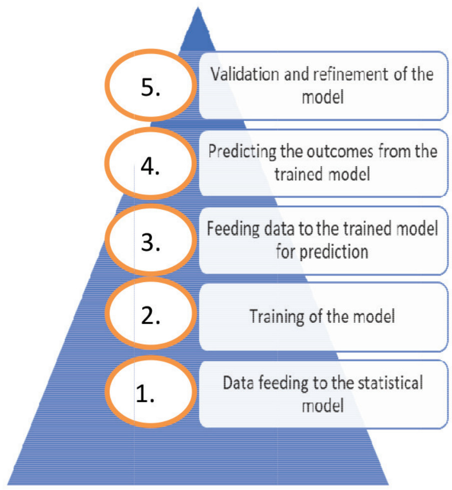

Figure 3. Processes of statistical models.

3. OVERVIEW OF DIFFERENT MINING SOFTWARE

Briefly the mining software has been classified into four categories viz. Production, Monitoring and Control System, Safety Management, Data Analytics and optimization. Although the domain of these software may overlap as well. An overview of different mining software is shown in Figure 4.

3.1. Software for production planning and optimization

Software is mainly used in various operations for production planning viz. mine planning, drilling & blasting, scheduling, fleet management etc. Following software are used in various operations of production planning and optimization (Milanovic *et al.*, 2019) :

JKSIM Blast : This software have a wide range of options to stimulate the detonation sequence on screen, with the help of JKSIM software we can also analyse energy, damage, timing, vibration and contour blast hole data. It has fully customized explosive and detonation properties.

Shot Plus : It is used in designing a blast in 3-Dimensional profile. It helps in designing the blasting sequence before firing.

WIPFRAG/FRAGALYST/SPLIT Desk Top : These are image analysis software, which are used for the analysis of fragment size distribution of the blasted muck.

BLASTMETRIX 3D (3GSM) : This software isused in mining and tunneling for bench face profiling and blast design. It provides precise data and optimize blast fields based on actual bench face geometry. The system of this software uses calibrated digital cameras and specialized software for 3D image surveys, volume calculations, and rock material quality assessment.

O-Pitblast : O-Pitblast offers tools for determining attenuation laws of terrains to predict ground vibration from each blast. It provides confidence level curves based on peak particle velocity (PPV) and distance from blast field, allowing for seismic analysis. Additionally, O-Pitblast has topography tools using UAV technology for realistic terrain surface information and easier blast field planning and design

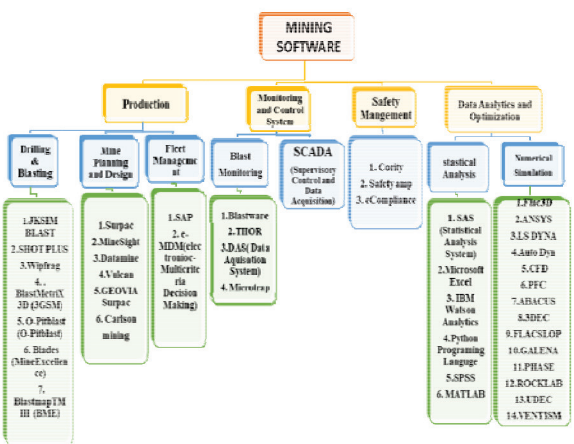

Figure 4. Overview of mining software.

Surpac : It is use for ore body modelling and open pit and underground mining designs based on the modelled orebody. It is widely used software for mine planning and designing. There are different types of tools for geological models and mine design. It consists of different types of set of data analyses and visualization tool for mine development (Sahoo & Pal, 2017).

Minesight : This software supports mine planning and design. It helps in geological modelling and mine scheduling (Eshun &Bediaku, 2018; Sepulveda et al., 2012).

Datamine : This software offers a range of applications for mine planning and design. It is used widely for open pit coal mine planning and scheduling (Keshmiri et al., 2005).

Vulcan : It is used for geological modelling and mine planning. It enables users to create detailed geological models, design mine layouts, and generate mine plans. Vulcan offers advanced tools for mine optimization and scheduling (Kapageridis, 2005).

GeoviaSurpac : It is a comprehensive software package for mine planning and design. It combines geological modelling, resource estimation, and mine design capabilities (Smirnova et al., 2022).

Carlson - Carlson Mining is a software solution specifically designed for mine planning and design. It provides tools for surface and underground mine design, geological modelling, and mine scheduling. Carlson Mining assists in creating accurate and optimized mine plans while considering various mining methods and constraints .

SAP : Sap stands for System Application andProducts Data Processing. It provides multiple business functions like invention, distribution, logistics, finance etc. SAP is a system designed to facilitate the flawless development and management of business processes and solutions that allow for data processing and the flow of information across organizations to be seamless. As a result, businesses can accelerate workflows, improve operational efficiency, raise productivity (Soliman & Youssef, 1998).

3.2. Software for monitoring and control system

These software are mainly used to analyse the data of various instruments. Instruments are used in different stages of mining to monitor the associated safety risks with mining operation. Following software modules are used widely for monitoring and control in mining operations:

Blastware : It is used to analyse the peak particle velocity and dominant frequency data obtained from the blast induced ground vibration monitoring. This software module has been developed by M/s Instantel Inc (Agrawal & Mishra, 2019).

THOR : This software has platform to store and manage blasting events on computer. It gives the data in form of bar graph and histogram graph. It also performs various analysis to understand the event data more accurately.

DAS : Das stands for Data Acquisition system. These software are used to store and analyse data from various instruments. Most of the strata monitoring instruments comes with DAS. The Velocity of Detonation (VoD) monitoring system also comes with DAS. Since the information in DAS is documented in digital form, it can be easily exported to Microsoft Word or Microsoft Excel (Nikolczuk et al., 2019).

SCADA : It stands for Supervisory Control and Data Acquisition. It is best suited for automating highly complex operation where human control is considered impractical. As needs of technology is increasing day by day, SCADA software is needed to increase because of its ability to make data driven real time information thereby eliminating the probability of human error. The major advantages of SCADA is cost reduction to industries, productivity enhancement, boost safety aspects and time utilization (El- Saba, (2017); Maseda et al., 2021).

3.3. Software for safety management

These software are used for emergency response management, personnel tracking, incident management, safety training and compliance etc. Some of the major safety management software used in mining industries are as follows:

Cority : Cority is a safety cloud software which is designed and refined by specialists to solve the problem related to safety. This software helps to analyse safety data in easier way. The platform also covers EHS (environmental health and safety).

Safety Amp: This software helps worker, safety team and project leaders to track all reports of safety data. It can also be used to monitor key safety indicators, deliver safety insights, and change safety outcomes. They also have a handful of configurable recordkeeping apps that can simplify the compliance tracking process by automatically capturing data, integrating workflows, and automating follow-up activities for all sorts of EHSQ (environmental, health, safety, and quality) activities.

eCompliance : This is a mobile-first EHS software solution that empowers front-line workers to do their best to reduce risk and maintain a safe work environment. One of their standout features is the ability to track equipment using ID numbers, barcodes, or RFID to ensure that the equipment is safe to use for field crews.

3.4. Software for data analytics and optimization

These software are used for developing prediction models and analysing patterns. These are either numerical simulation or statistical analysis based software. Some of the major statistical analysis software used in mining industries are as follows:

Microsoft Excel: It is a program created by Microsoft that have spreadsheet to organize formula, data, number, and functions. Excel help to perform data or numbers in more convenient form (Liengme, 2008) .

SAS : It stands for statistical analysis system. It is use to solve complex industrial problems. SAS can understand any type of data from any software or format. It run program in a loop. It is one of the most dominant software suite for data management and data mining.

IBM Watson Analytics : It is a cloud software which tries to bring sophisticated data discovery and analytics to industry users (Jaimahaprabhu et al., 2019).

Python Programming Language : It is an objected oriented high level programming language. It was launched in 1972. Python is the third most popular programming language. It is widely used for statistical data analysis and generating machine learning algorithm.

SPSS : It is a statistical package also known as IBM SPSS statistics. It is mainly used by research scientists to process critical data in simple steps.

MATLAB : MATLAB is a matrix-based language allowing the most natural expression of computational mathematics. It is capable of analysing data, developing algorithms and creating models. User can create their own functions using MATLAB programming interface (Janic et al., 2019).

Some of the major numerical simulation based software are summarised in Table 1 (Tewari et al., 2020; Azarafza et al., 2017; Rodriguez et al., 2013;).

Table 1. Summary numerical simulation software usedin mining.

Code	Source	Type
BESOL	Mining Stress Systems	2D/3D BEM
EXAMINE	Roc science Inc	2D/3D BEM
MAP 3D	Mine Modelling Ltd.	3D BEM
LaMODEL	NIOSH	3D BEM
MUSLIM/NL	USBM	3D BEM
FLAC	Itasca Consultancy Ltd.	2D/3D FDM
COSFLOW	CSIRO	3D FEM
Phase	Rock Science Inc.	2D FEM
ANSYS	ANSYS, Inc.	2D/3D FEM
ABAQUS	Dassault Systems Simulia Corp.	FEM
PFC	Itasca Consultancy Ltd.	2D/3D DEM
3DEC	Itasca Consultancy Ltd.	3D DEM
UDEC	Itasca Consultancy Ltd.	2D DEM
ELFEN	Rockfield Software Ltd.	2D/3D FE & DEM

4.0. BENEFITS OF SOFTWARE APPLICATION

Software provides ease to the management, technocrats and human resources. Best mining practices can be adopted using the software application. It helps in improving safety measures, enhancing operational efficiency, real time monitoring & control, effective environment management and decision making. The major benefits of software application have been outlined in Figure 5.

Figure 5. Outline of the benefits of software application

5.0. CHALLENGES AND LIMITATIONS OF SOFTWARE APPLICATIONS IN MINING

Despite many advantages of software applications, there are still some challenges specifically in mining industries which need to be resolved. Major challenges of software application in mining are as follows :

Technological Complexity : The implementation of software for mining practices often involves complex technological systems. Integrating these applications have significant challenges. The need for specialized technical expertise and resources for software installation, configuration, and maintenance is needful to resolve these issues.

Cost and Investment : Adopting software applications for mining practices requires a substantial investment in terms of both financial resources and time. Licensing fees, hardware upgrades, and training costs can accumulate, especially for small-scale mining operations with limited budgets. The initial capital outlay and ongoing expenses can deter some mining companies from embracing these technologies.

Data Accuracy and Quality : Software applications heavily rely on accurate and high-quality data to provide meaningful insights and recommendations. However, mining operations often face data collection challenges, such as inconsistent data sources, data gaps, and errors. Incomplete or inaccurate data can compromise the effectiveness and reliability of software-driven mining practices, leading to suboptimal outcomes.

Implementation and Integration : Integrating software applications into existing mining workflows and systems can be a complex and time-consuming process. Coordinating with multiple stakeholders, such as mine managers, IT teams, and software vendors, to ensure seamless integration poses logistical and operational challenges. Customizing software applications to suit specific mining operations may require additional development or configuration, further complicating the implementation process.

Training and Workforce Adaptation : The successful adoption of software applications for mining practices relies on a competent and adaptable workforce. However, transitioning from traditional mining methods to software-driven approaches requires adequate training and upskilling of personnel. Resistance to change and a lack of digital literacy among mining professionals can hinder the effective utilization of these applications.

Limited Tailoring Options : While many software applications offer a range of features and functionalities, they may not cater to all the unique requirements of every mining operation. Customization options can be limited, forcing mining companies to either adapt their processes to fit the software or develop costly, bespoke solutions. This lack of flexibility can impede the adoption of mining practices tailored to specific operational needs.

Cybersecurity and Data Privacy : The integration of software applications introduces additional vulnerabilities to cybersecurity threats and data breaches. Mining operations deal with sensitive information, such as geological data, operational plans, and financial records. The reliance on software applications necessitates robust security measures to safeguard against unauthorized access, data theft, and system intrusions.

Addressing these challenges and limitations is crucial to ensuring a successful and sustainable adoption of software applications for best mining practices. It requires careful planning, investment, stakeholder collaboration, and ongoing monitoring to overcome obstacles and maximize the benefits offered by these technologies.

6.0. FUTURE SCOPES IN SOFTWARE DEVELOPMENT FOR MINING

The Future working aspect in Mining industries is not only to introduce new technologies, it motives should be the introduce technology which will help to work in more efficient and safe form. If last few years in Mining Sector would be considered it reflects many developments in software application and automation. Still the future scopes are there to foster new opportunities for software applications (Himanshu et al., 2023b). Some of the prospects for future are as follows :

- There is prospect of big data analytics applications in future. The imputs and outputs on day-to-day basis would automatically be fed to a computer application. The model in this application would provide optimal input to be taken in future to control the desired output. The applications may be based on artificial intelligence, machine learning and big statistical analysis.
- There is prospect for development of robotic intrinsically safe device which can fly over the mines and identify the HIRA (hazard identification and risk assessment) of everything within the mine boundaries. It will help in achieving zero accident target.
- Dumper and locomotive location identification and other things are possible using the software application.
- There are prospects to place Internet of Things (IoT) enabled sensors in mines.

7.0. CONCLUSIONS :

Software plays a vital role in Mining industries. It provides ease to the miners and thereby work as a tool to adopt the best mining practices. During recent decades, software has been used in various applications in mining domain. It has touched production planning to designing, evaluating outcomes, costing and prediction of safety and production outcomes. Technocrats are able to predict the strata instability, blasting fragmentation outcomes and others using the software. Howaver, there are some associated limitations viz. technological complexity, cost, training and cyber security, which need to be taken care of for smooth applicability. In future there are scopes for more software for big data analytics, putting IoT based sensors etc.

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IMPROVING PRODUCTIVITY AND UTILIZATION OF HEMMIN OPENCAST MINES VIA DIGITAL ANALYSIS

Sujit Kumar[1]*, Nabyendu Neogi[2], Sanjoy De[1], Praveen Ranjan[1], Subhajit Halder[2]

Abstract

In large open pit operations, rear dumper and excavator fleet is widely used for excavation of overburden and winning of coal from Opencast mining. In present worldwide scenario, mostly mechanised mines, higher capacity of excavator is used in fleet which can handle gigantic capacity of materials. Excavator productivity and its utilization play a vital role in overall mines economics. Excavation of material contributes upto 60 percent of the total mining cost (Allen et al, 1999). Significant mine cost saving can be made by small improvement in load and haul productivity. This paper outlines the study in improvement of Load per trip of rear dumper, reduction in idle timing which includes loading & spotting timing and improvement in first load & last load of the hydraulic excavator. This literature also indicates that the monitoring of equipment & outcome of dump data with digital intervention and improvement in it directly impacts on production and utilization of excavation and hauling equipment in Quarry AB of Tata Steel West Bokaro Division.

Keywords - *Fleet Management System, Load Per Trip, Excavator Productivity, Excavator Utilization, Loading Cycle Time.*

INTRODUCTION

Productivity is measured in the total volume of material handled (m3) per net available time (hr.). The highest benchmark of Ex 2500 productivity is 1200m3/hr. The productivity is the key responsible factor behind the sustainable and profitable production of the mines. The proper utilization of machine (Brunton *et al.*, n.d.) also enhances the specific diesel consumption which is also important as in present international market scenario diesel prices are too high (~40% of total Opencast Mining cost) and thus reducing the Cost per ton (CPT) of the mineral which directly links it to profit. The study is carried out in Ex-2500 category with ~15m3 bucket capacity with Rear Dumper of 100T capacity in the Quarry AB mines of West Bokaro division which resulted an overall accrual saving of ~10.6 Cr in FY-22 by just improvement of productivity (Yuan & Grayson, n.d.) from 479 m3/hr. to 492 m3/hr. The improvement was possible due to Fleet Management System installed by Wenco & VTPL in the Quarry which could provide the actual data of performance of excavator. Truck-fleet productivity (Yuan & Grayson, n.d.) in open-pit mines has the lowest improvement rate among the three major unit operations: drilling, loading, and hauling (Michaelson *et al*,1974). With the increasingdemand for resource, the depth of mines and production is increasing leading to need for expansion of mining fleet while ignoring the underutilization of equipment. Under Utilization of equipment leads to loss in financial terms like loss in depreciation, interest paid to purchase the equipment, human resource utilization, specific diesel consumption, capital used to purchase the equipment. The selection of optimum shovel-truck combination is one of the major decisions in open-pit mine planning (Shein, 1988).

The study to improve productivity of Excavator is based on two factors which proper utilization

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of excavator and optimized selection of fleet of Heavy Earth Moving Machinery (HEMM). For the proper utilization of equipment, the need for setting of Productivity (m3/hr.) and Utilization (%) target with respect to Best Demonstrated Practice in the mining industry. The benchmark and target setting also depends on the skill and ability of the operator.

Table 1 BDP of Utilization and Productivity of Excavator

HEMM	Productivity(m3/hr)	BDP (m3/hr)	Utilization (%)	BDP (%)
Ex-2500	479	525	70	72
Ex-1200	348	353	62	65
RD-100T	113	152	49	60

The second part of the scope for improvement of productivity is proper selection of fleet size. The Bunching effect as described by (Shein, 1988) shows the underutilization of fleet due to poor selection.

Figure 1 Production Potentials versus Mismatching Effect

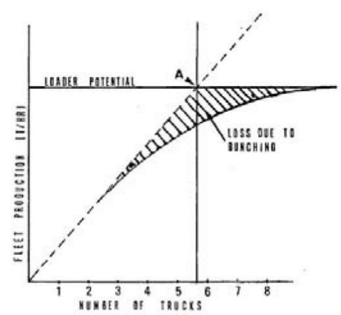


Figure 2 Bunching effect (Shein A etal,1988).

The irregular arrival of hauling units at the loading area leads to decreased operating efficiency, and the more they bunch up, the greater the efficiency loss (Shein A *et al*, 1988). The machinery employed for earthmoving and mining executes regular haul cycles during various phases. These phases comprise:

- Hauling (Empty)
- Spotting and manoeuvring at loading point
- Loading by Excavator
- Hauling (Loaded)
- Spotting and manoeuvring at dumping point
- Dumping

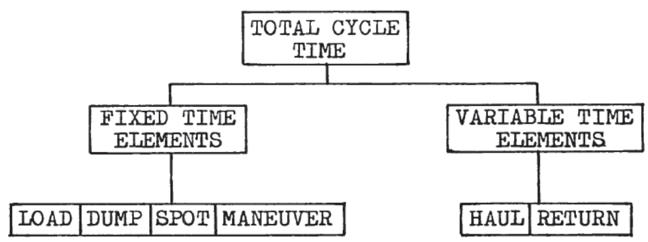


Figure 4 Description of Phases in Cycle time.

The cycle time represents the duration required to complete one full circuit of these phases. To simplify the estimation process for hauling units, the cycle time is divided into two fundamental components:

- Fixed time elements
- Variable time elements

The cycle time consists of two primary components: Fixed time components and variable time components. The Fixed time components encompass activities such as loading, dumping, spotting, and maneuvering. These elements have a consistent duration that does not change based on the specific job. On the other hand, the variable time components pertain to hauling and returning. The time required to complete these phases varies depending on the speed of travel and the distance of the haul. Both factors are dependent on the nature of the job being performed (Shein A *et al*,1988).

- **Loading time :** The duration of loading time depends on several factors, including the type of loading equipment utilized, the characteristics of the materials being loaded based on blast fragmentation (Dixit *et al.*, n.d.; Kumar *et al.*, n.d., 2017), and the specific method employed for loading.
- **Dumping time :** The time taken for dumping is mainly influenced by the speed at which the body of the vehicle tips and the conditions of the materials being dumped. The tipping speed may vary across different types and manufacturers of dump trucks.
- **Spotting and Manoeuvring Times :** Spotting and manoeuvring times refer to the time spent at both the loading and dumping points. These times are contingent on the level of precision required for accurate positioning and any additional manoeuvring actions, such as reversing, that might be necessary.

The variable time components, which include haul and return times, can be ascertained by referring to manufacturers' published performance diagrams. These diagrams provide valuable information for each hauling unit, covering both loaded and empty conditions. By consulting the performance diagram for a specific hauling unit, one can determine the maximum achievable speed of the vehicle based on the total resistance (combining grade resistance and rolling resistance) and the weight of the vehicle for any given situation. These performance diagrams offer essential data to estimate the time required for hauling and returning operations efficiently. Two different allocations of the mining fleet can be employed during the operation:

- **Static Allocation :** In static allocation, the fleet of excavators and dumpers is assigned based on manual assumptions. These decisions are made by humans and rely on factors such as lead/lift distance to the dump site, face condition, excavator capacity, haul road condition, dumper capacity, and the type of material (Himanshu *et al.*, 2020; Kumar & Himanshu, 2018) being hauled. However, this approach requires manual adjustments whenever changes occur, such as excavator breakdowns, material shortages, or increases in lead/lift distance due to various reasons.
- **Dynamic Allocation :** On the other hand, dynamic allocation involves using simulation software to optimize fleet allocation. This method takes into account lead/lift distance to dump/hopper/stock, excavator capacity, dumper capacity, queuing, and idling predictions. The software makes real-time adjustments based on the current situation and can automatically allocate dumpers to idling shovels, taking into consideration the queue of loaded shovels. The new loading and dumping locations are displayed on the Mobile Display Terminal (MDT) of the dumpers to ensure efficient and timely operations.

In Dynamic Allocation, the computer typically utilizes Monte Carlo simulation to optimize fleet allocation based on existing data. In a truck haulage system, Monte Carlo Simulation is employed when significant variations are likely to occur due to random changes in input variables. These input variables encompass loading time, dumping time, travel time (haul and return), delay times, and load weights. Each independent variable is modeled using a different distribution curve. Monte Carlo simulation allows for the consideration of the overall impact of interactions and interrelationships among these variables, which are inherent in the real system configuration. Often, such interactions cannot be accurately estimated using other methods. The production and operating data required for a simulation study are as follows: (Shein A et al,1988). The production and operating data needed for the simulation study are as follows :

(a) Haulage road profiles and characteristics, including distances between points, grades (slopes), rolling resistance, and speed limits. These factors play a crucial role in determining the travel time for the hauling units.

(b) Equipment characteristics and availabilities, such as speed-rim pull curves (relating vehicle speed to tractive effort), motor-current curves, mechanical availabilities (uptime/downtime), and empty vehicle weights. This information is essential for accurately modeling the performance and behavior of the hauling equipment.

(c) Field observations of shovel's loading time, truck's dumping times, and payload weights. These real-world data points help establish the loading and dumping times for the simulation, as well as the varying payload weights.

(d) Pit configuration, equipment configuration, and associated production during the time simulated. Understanding the layout of the pit and the arrangement of equipment (excavators, dumpers, etc.) is vital for creating an accurate simulation. Additionally, knowing the production rates during the simulated timehelps validate the model's performance against actual results.By incorporating these data sets into the Monte Carlo simulation, a comprehensive understanding of the haulage system's dynamics and potential optimizations can be achieved.

I. OVERVIEW OF QUARRY AB, WEST BOKARO DIVISION, TATASTEEL LTD.

West Bokaro Collieries of Tata Steel Ltd. is in the central part of West Bokaro Coalfields in the Mandu anchal of Ramgarh district in Jharkhand. The lease area is bounded by latitude 23° 46′ 24″ N and 23° 48′ 58″ N and longitudes 85° 31′ 17″ E and 85° 34′ 58″ E and falls in Survey of India Topo sheet no. 72E/9. The West Bokaro lease covers an area of 17.40 Sq. Km and, for operational convenience and understanding, it had been broadly divided into four sectoral divisions namely (i) Quarry SE in south –east sector (QSE), (ii) Quarry AB in central area (QAB) includes the QCD and central site area, (ii) Quarry E in area west of River Bokaro (QE), and (iv) Quarry NE in north-east section which is a virgin area (QNE). Eastern flank of Quarry AB has been restricted in the rise side (i.e., in the north) by the boundary of Banji village. The district headquarter Ramgarh is about 30 km from the leasehold area. Chainpur is the nearest railhead / siding (10 kms) on Gomoh-Barkakana loop line of East-Central railway. Danea is another railhead on the same line. Pucca road from TSL township about 16 kms, go out to Kuju town on the NH-33. Ranchi, the capital of Jharkhand state, is about 70 km via NH-33 from the West Bokaro Collieries (WBC) area. The West Bokaro Collieries is thus well connected to outside places. From the input parameters collected from the mine site and those supplied by M/s Tata Steel Ltd., the seams feasible for extraction at Quarry AB include seams XI, X U, XL, IX, VIII, VII, VI, V, IV and III occurring in descending order. So far mining has been restricted to Seam-V in Quarry AB, but it has been planned to extend the workings upto seam-III but by the end of 10th year stage plan. All these seams are gently dipping, with 3–70-degree inclination.

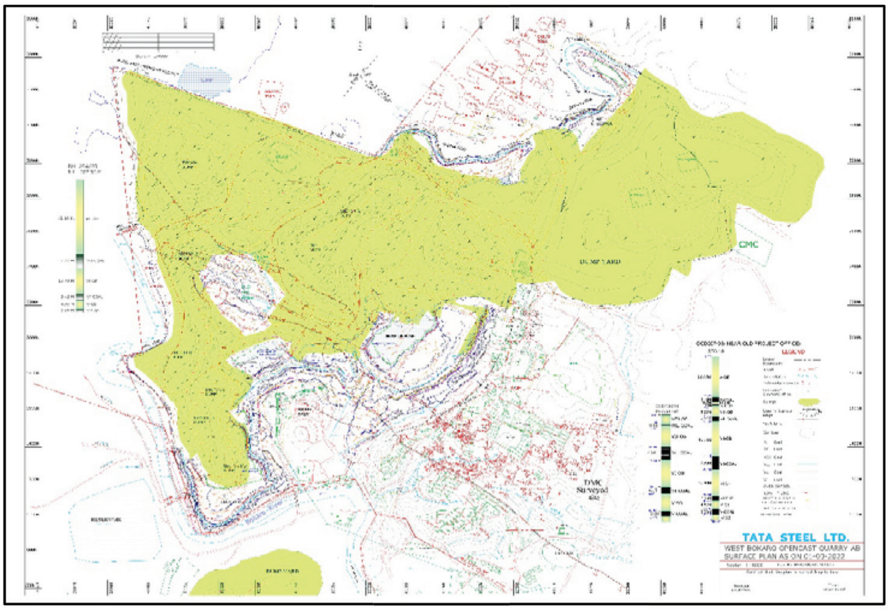


Figure 3 Map of Quarry-AB West Bokaro Division

II. DATA COLLECTION AND ANALYSIS

While improving productivity of equipment the monitoring part of the equipment play and important role on it. Monitoring of data and from that proper data analytics will help to predict the area of improvement that will impact our productivity of equipment's. Based on dump data available in fleet management system several areas have been identified for improvement such as load per trip of hauling equipment's for improving avg load per trip, Average cycle time of loading equipment, average sporting time of the hauling equipment's, study of idle timing during working hour in both hauling and loading equipment's & reducing marching timing of equipment's.

Figure 4 : Overview of Fleet Management System (FMS)

A. LOAD PER TRIP

Load per trip is generally measured in Tons. In 100T rear dumper in terms of capacity the optimum value of load is with tolerance (+/- 5%), thus between 95-100T. It is generally measured through Truck Dispatch Monitoring system and the value is displayed through Loadcell. The value of Load Per Trip (LPT) is also stored in Fleet Management System with data stamp of Rear Dumper Number, Operator Name & UID, Loading Unit, Hauling unit. In Quarry AB we measure average LPT of entire shift and day on daily basis. The incentive scheme of Loading Unit Operator was linked to Load Per Trip which led to moral motivation to increase LPT.

KOMATSU HD785-7

Hauling Unit	Quantity (MT)	Loads	Haul Distance (KM)	LOAD PER TRIP
RD208	1,090.20	13	22.74	83.9
RD209	587.80	7	12.31	84.0
RD210	776.40	9	15.28	86.3
RD211	813.80	9	21.34	90.4
RD212	548.20	9	21.72	60.9 Coal
RD215	1,281.80	14	27.10	91.6
RD216	583.10	7	13.75	83.3
RD217	1,222.30	14	27.15	87.3
RD218	1,194.40	14	26.52	85.3
RD219	1,089.00	13	22.41	83.8
RD220	1,504.70	18	29.36	83.6
RD221	693.50	8	10.11	86.7
RD222	724.40	8	14.78	90.6
RD223	1,224.60	14	21.11	87.5
RD224	537.60	6	11.62	89.6
RD225	1,655.50	19	32.81	87.1
RD226	983.50	11	17.87	89.4
RD228	999.00	11	19.11	90.8
	17,509.80	204	367.11	85.8

Figure 5. Monitoring of Load Per Trip

While monitoring the load per trip, we have work on profile of loading, alert for excavator operator by proper display in cabin, trained the operators and communicate the importance of load per trip of hauling equipment's. It results in improvement of Load per trip from 85T to 92T in FY 22 thus improving productivity of Excavator (refer to the mean Load per Trip at the bottom of Fig 5).

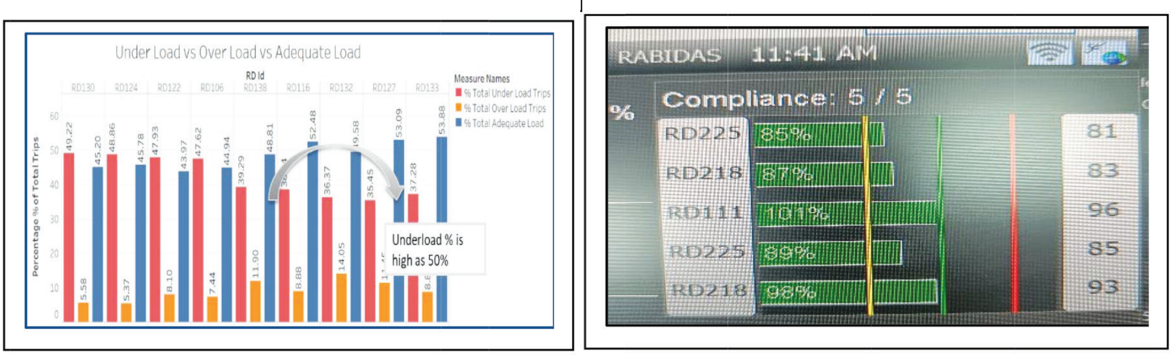


Figure 6. Analysis of Hauling Unit with Highest % of Under-Load Trips & Load compliance of 100T RD.

As in Fig 6. The Hauling unit were recognized which had highest % of underload trips and the operators were counselled who were operating the equipment in under-utilized condition. The target productivity of 100T rear dumper is 110 m3/hr while these Rear Dumpers were not able to achieve the rear dumper productivity due to underload condition.

B. AVERAGE TIME TAKEN PER LOAD

The average time per load in Ex-2500 T category is 1.5-2.5 min/Load which depends on various factors like blast fragmentation (Kumar & Mishra, 2020), face width, face condition, Hauling Unit allocation, Lead/Lift distance from dump to face.

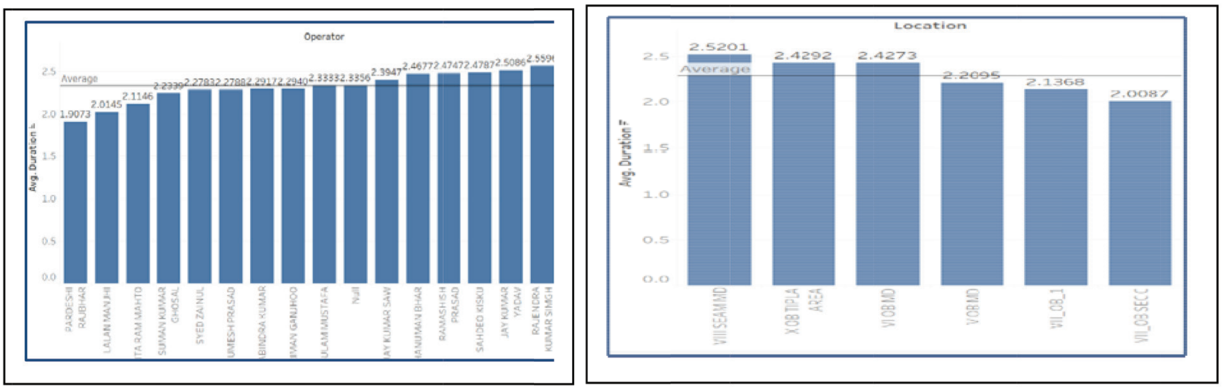


Figure 7. Operator wise & Area/Bench wise analysis of Average Loading Time (min/Load) for a span of month

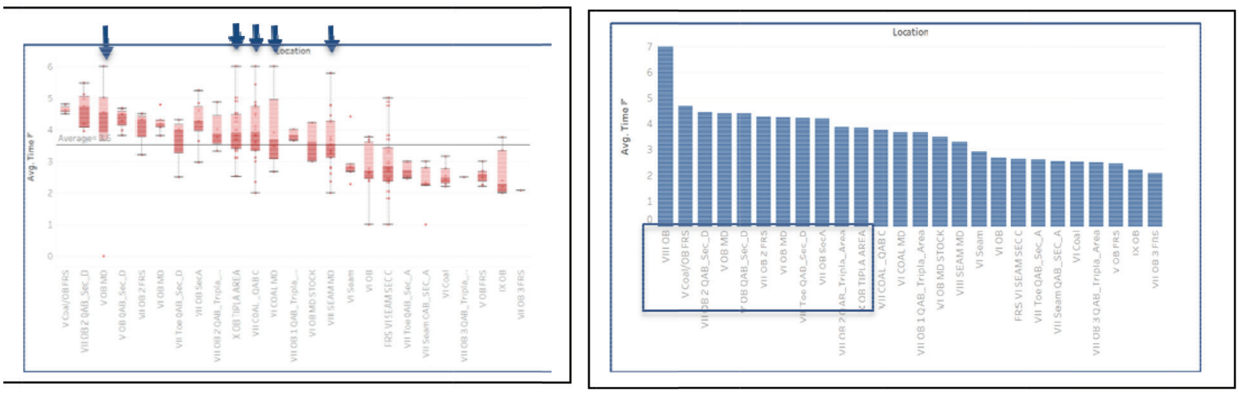


Figure 8 : Box & Whisker analysis and Average time taken of load.

As mentioned in Figure 7. Operator wise analysis was done and the operators who had lower loading time were rewarded, and higher loading time were counselled. As mentioned in Fig 7, area-wise loading time analysis was done and benches like VIII Seam Sector-A, X OB (Top Bench) were widened and loading conditions were improved to improve loading time. As mentioned in Fig. 8 Box plot analysis was done to measure the quartile, spread and average loading time in which it was observed that VIII OB, X OB and VIII OB range and quartile data was high in which loading conditions were improved.

C. AVERAGE SPOTTING TIME PER LOAD

The spotting time of loading unit depends on the spotting position, face width, face condition, Hauling Unitallocation, Lead/Lift distance from dump to face.

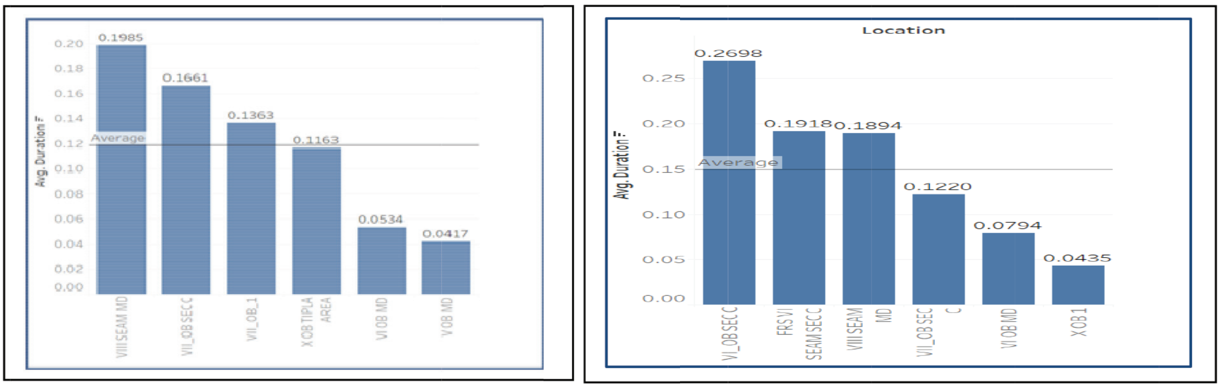


Figure 9 Area wise analysis of Average Spotting Time in Sector A & Sector C

As mentioned in Fig 9, Spotting time of VIII Seam, VII OB in Sector A and VI OB in Sector C were the areas where spotting time was high. The face width was widened, gradient of the loading face wasimproved, and proper loading condition were provided which led to increase productivity.

D. SEGREGATION OF IDLING HOURS INTO WORKING AND NON-WORKING IDLE HOURS

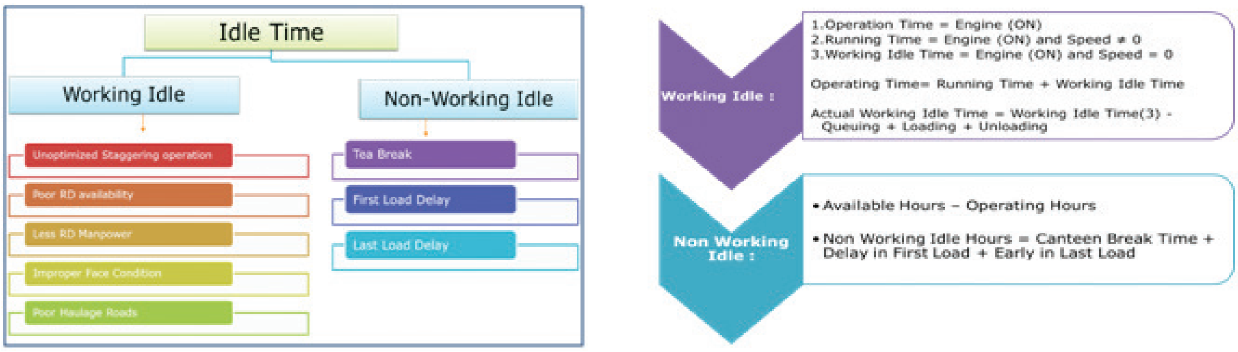


Figure 10. Differentiation between Working and Non-Working Idle Time of Excavator and the calculation behind it

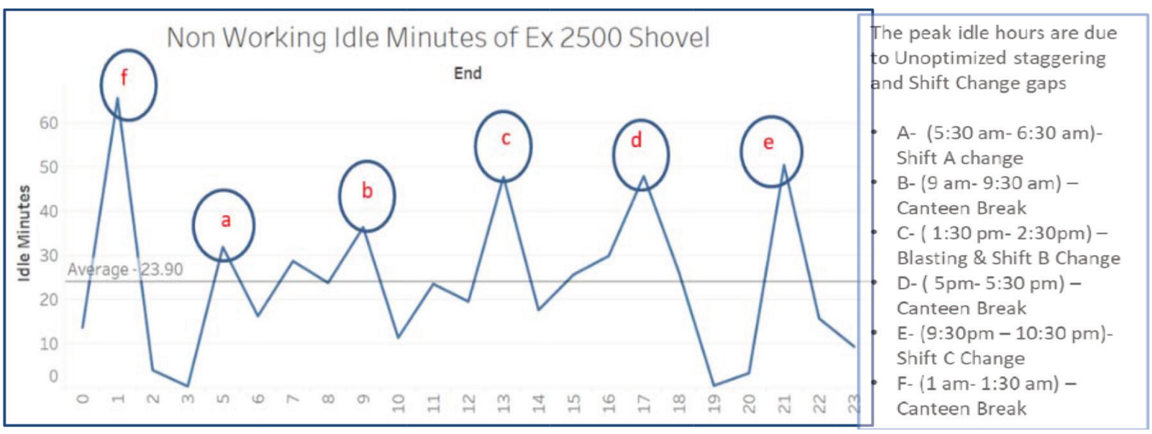
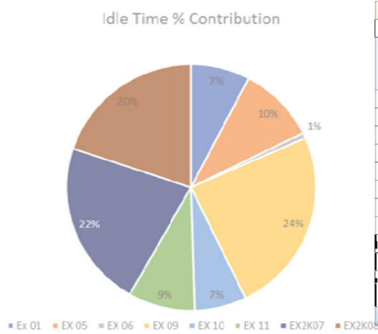


Figure 11. Non-Working Idling Analysis of Excavator

Non-Working refers to the idle time during Tea Breaks and First & Last Load Delay. As shown in Fig.11 Non-Working Idle time were at peak at these a,b,c,d,e,f time of the 24-hour analysis. Thus, reduction of these non-working idle time improves the utilizations of the machine.

E. WORKING IDLING ANALYSIS OF EXCAVATOR AREA/BENCH WISE.

Idling analysis was done of Excavator area wise and then the area in which the idling % was more, the face conditions were improved by increasing the face width and enhancing lead/lift condition.



Total Idle % Location wise			
Location	Net Average % in FY 21	Net Average % in FY 22	Remarks
VII A OB	8%	12%	Action Taken for improvement
VI A OB	5%	11%	Action Taken for improvement
VII A Coal	3%	2%	
VII OB SEC D	9%	15%	Action Taken
VII OB Sec D Coal	5%	7%	
X OB II M Devi	7%	8%	
X OB III M Devi	25%	15%	Action Implemented
X OB IV M Devi	22%	12%	Action Implemented
X OB I M Devi	2%	3%	
X OB cumulative	14%	10%	Action Implemented
X SHALE & IX PARTING M Devi	N.A	6%	
Grand Total	100%	100%	

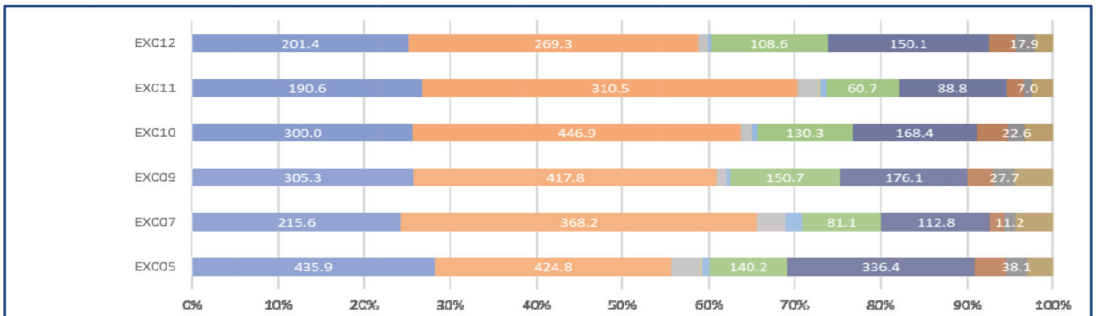
Figure 12. Excavator wise& Area-Bench wise Idling analysis

LOAD TIMING 22.8.2022 A SHIFT				
EQUIP	FIRST LOAD	CB START	CB END	LAST LOAD
EX05	06:30:08	08:39:30	10:43:16	13:12:19
EX06	06:40:30	08:49:52	10:03:22	13:20:37
EX07	06:46:49	08:32:10	10:42:16	13:16:50
EX09	06:55:54	08:33:12	10:29:59	13:09:12
EX11	06:48:14	STAGGER		13:10:37
EX12	06:41:58	08:52:19	10:19:30	12:55:44
PL05	06:36:07	STAGGER		12:50:29

Figure 13. First & Last Load Timimg in A shift(6am-2pm)

As mentioned in Fig.12 the idling percentage of area were reduced and hence productivity improved simultaneously. Action plan to be prepared area wise where idling is maximum. First and Last load timing doesn't directly affect the productivity, but it affects the production of mine and utilization of the machine.

F. CYCLE TIME ANALYSIS OF EXCAVATOR W.R.T TO HAULING UNIT

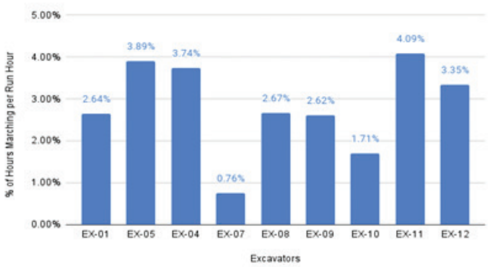


	EX005	EX007	EX009	EX010	EX011	EX012
Empty time	435.9	215.6	305.3	300.0	190.6	201.4
Empty stop time	424.8	368.2	417.8	446.9	310.5	269.3
Queue at LU	53.9	29.8	13.7	15.0	17.7	9.5
Wait at LU	0.3	0.2	0.2	0.0	0.3	0.0
Spotting time	13.9	17.2	4.9	7.2	4.9	2.3
Loading time	140.2	81.1	150.7	130.3	60.7	108.6
Hauling time	336.4	112.8	176.1	168.4	88.8	150.1
hauling stop time	56.2	14.8	37.0	43.3	13.7	24.0
waiting time at dump	38.1	11.2	27.7	22.6	7.0	17.9
dump time	46.9	39.4	54.3	38.8	18.2	18.2

Figure 14. Cycle Time analysis of Excavator in period of a month

Cycle time analysis in clustered bar graph helps us in focusing on area of improvement in excavator. As mentioned in Fig. 13, Ex-07 & Ex-11 Hauling Units were higher empty stopped as compared to others, thus losing utilization. From Fig. 14 we inferred that Ex-05 had more Empty time compared to other which refers to face congestion and queuing, thus we improved face width to improve productivity.

G. MARCHING HOUR ANALYSIS OF EXCAVATOR



KPI	% of Marching Hours
Feb	2.39%
March	3.37%
April	2.40%
June	1.70%

Figure 14. Marching hour of Excavator's

Marching of Excavator affects the production and utilization of the machine. Frequent marching of Ex-04 & Ex-11 were monitored, and thus overall marching hours could be reduced from February to June. The marching of excavator also increases the wear of roller pins and track chain of the machine; thus, marching should be minimized as much as possible. Proper mine planning reduces the marching of machine.

III. DISCUSSION

The main reason behind the study is the suggested ways to improve the productivity and utilization of high capital excavators. The continuous monitoring of Load per trip – frequency per shift that helps to improve the Load per trip of the hauling equipment from 85 Tons to 92 Tons, Average Loading time- frequency per monthhas been improved by

5% over the FY'22, Idling of Excavator (both Working and Non-Working Idle time) -frequency per month has been reduced by 10% over the FY'22, Marching of Excavator- frequency per month has been improved by 2% over the FY'22, Cycle time of Excavator- frequency per month with respect to Hauling trucks has been added in the improvement of productivity of equipment's. Improvement of Productivity led to improvement of specific diesel consumption from 0.95 to 0.89 liter/cum in FY 22. Productivity improvement leads to both effective and efficient utilization of excavator. Analysis has been done both area wise, bench wise and equipment wise. Focus should be led to mining areas and equipment's where performance is low and could be improvement. Productivity of excavator when improved, the productivity of Dumper (Hauling Equipment) improves simultaneously.

IV. CONCLUSION

With the reduction in average loading time of excavator, Idling of Excavator (both Working and Non-Working Idle time), Marching of Excavator, average spotting time of hauling equipment's and the improvement of load per trip of the hauling equipment's in FY'22 has been resulted in terms of the improvement of the Productivity of Rear Dumper-100T capacity (Hauling Unit) increased by 15%, Ex-1200 by 22% and Ex-2500 by 3% which led to an accrual saving by ~10.5 cr. The load per trip of the fleet improved from 86 T to 91 T.

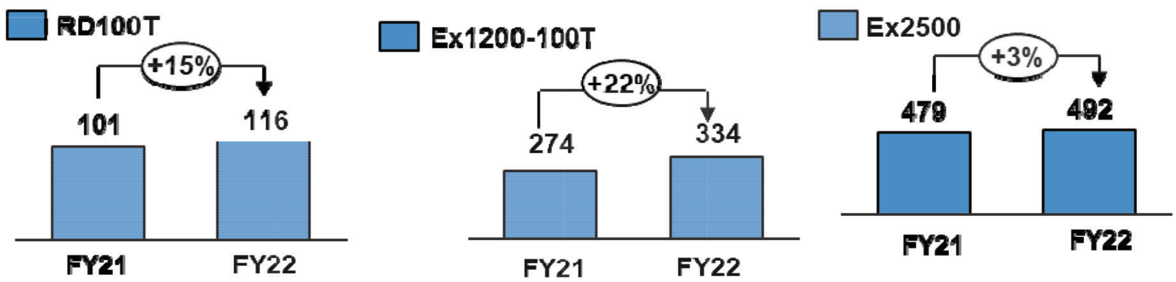


Figure 14. Improvement % of Rear Dumper 100T& Excavator's (Ex-1200 & Ex-2500).

V. ACKNOWLEDGEMENT

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CRITICAL ELEMENTS OF FORESTRY CLEARANCE : EESO MODEL THE SOLUTION

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Abstract

A conceptual framework for anlysing the critical elements of forestry clearance process for opencast coal mines in Jharkhand and its recoupment are proposed in this article. In this papermore than 50 issues have been included and covers all the seven scenarios given at the manual released by the Ministry of Environment, Forest and Climate Change (MoEFCC) in July'2023. The provisions as stipulated by MoEFCC vide its guidelines on 'Compensatory Afforestation' (CA) & Accredited Compensatory Afforestation (ACA) on dtd. 21 Aug'2023 & 24 Jan '2023 respectively have been suggested through 'Economic, Environmental, Social and Other model' (EESO) along with a flow sheet for forest clearance process as per Forest (Conservation) Rule, 2022. Other issues related to 'Authenticated Land Schedule'(ALS), Certificate under Forest Right Act-2006 (FRA) along with other has also been addressed in this research paper. The paper will explore ways to effectuate robust governance system ensuring application of effective diversion of forest land with focus on Just transition and climate justice.

Proactive afforestation, obviate delays, flow of Environmental Sustainability Goals (ESG) in advance, investment in forest sector, meeting NDCs targets, cost saving etc. are some of the benefits flagged for UA & community in and around the forest area. Issues to be addressed have been pin pointed in this paper which will help the coal mines managers in resolving the troika of social, environment & developmental challenges in addressing forest clearance process in their mining complexes. Intervention of government machinery like MoEFCC in cutting short of timeline of proposal disposal process will help the mine managers to obtain the forest clearance as per their plan.

Keywords - *CA, ACA, EESO, ALS, FRA, ESG.*

1.0 INTRODUCTION

Opencast coal mining operations starts with clearing (bushes, trees etc) over the land, removal of overburden (including topsoil & sub soil), dumping of over burden and/or backfilling in excavated areas, digging out coal and transport coal to its destination/end users. Thus, opening an open cast mine requires a huge quantity of land. In context to Forest (Conservation) Act, 1980 (FCA) these lands may have been categorized as forest land or non-forest land. The coal mining activity being of non-forest use, as such forest land involved in coal mining activity as per section 2 of FCA attracts permission for its diversion. This very section stipulates that no State Government or other authority shall make, except with the prior approval of the Central Government, any order directing, inter alia, that any forest land or any portion thereof may be used for non-forest purposes. Forest Conservation Rules 2022 (FCR) advocates the process of obtaining forest diversion/clearances. These rules have provided certain relaxation to user agency (UA), who makes application for forest clearance. These rules have provided several windows of interaction with several forest officials, which were missing in FCR-2004. Formulating a forest application still requires attention as it requires several documents which may not be under control of UA. These documents are required at different stages of FC process. While formulating an application one must know type of forest land. Delineation of land into forest and non forest land remains one of the daunted task.

2.0. DELINEATION OF LAND

The land required for coal mining activity are to be delineated to forest land or non forest land. Notified forest, Revenue Forest, GairMajarua Jungle Jhari, zudpi jungle, civil-soyamchhote/bade jharka jungle, orange lands etc. may be delineated as forest land. Any type of land recorded as forest in any government records are also forest land. Other lands like GairMazaruaAam, GairMazaruaKhash, Tenancy, Kesar Hind, Bhuari, Paritpathar, Baid etc. attacts nonforest for the purpose.

3.0. STATUTORY PROVISIONS

FCA warrants obtaining diversion of forest land for its non forest use. Rule 9 of FCR-22 provides the provisions to UA that the UA shall make an application to the State Government (SG) or Union territory Administration (UTA) for approval of the Central Government (CG) under section 2 of the FCA for dereservation of forest land, use of forest land for non-forest purposes or for assignment of lease, in the specified online Forms (Form A/B/C). UA to make application on Parivesh 2.0 portal after registering over it. Parivesh 2.0 facilitates UA to make application after 4th September 2022 for obtaining clearance for Environment, Forest Wildlife, Coastal regulatory zone on one platform. This platform reflects applied, approved, and rejected proposals of each category. UA can also manage the previously applied proposals on this platform only. UA can also visit the proposals applied between 29th June to 4th Sep 2022. After making application by UA, the system simultaneously forwarded to copy of application to the concerned Divisional Forest Officers (DFOs), District Collectors (DCs), Conservator of Forests (CFs), Chief Conservator of Forests (CCFs) and the Nodal Officer (NO) of the SG/UT. Each of whom independently separately to undertake preliminary examination for the completeness of documentation of the proposal for the purpose of examination by the Project Screening Committee (PSC). Different Steps involved in the process are listed in Table 1.

TABLE I. : STEPS OF FOREST CLEARANCE PROCESS

Sl	Item	Description
1	Submission of FC Proposal	UA submit FC proposal to SG through online portal.
2	Check by PSC	For completeness. Unique Proposal Identity Number generated.
3	Field Verification	DCs, CFs, CCF, DFOs for field verification;
4	Examining Feasibility	For recommendation to SG / UT Administration along withmitigation measures to be adopted by the UA.
5	In-principle approval	SG / UT Administration agrees for Inprinciple approval.
6	Grant In principle Approval	CG (MOEFCC) / Integrated RO grants Approval
7	Compliance report of Stage I	UA to submit compliance to the stipulated condition/s of stage I approval.
8	Issuance of diversion order	Grant of diversion order /Stage II by SG/UT for forest clearance
9	Compliance report of Stage II	UA to submit compliance to the stipulated condition/s of stage II approval.
10	Site Hand over (SH)	After satisfactory Compliance of Stage-II conditions
11	Physical Hand Over	UA can start work

3.1. Steps of possession of Forest Land

The stepwise FC process as per FCR-22 is illustrated in Fig. 1.

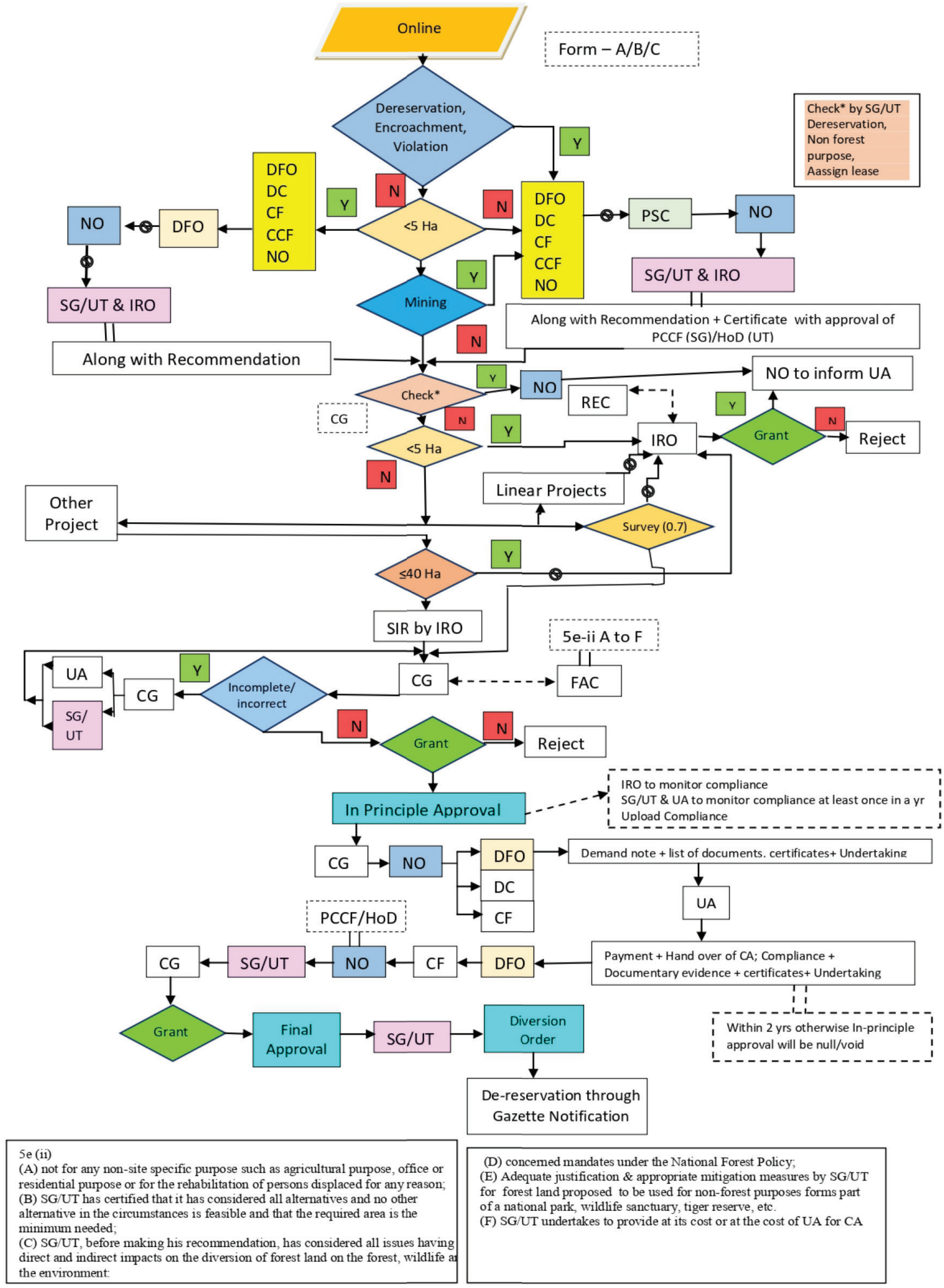

Fig. 1 : Flowsheet for Forest Clearance Process

4.0. GROUPING OF DOCUMENTATION OF FC PROCESS

4.1. Documentation

Preparation of documents, plans/section, reports etc., implementation of reports and plans by the UA are most important part of formulating a successful application. The process has been divided under two heads for this paper- one is while making application for Stage I ie Pre-in-principle approval and others while making compliances to stage I conditions for obtaining Stage II ie. post in-principle approval. Certain specific documents in specific format, scale are required. Eg. Marking of forest proposals on Toposheet (1:50,000) & Cadastral Map (1:3860 miles), KML Plan & DGPS of forest Proposal & CA Land, Land Use Plan (1:4,000) are required. Authenticated Land Schedule (ALS) is one of the prime documents along with FRA for Forest Land (Notified Forest , GMKJJ) , Translated Copy of Proceedings of FRA, NOC for GMKJJ are to be obtained from state missionaries. Various other documents required by UA in Pre in-principle approval stage are R &R Plan, CBA Report, Tree Enumeration Report, Payment for NPV, CA, other levies, Transportation & Linkage Details, EC letter/ Status, Stage – I/ Stage-II letter and Latest Compliance, Authorization, Mine Plan and its Approval, Leasehold Area Details, Justification, 3-D Analysis Report for UG Project, Undertakings etc. Reports like Reclamation Plan, Soil Erosion Report, Avifauna Study, Wildlife Management Plan etc. may be required at latter stage. The remunerations as per various OMs of MoEFCC have to paid eg. Soil & moisture conservation, Wildlife etc.

4.2 Segregation of Issues into EESO model

Unless planned properly obtaining forest clearance for forest land for opencast coal mining is full of Challenges. Different issues involved and the challenges faced are having Environmental, Social, and Economic facets. These challenges are related to the more than 49 documents which are required to be submitted at different steps of the FC process as detailed at table 1. These challenges related to documents and other process are often under the control of UA. Many a times it has been observed that these challenges are beyond the control of UA. The challenges / issues are categorized as per EESO model in Fig. 2.

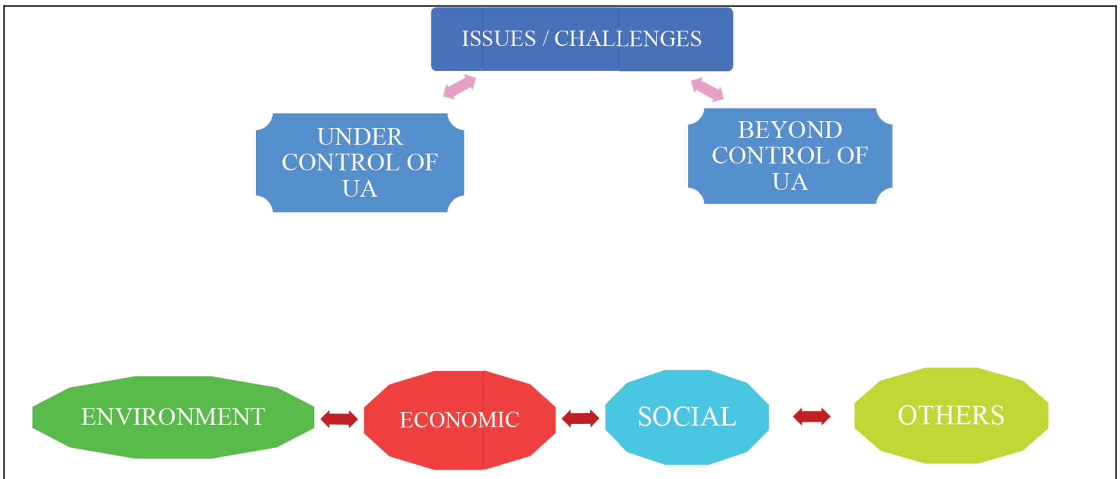

Fig. 2: EESO Model

5.0. GOVERNANCE ADHOCISM OF ISSUES

Adhocism is a policy or method characterized by actions or decision chosen to suit or fulfil immediate needs or goals. The practice of reacting to what happens or is needed at time, rather planning. This further necessitate to form a structure and designing the process to ensure accountability, transparency, responsiveness, stability, inclusiveness, and brod-based participation. These are segregated whether it is under control of UA or beyond control of UA. These may be further regrouped into EESO ie Environmental, Economic, Social and other issues/challenges . As such Governanc eadhocism is required to monitor the process.

5.1.Environmental Issues

Table 2 : Environmental Issues

	Issues		Issues
1	EC letter	8	Reclamation Plan
2	Mapping of Stage – I/ Stage-II	9	Avifauna Plan/Study
3	Compliances of Stage-I/II if any	10	Land Surrender Schedule
4	Cadastral Map	11	EC Compliance if any
5	Land Use Plan (scale 1:4000)	12	KML & DGPS plan of Forest Land
6	Soil & Moisture conservation Report	13	KML & DGPS plan of CA Land
7	Wild life Management Plan		

5.2. Economic Issues

Table 3 : Economic Issues

	Issues		Issues
1	CBA Report	5	Demarcation of Pillar
2	Tree Enumeration Report	6	Payment for Wildlife Management Plan
3	Payment for NPV, Penal NPV, CA, Penal CA other levies	7	Payment for Soil Moisture Conservation Plan
4	Compensatory Afforestation (CA)	8	ACA

5.3. Social Issues :

Table 4 : Social Issues

	Issues		Issues
1	Authenticated Land Schedule (ALS)	12	Land under CNT Act - purchased &sold
2	Fixing Physical Boundary (PB)	13	Encroachment of land
3	Plotting PB on cadastral Plan (CP)	14	Interference of Ministry
4	Land Schedule preparation	15	Non authenticity of record in Register II
5	Non availability of land records at Circle office		

6	Land records - Missing	16	Certificate under FRA
7	Non updation of Register-II	17	Translated Copy of Proceedings of FRA
8	Torn out khatiyan	18	NOC for GMKJJ
9	CS / RS Survey	19	Documents signed in / attested
10	Govt. issued guidelines	20	Mine Plan and its Approval
11	Unauthorized occupancy on Govt. Land	21	Identification of CA Land

5.4. Other Issues

Table 5 : Other Issues

	Issues		Issues
1	Authorization for Online Application	5	Undertakings
2	Leasehold Area Details : Land Details As per Acquisition	6	Inspection and inspection report
3	Inspection by DCF/DFO & CF/RCCF	7	Inspection by IRO MoEFCC
4	Justification		

6.0. COMPENSATORY AFFORESTATION (CA) & ACCREDITED COMPENSATORY AFFORESTATION (ACA)

CA means that when the forest land is utilized for non-forest purposes, the UA have to provide alternate land as compensation for the land to be diverted. An equal area of non-forest land is to be compensated for the forest land proposed for diversion. Degraded forest land that is double the area of cleared forest land has to be afforested to recompense, if non-forest land is not available. It is a critical area of concern for the Union Government, which has been tried to resolve the issue to some extent after enactment of FCR-22. ACA has been introduced vide these rules and there is a need for improving the mechanism. ACA is a system of proactive afforestation which can be used instead of fulfilling obligations for compensatory afforestation. CA land and some of the provisions of ACA are given in schedule I as per rule 11 (1) and rule 11 (3) of FCR-2022. Persons or agencies from private as well as Govt. sector may register for ACA scheme. ACA mechanism envisages the considerations to be taken while formulating proposals under FC Act 1980 using ACAs lands. It facilities entry of the private party as person or agency. One can develop ACA credit and can sell to the needy organization. The details of which is given at Fig. 3.

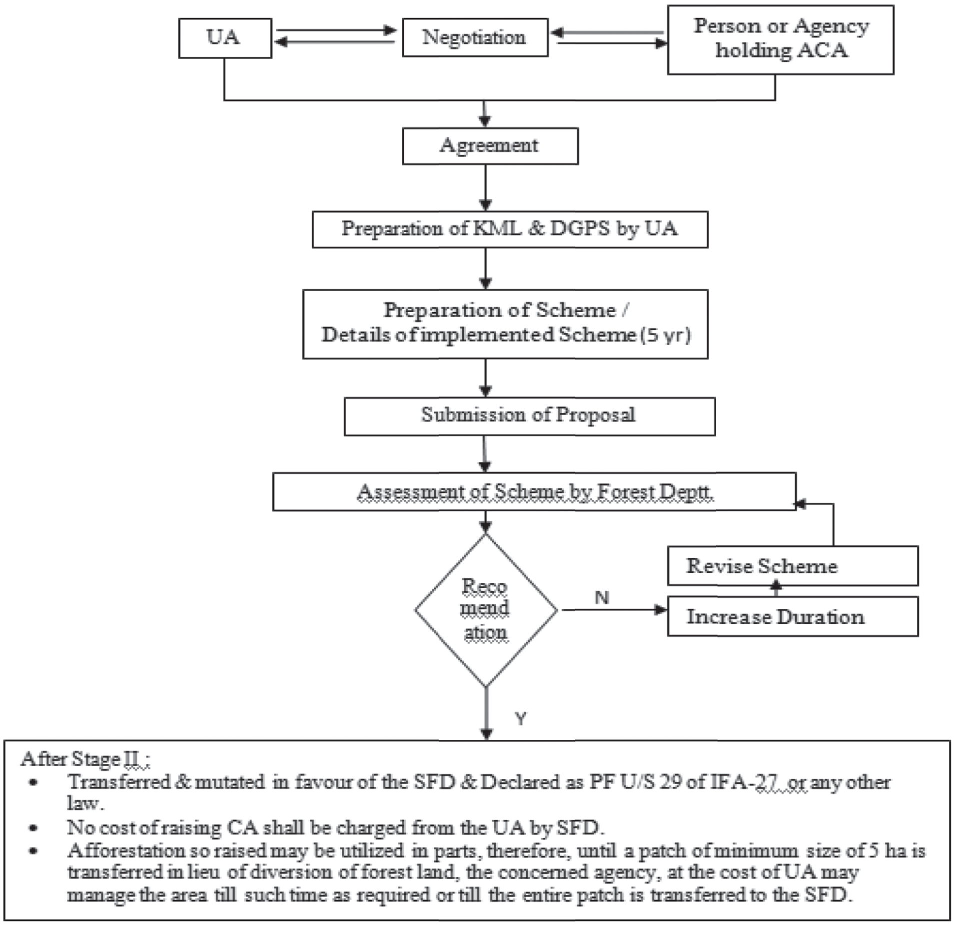

Fig 3: Flow chart for using ACA as per FCA-80

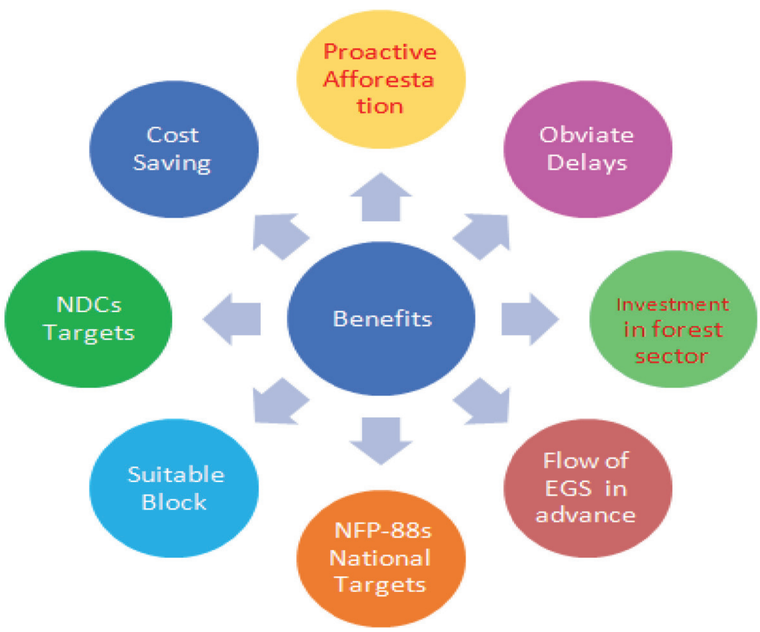

Fig 2 : Benefits of ACA Scheme

7.0. ISSUES TO BE ADDRESSED

Identification of land for CA and preparation of schemes are causing delay in processing of proposals. As per clause 2.5 (i)(f) – Special provisions for CA, of Handbook on guideline stipulates that "CA shall be raised and maintained at the cost of the user agency on degraded forest land twice in extent of the forest area diverted" and exemption from getting certificate from state Government to the effect that suitable land required for compensatory Afforestation under this clause is not available. (Clause 11-1(a)).

It is not clear whether in case of UA acquires any non forest land for the execution of the project, the exceptions in case of CG agencies, CPSUs and SPSUs as above shall not be applicable. Reclaimed non forest lands after completion of mining can be considered for CA and can be brought under clause 11(3) of FC Rules 2022. ie. Accredited Compensatory Afforestion without transferring to SFD. Such land may be demarcated as forest land for further records. In respect of land acquired under CBA (A&D) Act 1957 issue of transferring the Biologically reclaimed non-forest land considered for CA to Forest Department, needs to be addressed.

8.0. RECOUPMENT OF CHALLENGES

As the issues and challenges pinpointed in the previous sections are often inter related and inter changeable as such the recoupment of challenges have been suggested taking into considertaion of the fact.

As mentioned, the issues and the challenges related to Authentication of Land Schedule are related to socio issues. Dealing with social issues is still a major challenge for many opencast coal mining companies, owing to a lack of internal capacity and specialist skills, which are important for understanding how and why community engagement should be carried out meaning- fully and effectively. Company- community grievance mechanism can be one tool to help establish and maintain a social license to operate. However, effective community engagement could, in turn, benefit a mining operation. Liaising at all level at Karmchari, CI, CO, AC, DC, Secretary, Minister/ CM. Showing similar documents issued from other officers often works for issuance of certificate/ orders required for FC application. CP to be explored from Mukhia/Surpanch or old people in the village if it is not available from govt. records. LS prepared at UA end requires to be verified from Form II register usually kept at CO office. The forest land is to tallied with the records available at range office of forest department often saves time. These tallied records will help in future conflicts being raised at forest offices while processing the forest application.

Correct or near correct land schedule will often pave way for smooth and correctly preparation of key hole markup language (KML) file, differential global positioning system (DGPS) map of forestland, Land use of forest application, request for certificate under FRA-2006, request for issuance of no objection certificate (NoC) for GMJJ/Revenue forest etc.

Building trust can be another tool, which helps to establish and improve social relationship. Building trust takes time and patience. User agency need to find a way to build long-term dialogue with communities, and local representatives and representatives from UA side should be actively involved. Officials at project level can play a very important role. User agency need to demonstrate, through action, that they are taking people's concerns seriously and are fulfilling their promises. They also need to ensure that there is good communication with villagers, service providers and third parties, so that those responsible for carrying out activities on the ground are aware of the promises made and are committed to fulfilling those promises.

For searching cadastral map it is suggested to search it to the older people of the villages. Building trust of the activities amongst the villagers may help for this purpose. It is suggested to use the topo sheets available at GSI stores, which can be purchased on nominal charge, in comparison to using scanned copy or Xerox copies for accuracy. UA have to use the issues raised in Gram sabha – a interacting platform for UA and local people.

To avoid delay in the process of the forest application user agency must ensure that minutes of the proceedings of the FRA certificate issued are translated.

The UA to prepare and implement the R&R Plan as per the R&R Policy of State Government in consonance with National R&R Policy, Government of India before the commencement of the project work and implementation or else annex the proper approval. Approval at company level or area level is serving at present.

The guideline making clarity in contents to be shown on landuse map with complete details will help UA in making the compact and flawless proposal due to which there is delay in disposal of proposals at many times. State government to timely provide the CA lad along with accurate shape file and the degraded land to have forest density as 40 percent.

Regarding attestation of documents, requisite copies need to be collected by UA from issuing authority. Further authorization to be issued to such person of long tenure to the place so that frequent change in profile and signature on documents be avoided and further cutting short the FC processing time.

It is a good practice that authorized person to put his/her signature and put seal containing his/her name to avoid delay in processing of forest application. The delay caused due to non-mapping of proposals needs MoEFCC interventions and proper follow up at divisional offices of the forest department and NIC offices of MoEFCC to map all forest on the Parivesh portal of MoEFCC. From different study authors are in the opine that inhabitants concerns are mostly related to socio economic issues which needs to be categorized and prioritized in line with mining plan and needs drawing up the action plan to deal with the issues.

Consulting the maps related to KML, Shape file for forest & CA at DSS maintained at Forest headquarter, Divisional offices, Regional offices of MoEFCC can help UA in resolving some of the issues.

Most of the issues can be recouped by making some of the details in planning itself. Incorporating proper land details, details of R&R plan in project report or mine plan can resolve most of the challenges faced by UA.

9.0. CONCLUSION

Based on the study, the following conclusions are drawn :

- EESO model developed in this study may help mine manages in formulating
- Flow Chart developed for processing of FC process will help in timely obtaining of FC.
- The voices of the communities need to be heard.
- Company- Community grievance mechanism in FRA process, liaising for upward movement of proposals, building trust, stickiness to the promises made etc. are few tools will help in clearing rift in Gram Sabha.

- Not to blame government agency in delaying rather affirmative approach is suggested.
- Correct and related documents and report at right place are advised to file application of nearly zero defect.
- FCR-22 gives solution to certain issues (CA ➜ ACA).
- ACA to be encouraged by providing an incentive for persons to develop plantations and undertake agro-forestry, which has also been suggested in ACA guideline.
- Parivesh version 2.0 of MoEFCC is a good and favourable move by the government in favour of UA.

10.0. ACKNOWLEDGEMENT

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LITHIUM : THE CHANGING LANDSCAPE OF PRODUCTION AND ECONOMICS

Dr. Samindra Narayan Mitra

Abstract

Lithium plays a critical role in the transition towards green energy, by virtue of its presently irreplaceable position in the rechargeable energy storage systems. Responding to rapidly growing demand from incentivised adoption of electric vehicles (EV), lithium supplies have grown exponentially in the last decade, from expanding traditional sources as well as diversified new ones. Consequently, Government's of the EV-adopting nations, have designed policies to reduce supply-risk and vulnerability by realigning the asymmetrically concentrated lithium supply chain, wherein the final consuming countries so far had limited participation, and China (owning the most competitive mines and refining capacities), along with Japan and South Korea in components and battery-making, occupies an apparently unassailable position due to the prior investments. As growing supplies balance off and surpass stabilising demand shortly, and financial returns 'normalise', presently diversifying economic landscape is set to change, through optimised vertical integrations (and consolidations) that may balance distribution of gains along the value chain. Technological progress, including the upstream and midstream activities, can make this industry truly sustainable, both economically and environmentally, with due government support and guidance. India needs to seize the upcoming opportunities to gainfully participate in the value chain and achieve self-reliance, too.

Keywords : *Lithium, EV, Supply, Demand, Costs, Economics, Balance, Global.*

1. INTRODUCTION :

Lithium, the lightest metal with a soft white appearance, plays an important role in the global battle against climate change, especially as we move from fossil fuels to renewable energy in transportation. The complexities and vulnerabilities of the asymmetrically concentrated lithium supply chain, from mining and refining, to lithium-ion batteries (LIB) in electric vehicles (EV), make it a 'critical mineral' susceptible to disruption, especially due to high dependency on a set of nations. Consequently, several nations planned to develop 'secure' supply chains through policy mandates. With the ensuing geo-political realignment, diversifications and expansions, the landscape of lithium production and economics may witness substantive changes.

2. THE DEMAND PROFILE :

Since 2012, the surging demand from EV and ESS (Energy-Storage-System) batteries has set the demand growth into an exponential path. Demand for lithium batteries equated to nearly 80% of all lithium use in 2022, and may grow to 90% by 2028, as share of lower–priced EVs grow (Table 1) in the global passenger car market, while other industrial demand maintains historical growth of about 2.2% p.a. (per annum) (S&P Global, 2023). International Energy Authority (IEA, 2023) has projected the derived battery demand in terms of TWh/year, in four assumed scenarios of adoption, namely Stated Policies Scenario (STEPS), Announced Pledges Scenario (APS) and Net Zero Emissions by 2050 Scenario (NZE). In 2030, the projected bat-

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tery demands are, in respective scenarios: 3, 3.5 and 5.5 TWh p.a. that will be nearly matched (at NZE) by presently announced capacity (at 85% utilization), says IEA (2023).

Roland (2022), forecasting demand (based on EV-makers' plans) at 3.2 TWh in 2030, estimates capacity to reach 4.2 TWh p.a., surpassing demand. Thus, the challenge remains only in providing requisite raw material supplies.

Table 1. Share of EV in vehicle sales (forecast) Data : Goldman Sachs, 2023

Country/ Region	EV share 2030	EV share 2035	EV share 2040
U	70%	100%	100%
EUSA	50%	70%	85%
Japan	20%	50%	80%
China	45%	68%	77%
India	20%	37%	55%
Global	35%	50%	61%

Lithium is consumed in LIB through lithium-carbonate (having 19% lithium) and lithium-hydroxide (containing 29% lithium). Hence, production/consumption volumes and prices are expressed in Lithium-Carbonate-Equivalent (LCE) terms, in the discussion below :

BCG (2022) projected a demand of 1.4 mill tonnes per annum (t.p.a.) in 2025, rising to 2.90 mill t.p.a. in 2030 and 4.60 mill t.p.a.in 2035. Thereafter, McKinsey (2023) forecasted three plausible lithium demand profiles, based on the likely pace of EV adoption and technological changes. The 'Base Case' assumes a steady 20% p.a. (per annum) growth in Lithium demand (as opposed to 25% p.a. growth during 2018 to 2022), derived from a 26% p.a. growth in EV production, from 2022 figure of 0.72 mill t.p.a., to reach 1.44 mill t.p.a. in 2025, and 3.06 mill t.p.a. in 2030; while the 'High Case' assuming higher lithium content in cells (lithium metal anodes arrive by 2026) in EV production of base case, projects a demand of 1.5 mill t.p.a. and 3.5 mill t.p.a., respectively in 2025 and 2030; and the corresponding volumes in 'Low Case' that assumes slower pace of EV production, are 1.2 mill t.p.a. and 2.55 mill t.p.a., respectively. McKinsey (2023) reckons that demand for lithium-hydroxide, increasingly favoured by EV producers, will grow faster than that of lithium-carbonate, reaching 1.54 mill t.p.a.in 2030, vis-à-vis 1.21 mill t.p.a. for lithium-carbonate.

In the 'Base Case', the growth above 2022 volume, in terms of mill t.p.a., will come from China (0.90), Europe (0.58), USA (0.29), and others, including India (0.57). European mining giant, Eramet (2023) that plans to supply 15-20% of Europe's lithium demand from African operations, expects lithium demand to reach about 2.6 mill t.p.a. in 2030.

Office of the Chief Economist, Australia, projects that the market will balance in 2027 and production (2.1 mill t.p.a.) will outstrip demand (2 mill t.p.a.) in 2028, wherein Asia will remain the biggest consumer despite the gains in battery-capacity in Europe and USA (S&P Global, 2023). Maximum increase in output will come from Australia (largest share, expected 32%), followed by Chile and Argentina, along with additional supplies from China, Brazil and Canada.

Similar views are expressed by Fast markets (2023), Reuters (2023) and Goldman Sachs (2023) that market is likely to balance off by 2028-30, as EV sales growth levels off gradually to 20% p.a. in 2030 and in steps to 5% p.a. in 2040.

Mckinsey (2023) envisages a surplus of 220,000 t LCE in 2030, if all current projects fructify as planned.

3. THE LITHIUM SUPPLY CHAIN :

Lithium is found in two distinctly different types of economic deposits : a) hard rock ores, (mainly as spodumene, and also as lepidolite, petalite etc.) spread over Australia, China, Portugal, Canada, Zimbabwe, Brazil etc., and in a slightly altered form in the USA; and b) salt brine deposits, occurring mainly in the Latin American belt (the Lithium Triangle of Chile, Argentina and Bolivia), and also in parts of USA and China (Tibet). Lithium occurrences and production are highly concentrated (Table 2): Australia, Chile and China accounted for 92% of global production in 2022, while Argentina and Brazil added further 6.5%, to cover 98.5% of global volume.

Table 2. Global lithium production
(In Li terms, in `000 t), Data : USGS 2023

Country	2010	`15	`19	`22
Argentina	2.9	3.8	6.3	6.2
Australia	8.5	13.4	45	61
Brazil	0.18	0.16	2.4	2.2
Canada	-	-	0.2	0.5
Chile	8.8	11.7	19.3	39
China	4.5	2.2	10.8	19
Portugal		0.3	0.9	0.6
Zimbabwe	0.47	0.9	1.2	0.8
Total	25.3	32.5	86	129

While sufficient lithium resources (Appendix 1, shows active and upcoming countries with respective presently identified resources) exist to meet the burgeoning demand, scaling up the production in the short term is fraught with bottlenecks (Olivetti et al., 2017).

Lithium supply structure is oligopolistic, with a handful of companies controlling the majority of production. The largest lithium-producing mining companies in 2022 (Fitch, 2022) are, Sociedad Quimica y Miner a de Chile (SQM) that has large brine lake in Chile (Salar del Carmen) and holds 50% interest in Mt Holland (spodumene, Australia) jointly with Wesfarmers; Mineral Resources Ltd. (Australia), that holds the Mt Marion mine together with Ganfeng Lithium; Tianqi Lithium (China), owning 51% and operating (through Talison Lithium Ltd., a 51:49 JV of Tianqi and IGO Australia) the largest and lowest-cost mine of the world, Greenbushes (Australia) jointly with Albemarle (holding 49%); Albemarle Corporation (USA), holding resources in Chile's brines (Atacama, La Negra), Australia (Greenbushes) and USA (Silver Peak), and new projects (Antofalla, Argentina); and Ganfeng Lithium (China), owning mines in China and Australia, along with new projects in Argentina, Mexico, Ireland, and shares in junior miners having new projects. The average operating margin of these top companies runs above 40% (Berry, 2020), while the top 40 mining companies worldwide (2002-23) reported net profit margins between 7 to 17%, excepting 26-27% during boom and -7% post-boom, and a forecast of 14% in 2023 (Statista 2023).

China, led by Ganfeng Lithium, General Lithium, Sichuan Yahua Industrial Group and Tianqi (TQC) et al., accounts for nearly 50% of global refining of lithium into chemical compounds, and converts almost entire spodumene concentrate (beneficiated spodumene ore) from Australia, Brazil and China (Graham et al., 2021).

Albemarle (USA) too, processes its Australian and South American (brine-based lithium carbonate) supplies, in China.

Chilean and Argentinian brines are processed locally into lithium carbonate and shipped either directly to LIB-manufacturers, or to China for processing into lithium hydroxide.

These lithium compounds get processed with other metals like nickel and cobalt to make electrodes, or with solvents to yield electrolytes, for the LIB industry.

Table 3. China's share in LIB Cell manufacturing capacity

Data : Altiparmak, 2022

Country/Region	2020 Share %	2030 Share %
China	72.5	66.9
N. America	9.2	11.9
Europe	5.4	16.7
Asia	12.9	4.0
Others	-	0.5
Total Capacity	0.5 TWh	3 TWh

Table 4. China's share in LIB Component Making. Data : Goldman Sachs, 2023

Country/ Component	Cathode mfg Share	Anode mfg. Share	Electrolyte Share	Separator Share
China	42%	65%	65%	44%
Japan	34%	19%	12%	21%
S. Korea	15%	6%	4%	28%
USA	-	10%	3%	6%
Rest	10%	-	17%	2%

China holds the dominant position in manufacturing of LIB cells (Table 3) and its components (Table 4), followed by Japan, South Korea and USA in components, and N. America, Europe and Asian countries in cells. China, Japan, and South Korea consume LIBs domestically, and also export to EV-makers in USA and EU. In EV manufacturing, China leads with nearly 50% global share, followed by EU and USA (Fliegel et al., 2021).

4. ECONOMICS OF LITHIUM :

a) Costs of production (Ores and Brine):

The presently estimated total cash cost of production of spodumene concentrate is about USD 2540/t LCE (2019 average of 11 operating mines, all costs included, delivered at China port), consisting of labour (30%, especially high in Australia), energy, reagents, offsite transport and shipping, royalty and other costs. Labour and energy together are just above USD 1000/t LCE. On the other hand, the total cash cost of production of lithium carbonate (processed directly from brines) comes to about USD 5580/t LCE (2019 average 9 operations) (S&P Global 2019b). About 37% of this cost is attributed to reagents for complex chemical conversion and about 23% to royalty (as Chile's royalty rates more than doubled from 2017 to 2019). In brines, the labour plus energy component of the cash cost, being merely 9%, is lower than that of spodumene ores, i.e. marginally below USD 1000/t LCE. However, lithium carbonate begets a much higher price than that of spodumene concentrate, resulting in better operating margin for brines. For reference, in 2019, the total cash operating margin from brines was about USD 5386/t LCE, which is almost double that of spodumene miners. Cost of production is inversely proportional to the grade of in-situ spodumene ore or brine concentration, and the impurities contained.

The game changes dramatically if spodumene is directly converted on-site to lithium-hydroxide, beating the costlier chemical conversion from brines' lithium carbonate. Mckinsey (2023) projects Australia as the lowest cost producer (all costs on LCE basis) at USD 6500/t in 2030, for lithium-hydroxide, inclusive of sustaining capital costs and freight, having the lowest raw material cost in the world and with highest level of integration, followed by South Korea at USD 7600/t and Canada at 10400/t; while China and USA stood close with costs USD 12600/t and 12800/t respectively, with medium level of integration, and Russia and Europe with least level of integration are expected to have costs of USD 14700/t and 15100/t respectively. Rest of the world may operate at USD 12700/t with medium level of integration.

In 2019, half of the then global total production of about 600,000 t.p.a. (LCE), coming from hard rock, cost below USD 3000/t LCE, of which about 100,000 t.p.a. was lower than USD 1000/t LCE (Australian), and majority stood near USD 2000/t LCE. Lowest cost brine operations (about 50,000 t.p.a.) came around USD 3300/t LCE, followed by another 50,000 t.p.a. at about 4600/t LCE; similar to the highest cost hard-rock (China), up to about USD 5500/t LCE level, again followed by a large-output brine at about USD 5800/t LCE. Beyond this point, the costs went up sharply to USD 8500/t, and finally to the highest level at USD 12000/t LCE, from the new entrants, especially in EU, and/or with thinner/complex ores, albeit with small outputs.

In comparison, in a flatter industry cost curve most producers operated at around USD 5000/t in 2017 (Mckinsey, 2018), barring a few at USD 6000 to 7000/t, and the lowest ones at about USD 2500/t LCE. The estimated marginal cost of production was USD 6500/t LCE, with SQM, Albemarle and Talison (Green bushes, Australia) being most cost-competitive. Marginal cost of production is forecasted in the range between USD 8500/t and USD 11500/t LCE in 2025, on the basis of brownfield expansions, ensuring viability for projects in USD 8000/t band, such as Pilbara Minerals, Baconara, Nemaska and Altura.

While significant new capacities at cash cost about USD 3500/t LCE (the lowest quartile) are slated to join the supply stream (Eramet, 2023; Ibarra-Gutiérrez et al., 2021), strategically important projects may join the supply at nearly double this cost (USD 6743/t projected) too (Lithium Americas, 2023), thus suggesting a steeper industry cost curve with higher risks.

b) Long-term off-take agreements vs. open market pricing :

Lithium products are mostly traded through long-term offtake contracts, which are linked to the grade and impurities contained. While spot market price reflects the price of marginally traded products in open market, offtake agreements usually contain a minimum 'floor' and a maximum 'ceiling' price, with a 'market-price'-linked movement, so as to safeguard the interests of both the consumer and the supplier. EV makers like Tesla have consistently tied up with the low-cost high-grade miners in low risk countries, to ensure cost competitive and reliable supplies.

In a typical offtake agreement, Sayona Quebec (January 2021) committed to supply Piedmont Lithium 50% of their spodumene concentrate (6% Li2O, SC6) production (subject to minimum volume of 113,000 t.p.a.) from their NAL and Authier projects, priced on an equivalent of 'CIF' (cost, insurance and freight) market price, China basis to Cherryville, North Carolina, USA, while adhering to a minimum (floor) of \$500/t and a maximum (ceiling) price of \$900/t, with incremental movements linked to China market price (Piedmont, 2022). Unit operating ex-mines (pit-head, milling) cost of Authier project is reported to be USD 48.89/t of concentrate, similar to other projects (Quebec Lithium USD 58.75/t, Whabouchi USD 63.93/t) in Canada (Ibarra-Gutiérrez et al., 2021). These costs are, however, on per tonne of gross mineral processed output of SC6 (6% Li2O content) without royalty, offsite transport, reagents, shipping, etc. and not on LCE terms. Sayona (Australia) had acquired NAL (North American Lithium) in 2021, after they suspended production and filed for bankruptcy protection in 2019. Piedmont further supplies to Tesla and LG Chem with a formula-based, market-linked pricing. This Canadian SC6 ultimately helps LG Chem to meet the requirements of the Inflation Reduction Act of 2022 (IRA of USA), to support the development of secure U.S. battery supply chain (Piedmont, 2023).

The strategically important (EU) Barrosso Project, Portugal, estimates C1 cash operating cost at USD 292/t of spodumene 6% concentrate, and all-in sustaining cost at USD 409/t. Assuming long-term concentrate price at USD 1597/t, average for mine life, it projected post-tax IRR 77.3% and payback period 1.3 years (Savannah, 2023).

Leading players (SQM, 2022) typically contract approximately 20% of the sales volumes at a fixed price or at a variable price with specific floors and ceilings, while keeping approximately 50% of sales with prices linked to variable specific benchmarks, and leave the rest open, to balance risks. The actual price realization is therefore a weighted average of the aforesaid mix, according to market conditions.

c) Margin distribution along the value chain :

BCG (2022) estimates that the upstream extraction (lithium salts from hard rock or brine) facilities enjoy about 25-30% share of the total profit pool of the Lithium value chain, while the midstream units such as primary processing and refining (from lithium-salts to lithium-carbonates and/or lithium-hydroxides), and cell-component (cathodes, anodes and electrolytes) manufacturing get 20-25% share, leaving the downstream entities engaged in cell-manufacturing-and-integration and vehicle-manufacturing, with about 45-50% share.

5. DISCUSSIONS ON EMERGING SCENARIO :

a) The future technological imperatives :

The EV revolution owes its success to direct government subsidies and several technological wonders, including the battery chemistry, pack and cell design, energy density and so on that ensured a 97% drop in battery prices from USD 7500/KWh (1991) to USD 181/KWh (2018), halving almost every four years, and to USD 132/KWh in 2021 (Frith, 2023; Ziegler & Trancik, 2021) despite rising lithium price.

At a battery cost of USD 100/KWh, EVs are said to cost the same as ICE-riven vehicles to own, but it's not likely before 2027 (Mckinsey, 2018).

Costs of lithium and other ingredients are crucial in breaching this tipping point, as it takes a higher share in declining LIB cost (Olivetti et al., 2017). In 2022, higher nickel and lithium prices drove the battery prices up by about 7% (OCE, 2023).

Innovations also need to overcome the glaring-inefficiencies in the upstream and midstream processes in terms of environmental costs and loss of lithium values (Table 5).

Direct Lithium Extraction, or DLE and Direct Lithium to Product, or DLP (based on polymer containment) technologies promise to catapult the lithium recovery from present 40-45% in spodumene to a whopping 80-95% (Mckinsey, 2022) increasing net metal unit supply.

Recycling to reclaim the lithium units from the soon-to-be-discarded batteries is expected to contribute too, through new technologies (Eramet, 2023).

Table 5. Process Losses of Li units

Data : Calisaya-Azpilcueta et al., 2020

From/Source	To/Output	Li Units Lost
Hard Rock (Spodumene)	Li Hydroxide Li Carbonate	50%
Li Hydroxide	Batteries	46%
Li Carbonate	Li Hydroxide	15%
Li Carbonate	Li Chloride	10%
Li Carbonate	Batteries	5-10%
Li Chloride	Li Metal	43%
Li Metal	Batteries	50%

b) Consolidations after fragmented growth and balancing of demand-supply :

Nearly half of the projected 2030 lithium supply of 3.28 mill t.p.a. LCE (Mckinsey, 2023) is scheduled to come from new projects in the pipeline.

Balance about 0.89 millt.p.a. is from expansions, restarts and ramp-ups and confirmed projects. Fitch Solutions (2022) reported that out of a database of 105 companies running total 129 operations, only 18 had more than one mines. The relatively small presence of large and experienced mining players raises the risk of timely execution within the stipulated budget, especially in an inflationary environment. Leading players are taking this opportunity to consolidate their portfolios by acquiring proven and profitable assets.

Examples include integration activities of Tesla (Liontown Resources off take), Ford (Liontown debt facility), Stellantis (Vulcan stake), BYD China (reported acquisitions across Africa); and acquisitions of Rio Tinto (Rincon Mining, Australia project), Ganfeng (Lithea, for Argentinian brines), Zijin Mining (Jinshi Mining, Tibet salt lakes), Zhejiang Huayou (Prospect Resources Australia, for Arcadia project in Zimbabwe), etc. Junior miners began approaching automakers and large mining houses, since 2022, to fund the last stages of project, in lieu of floor-ceiling-capped offtake pricing. Albeit this reduces financing risks, country/political risks loom large on a number of projects in Argentina, Brazil, Zimbabwe, Mali, D.R. Congo, Chile, Mexico, and Peru etc. Many projects including Europe's local ones, are also facing headwinds on environmental grounds (Graham et al., 2021). Upcoming projects in mining-friendly jurisdictions, such as Australia, Canada and USA, particularly spodumene-based ones (low-gestation/low-cost/low-impurity) are at an advantageous position.

c) A Realigned Future Landscape :

Global North appears keen to achieve self-reliance and reduce China/Asia-dependency without taking on the associated environmental costs that is borne mostly by the Global South so far, Australia and China included (Riofrancos, 2023). China is at an advantage, given its timely acquisitions of low-cost resources (Altiparmak, 2022, lists the key Chinese acquisitions globally, with the investments made in each case, between 2012-21) and competitive refining and processing facilities (Altiparmak, 2022), backed by burgeoning domestic demand, while EU and USA may achieve partial self-sufficiency. Despite 17% share in ore production, China accounted for 77% of refining in 2022 (Mckinsey, 2023), and should enjoy more than 60% share till 2035 (OCE, 2023). Australia and Canada are the imminent challengers, given their low country risk, neutrality and high-quality, cost-competitive resources, while Chile and Argentina, when aided by rational governmental policies, may provide the balance.

At this juncture, at least five different economic and political forces, including glimpses of resource nationalism, are concurrently reshaping the landscape of lithium industry: a) the geo-political realignment in supply chains driven by governmental policies (USA et al.) aimed at lowering risk and vulnerability, b) backward vertical integration efforts by automakers (Tesla, VW, BYD, Toyota et al.) and battery-makers (highly concentrated: top 5 companies control above 80% capacity) to stabilise the supply chain at lowered cost and increase gains from value adding, c) similar forward integration efforts by rich miners including the new formidable entrants such as Eramet, Rio Tinto et al. (Goldman Sachs, 2022), to invest in on-site value-addition, which is deemed as the most cost-efficient model (Mckinsey, 2023), d) regulation of growth within environmental norms and societal limitations, as evident in the cases of Chile water loss issue, Australian waste disposal issue, Serbian community issue and so on (Graham et al., 2021), and e) Consolidation and alignment of the fragmented project pipeline as the market in-balance or in-surplus, leads to lowering of projected financial returns and increase in project risks. A market in surplus may drive the spot prices considerably lower, as uptakes shrink in spot.

In past, post imbalance-driven booms, mineral prices have often breached the marginal cost of production. Given the emerging steep cost curve, such stress may cause many of the capital-intensive higher cost projects to falter. During spodumene price crash (2018-19), the project pipeline showed signs of severe stress, causing delays in funding, followed by time/cost overruns etc., prompting suspensions/mothballing, exits, and latermergers/buy-outs/tie-ups.

Present process of rationalisation of growth may eventually yield an efficient, technologically superior (in terms of cost reduction, waste minimisation, recovery enhancement etc.), environmentally friendly, diversified and low-risk production landscape, which may have more varied economic profile than before (Roland, 2022), as it eliminates excessive dependency on any particular country or continent.

Vertically integrated, optimised and efficient value chains may balance the presently asymmetric profitability wherein certain intermediate players make super-normal profits and EVs need governmental subsidies to compete.

6. STRATEGIC OPTIONS FOR INDIA :

As the share of EV is slated to grow in India (Table 1), Ministry of Mines (2023), in its report on critical minerals, lists Lithium as having high economic importance and supply risk. In order to build her own supply chain, integrated or at least sourced from 'friendly' bases, and value-add locally till the final stage, India needs to act fast to secure assets, explore and develop 'inferred' ones and create onward refining to LIB-component and battery-making capabilities, perhaps through policy mandates, while investing in research to innovate better routes, including that of recycling. India has a golden opportunity to gain a toehold in this industry during the realignment of lithium value chain, to achieve self-reliance and also emerge as a green alternative to China.

7. CONCLUSION :

Lithium-Ion batteries have no known replacements yet (OCE, 2023). Lithium, therefore, may continue to play a pivotal role in global energy transition. The process of supply chain optimisation, with due governmental policy support, may establish lithium-backed green energy system as a viable and the most-preferred option in the long run.

Appendix 1. Global Lithium Availability (2023 update), Data Source: USGS, 2023

Country	Identified Resources (In Mill t)	Remarks
Bolivia	21	Inactive
Argentina	20	Active
USA	12	Active
Chile	11	Active
Australia	7.9	Active
China	6.8	Active
Germany	3.2	Upcoming
Congo	3	Upcoming
Canada	2.9	Active
Mexico	1.7	Active
Czechia	1.3	Upcoming
Serbia	1.2	Upcoming
Russia	1	Active
Peru	0.88	Active
Mali	0.84	Upcoming
Brazil	0.73	Active
Zimbabwe	0.69	Active
Spain	0.32	Active
Portugal	0.27	Active
Namibia	0.23	Active

Ghana	0.18	Upcoming
Finland	0.068	Upcoming
Austria	0.06	Upcoming
Kazakhstan	0.05	Active

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ESTIMATION OF SIDE SPALLING IN BORD AND PILLAR MINING METHOD BASED ON FIELD AND SIMULATION STUDIES

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Abstract

Side spalling of pillar (SSP) is an important issue for Bord & Pillar Mining Method (BPMM) especially during pillar extraction. Design of a larger and competent pillar does not alleviate the problem of spalling/slabbing as it is more affected by the status of overlying strata in the goaf/void than the size of pillar under depillaring. This paper has attempted to study the SSP which affects safety and productivity during pillar extraction using Continuous Miner technology in BPMM. It has affected the BPMM workings of Vakilpallimine of SCCL, Churcha mine of SECL and many more resulting, in the worst case, into premature closure of workings in a panel. Such problems will be experienced more in upcoming BPMM projects considering the favourable and bright future of underground coal mines in India with the introduction of mechanisation, especially for continuous miner technology. Field study has been carried in a couple of mine to develop an understanding about the phenomenon of SSP at different stages of workings under varying geo-mining conditions of Indian coalfields. It is also found that the strength of coal, nature of roof, depth of cover, poor caveability of strata and induced stress due to large overhang of strata in the goaf are the major factors affecting SSP. Simulation studies are also conducted on calibrated numerical models for determining the amount of side spalling, ab initio while developing pillars in a virgin coal seam.

Keywords : *Coal Pillar; Development; Depillaring; Strength; Goaf; Side Spalling*

INTRODUCTION

Development and depillaring are the two key operations in Bord & Pillar Mining Method (BPMM). Most of the underground coal mines in India have been worked out by BPMM. This method accounts for more than 98% of coal production from underground mines. It faced a number of strata control issues during depillaring since its initial days of field implementation due to different techno-economic reasons. This method remained limited mostly for development of coal pillars only which led to locking of 3.2 Bt (Dixit and Mishra 2010) of coal in pillars in different coalfields of India. Development in BPMM is an easy operation where 30-35% of coal is extracted economically without any major strata control issues. Pillar extraction (depillaring) operation in BPMM recovers maximum coal but experiences pillar spalling due to high induced stresses and roof sagging along the maximum span of diagonal line of extraction which affects the stability of the working.

Easy and cheap production of coal from opencast mining method led to less development in rock mechanics technology and mechanisation in BPMM. Mining industry was looking for suitable technology along with rock mechanics

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development to maintain safety in order to extract locked-up coal pillars and resume underground mining. Mass production technology using Continuous Miner package was first introduced in 2003 at Anjan Hill Mine of South Eastern Coalfields Limited (a subsidiary of Coal India Limited). This technology received mixed response from the industry but brought a paradigm shift in production, productivity and safety during pillar extraction. Further, it restored the faith of mining industry in underground mines and promoted coal production using underground mining methods with progress of time.

Further, the issues of design norms for different geotechnical elements (rhomboid pillars, gallery width, cut-out distance, rib/snook, roof bolts-based breaker line support RBBLS, roof span for major/local fall, caveability characteristics of roof etc.) were addressed while involving Continuous miners deployed during depillaring. Coal Mines Regulation (2017) and DGMS Circulars do not mention about the design norms of various geotechnical elements applicable during working with continuous miner. Researchers (Singh et al. 2016; Ram et al. 2017; Kumar et al. 2019a; Kumar et al. 2019b; Kumar et al. 2019c; Kumar et al. 2020; Kumar et al. 2021a; Kumar et al. 2021b; Kumar et al. 2023) have made efforts and developed a number of empirical formulations to design these structures (ribs/snooks, RBBLS, cut-out distance etc.) based on field study and parametric study over calibrated numerical models. However, extent of pillar spalling in varying geo-mining conditions of Indian coalfields is yet to be established during working with this technology especially under strong and massive nature of immediate roof which also affects the developed design of ribs/snooks and RBBLS. Width of spalling is an important geotechnical element which decides the design of rib/snook and roof bolts-based breaker line support (Kumar et al. 2023). The phenomenon of pillar spalling also indicates overhanging of roof in the goaf and impending roof fall. Prediction of roof fall is another challenge during underground coal mining. Sudden falls may lead to poor coal recovery, injuries to miners and fatal accident. Roof fall is usually followed by pillar spalling at the goaf edges showing higher values of induced stress over pillars and maximum roof sagging in the gallery around the goaf edges. Thus, the outcomes of this study will be useful in design of coal pillars, prediction of impending roof falls and design of ribs/snooks and RBBLS.

Literature Review

Design of a larger and competent pillar does not alleviate the issue of spalling/slabbing as it is more affected by the status of overlying strata in the goaf/void than its size. Brief study has also been carried out for the design of coal pillars.

Safety of a mine is determined by the stability of its coal pillars (Gao 2014). Slender pillars having width-to-height ratio less than 5 behave differently from squat pillars with width-to-height ratio more than or equal to 5 due to issues related to a confined core. The core of squat pillars experiences the confinement from the coal all along the circumference which enriches the overall pillar strength. Slender pillars do not have sufficient confinement due to absence of peripheral coal which results into reduction in pillar strength. It has been found in the field that strength of a pillar is dependent over its shape and width/volume (Salamon and Munro 1967; Brady and Brown 1985; Kumar et al., 2019). Empirically developed pillar strength formulations based on failed and stable cases have found acceptance by the mining academicians, researchers and practitioners widely (Mark 1999; Kumar et al., 2019c). However, empirical formulations have been developed considering a fixed range of variation in geo-mining parameters and its application is limited when there is difference in conditions (Kumar *et al.*, 2019c). Parametric study over calibrated numerical models in combination with laboratory testing and instrumentation and monitoring-based field investigations has gained popularity in design of geotechnical structures (Kumar et al., 2021b; Esterhuizen 2006). Sheorey (1993) recommended that the factor of safety should be more than 2 for long-term stability of a coal pillar to compensate anisotropic rock mass properties and mining dimensions.

Kumar *et al.* (2019b) mentioned about the uncontrolled pillar spalling in Mathani mine of WCL which led to goaf encroachment and ultimately, premature closure of a panel. This mine practised conventional drilling and blasting method of pillar extraction. Spontaneous heating problem was also detected in the mines due to presence of fractured coal in the goaf, leakage of air and slow-paced workings. Kumar et al. (2023) mentioned about status of side spalling in pillar during working with Continuous Miner Technology (CMT) in VK7 mine of Singareni Collieries Company Limited with difficult-caving roof having RMR value as 62. Kumar *et al.* (2023) also mentioned about status of side spalling in pillar during working with CMT in Churcha mine of South Eastern Collieries Company Limited (SECL) with difficult-caving roof having RMR value as 63.

Mechanics of Side Spalling

Coal is a sedimentary deposit and has relatively lower strength compared to other rock masses. The principal stress is vertical in majority of the cases (Seedsman 2022). Relatively, higher value of induced stresses is experienced at the goaf edges and may cause side spalling of pillar around the goaf edges, if not controlled. The side spalling of coal pillar is driven the amount of induced-stress around the goaf edges. In side spalling, sometimes, coal dislodges and separates from the actual in-situ pillar coal mass and giving to a shape of pillar sides similar to Figure 2(c). The depth of side spalling in some of the cases are mentioned in Table 1 and Figure 4. Pillar side spalling can be related to issues of structurally and stress-controlled failure resembling hourglass shapes (Figure 3 and Figure 5).

Pillars indicate instability before their failure at different stages of working. With the increase of stress over a pillar, fracturing/spalling of its sides and corners occur which may extend up to its core leading to catastrophic failure. Pillars which experience the stress beyond their strength forms an hourglass shaped failure pattern (Lunder 1994). These knowledge of instability in pillars is useful in their design and assessing the integrity of a panel. Spalling/fracturing of corners and sides of pillar is an early indication of increase in induced stress in the working. Spalling in terms of fracture occurs parallel to the direction of maximum stress. It initiates from the corners of pillar which is under uniaxial compression and therefore it becomes easy to fracture a rock in uniaxial compared to triaxial compression which is experienced by pillar core. Further, unfavourable rock joints and manual drilling and blasting practises aggravate the issue of pillar spalling. Factors like mining method (full or partial extraction), loss of confinement, stress field (high insitu + induced stress + depth + stiff and massive roof strata), seismic shock (from caving of thick and massive strata or sudden failure of strata spanning gob area or impact of massive volume of rock onto the floor) are found to be affecting the side spalling of coal pillars.

Spalling/fracturing of corners and sides results into reduction of overall size of a pillar and increase in gallery width. Sometimes, wire meshes along with roof bolts are installed in a pillar to provide confinement to the spalled zones. Continuous miner based mechanised depillaring practises installation of cuttable fibre side bolts in the pillar to avoid their spalling. Spalling is a phenomenon which occurs in presence of low confining stress and the rock fractures in a direction parallel to the major compressive stress and forms slabs (called as spalling) which can separates from the pillar and fall (Stacey, 1981) resulting into weakening of cohesive strength (Hajiabdolmajid et al. 2000). Pillar spalling can initiate at a stress lower than the compressive strength of coal (Diederichs 2002; Stacey and Yathavan 2003). It is required to estimate the lower level of stress for the commencement of pillar spalling as there are a number of hazards associated with this phenomenon. Esterhuizen et al. (2011) found initiation of spalling in stone mines when the average pillar stress is only about 10% of the UCS of the rock.

The magnitude of induced stress is related to depth of cover and stiffness of the strata. A coal pillar deforms under the induced stress caused by mining. As the confinement to the spalled pillar is increased by the installation of wire meshes along with roof bolts, it changes the frictional properties which leads to increase in cohesive strength of coal. The process of deformation during failure of coal is divided into three phases: the elastic phase, the plastic softening phase and the plastic rheological phase. Width-to-height ratio affects pillar strength and width of a coal pillar is controlled by the width of its non-elastic zone. Extent of pillar spalling will vary from flat to inclined coal seam. Wilson (1972) developed an empirical equation to estimate the non-elastic zone based on height of extraction and depth of cover of the working seam (Equation 1).

$$x_0 = 0.00492hH \qquad (1)$$

where, h is the height of coal pillar (m) and H is depth of cover (m).

Literature survey and different field investigations in Indian coalfields have found that higher value of vertical induced stress is experienced by coal pillars/fenders/ribs/snooks at the goaf edge during mechanised depillaring (MD) by CMT. This phenomenon is more pronounced when MD is being carried out under a difficult and massive roof at deeper cover. Deterioration of pillar develops in the form of non-elastic zone as side spalling on the outer part and the inner part remains under elastic zone. Further, the non-elastic part is divided into loose (spalled) zone and plastic zone (Gao, 2014) (Figure 1**.** The spalled part of pillar is almost dislodged and hanging, incapable of providing any resistance against load whereas the plastic part of pillar remains attached to the pillar which may act against a load. Thus, it results in fracturing and spalling of corners and sides of pillars, reducing overall size and strength of a pillar. It ultimately affects the size and shape of rib/snook to be left and performance of roof bolt-based breaker line support (RBBLS) and instrumentation plan considering location of instruments to be installed for strata monitoring around the goaf edges.

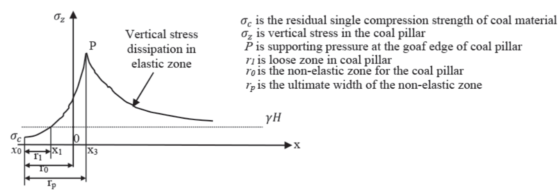


Figure 1 : Distribution of the vertical stress for the coal pillar in the limiting equilibrium state (after Suchower ska et al., 2013 and Gao and Ge, 2016).

Higher value of vertical induced stress is experienced by coal pillars/fenders/ribs/ snooks at the goaf edge during mechanised depillaring with continuous miner technology. This phenomenon is more pronounced when depillaring is being carried out under difficult and massive roof at deeper cover. Deterioration of pillar develops in the form of non-elastic zone as side spalling on the outer part and the inner part remains under elastic zone. Further, the non-elastic part is divided into loose (spalled) zone and plastic zone (Gao, 2014). The spalled part of pillar is almost dislodged and hanging, incapable to provide any resistance against load whereas the plastic part of pillar remains attached to the pillar which may act against a load. Thus, it results into fracturing and spalling of corners and sides of pillars, reducing overall size and strength of a pillar. It ultimately affects the size and shape of rib/snook to be left for the safety of depillaring operation and performance of roof bolt-based breaker line support and geotechnical instruments to be installed for strata monitoring around the goaf edges.

With the increase in depth of underground workings in Longwall Mining Method (LMM), and Bord and Pillar Mining Method (BPMM), side spalling of pillar is identified as a potential hazard and risk to underground mines. Design of pillar and method of goaf treatment (caving or backfilling) becomes an important issue during underground coal mining. Side spalling problems are less visible in backfilling technique of goaf treatment due to negligible span of hanging roof in the voids as majority of the void/goaf is backfilled with incombustible material. Problems of goaf encroachment and spontaneous heating has been found to be occurring due to side spalling during caving technique of void/goaf treatment. Unattended side spalling problems results into continuous reduction in effective load bearing width of a coal pillar and ultimately cause regional instability (coal bursts/bumps).It is not always advisable to develop an over-size pillar considering the side spalling issue.

Pillar shape is also a factor which severely affects its side spalling due to formation of acute corners at the junctions. CMT has a limitation that it cannot take sharp 90^0 turning, therefore, resulting into rhomboid shaped coal pillars. When studying coal pillar side spalling in Bord and Pillar Mining Method (BPMM), it is important to understand factors such as pillar geometry, geological conditions, stress distribution, and mining methods. Numerical modelling, laboratory testing, and field observations are commonly used techniques to estimate pillar stability and side spalling potential. In-situ pillar conditions are complex in nature; therefore, a combination of theoretical knowledge and practical experience is essential for accurate estimation and decision-making. Side spalling is therefore a complex process that involves integrating geological, geotechnical, and engineering knowledge (Figure 3). Practical experience and a thorough understanding of local geological conditions are crucial for accurate estimation.

Table 1 **:** Brief summary of side spalling experience in coal pillars of different countries using different mining methods.

Country	Mining method	Depth of side spalling in coal pillars (m)	Seam thickness (m)
South-African coal mines	Bord & Pillar	0.30 to 1.42	1.50 to 3.00
USA coal mines	Longwall face 240 m deep	20 times of extracted height -	-
0VK7 (Kumar et al. 2021)	Bord & Pillar	0.16	5.5
Churcha mine (Kumar et al. 2021)	Bord & Pillar	3.00-6.00	4.8

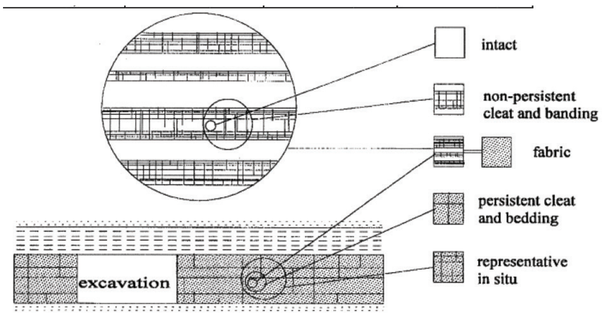


Figure 2 : Status of coal at different scales in an underground working (after Trueman and Medhurst 1994).

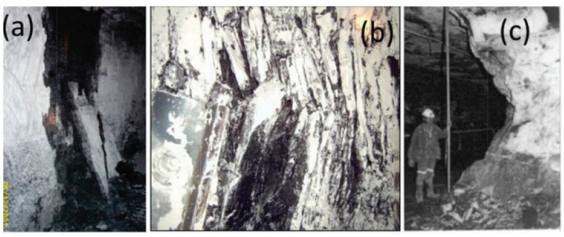


Figure 3: Side spalling of coal pillars in different conditions (a) unbolted coal pillar at 60 m depth with UCS of 10 MPa; (b) bolted pillar at 400 m depth with UCS of 15-20 MPa and (c) spalled coal pillar in a South African coal mine. (after van der Merwe 2004)

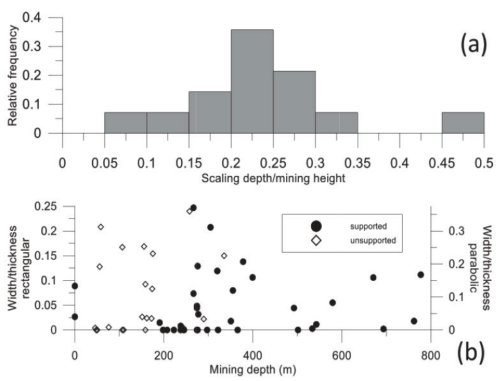


Figure 4 : (a) Ratio of spalling depth to seam height for South African coal pillars from van der Merwe (2016) and (b) same data for USA mines from Mohamed et al. (2016)

(a) Underground limestone mine (Esterhuizen 2011).

(b) Underground coal mine

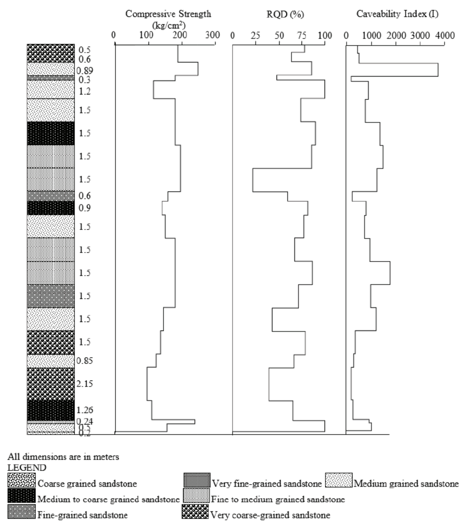


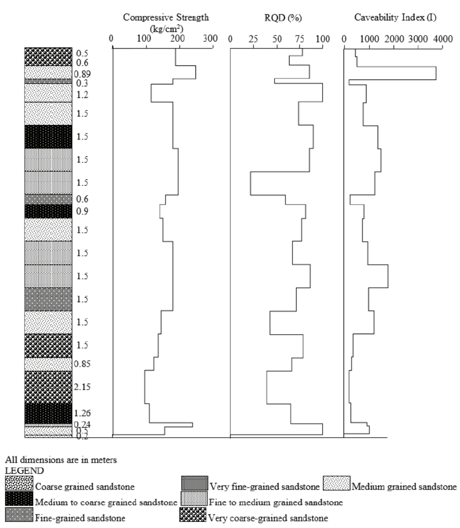
Figure 5 : Stone and coal pillar exhibiting hourglass failure shape due to elevated stress leading to continuous side spalling.

Field Study

Brief study of side spalling of pillar in VK7 of SCCL and Churcha mines of SECL are presented. Geo-manning conditions and details of method working is mentioned in Table 2.

Table 2 : Geo-mining details of respective panels of VK7 and Churcha mine.

Parameter	VK7	Churcha
Name of the seam	King seam	Seam-V
Seam thickness, m	7.9	3.0-4.5
Gradient of seam	1 in 8	1 in 10-20
Depth of cover, m	330-410	341
Panel length (m)	225	450
Panel width (m)	180	225
Number of pillars	20	50
RMR	62	62
Immediate roof	Grey sand-stone	Massive sandstone
Caving nature	Extremely difficult	Extremely difficult
Immediate floor	Coal	Sandstone
Pillar size (centre to centre), (m x m)	45 x 45	45 x 45
Original gallery width, m	4.5	4.5
Working height, m	4.5	4.6
Cut-out distance, m	15	15
Breaker line support	3 rows of RBBLS	2 rows of RBBLS



Details of borehole lithology of both the mines are shown in Figure 6 & Figure 7. Manner of pillar extraction for both the mines is shown in Figure 8 & Figure 9. The shapes and sizes of rib/snook in both mines are shown in Figure10 & Figure 11.

Site conditions of CM panels at VK7 were observed to be difficult. The roof collapse in the CM panel initially occurred mainly due to poor understanding of the overlying roof strata and presence of barrier pillar of overlying longwall worked-out panel at the accidental site. Subsequently, there was an apprehension about the adoption of the partial extraction and its field trial also encountered strata control problems. High depth of cover and presence of competent roof strata at VK7 created a difficult geo-mining conditions for the depillaring. However, the adopted partial extraction created even more challenging conditions and, ultimately, full caving is adopted for the conditions. Heavy spalling in the pillar created issue in observation of induced stresses in the panels as stress meters could not work in fractured zone. Side spalling in coal pillar is observed to be 3-6 m towards outbye side from the goaf edge which further affected the proposed design and FOS of the rib/snook in the panels. VK7 mine installed 4-way rib extensometers and anchored it at distance of 4 m, 6 m, 8 m, and 10 m in the pillar. Maximum rib dilation of 160 mm was recorded in the pillar due to high induced stresses. The zone wise observed dilation was 78.4 mm for zone1 (0 to 4 m), 75.6 mm for zone 2 (4 to 6 m), 4.10 mm for zone 3 (6 to 8 m) and 4.10 mm for zone 4 (8 to 10 m). Area of rib/snook left in the panels worked satisfactorily and did not inhibit the caving.

In case of Churcha mine, spalling in coal pillar is observed to be 3-6 m towards outbye side of the goaf edge. Heavy spalling in the pillar created issue in observation of induced stresses in the panels. It also affected the proposed design and FOS of the rib/snook in the panels.

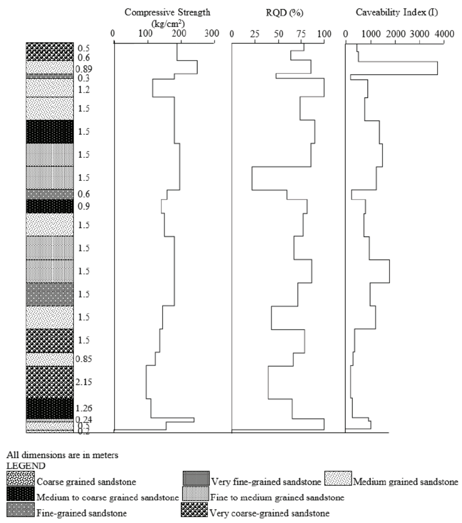
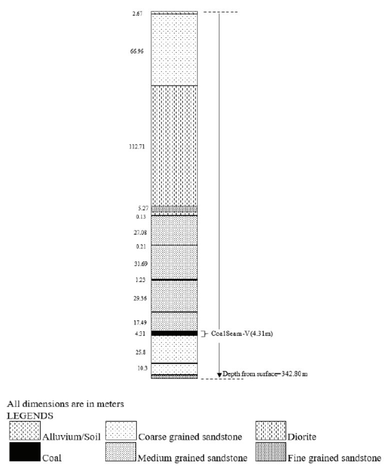
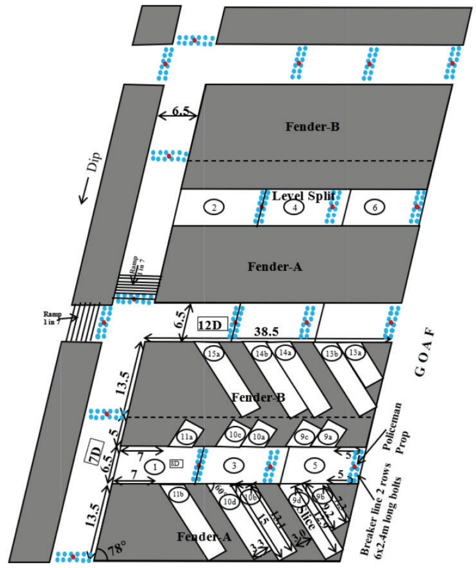


Figure 6 : Borehole lithology and physico-mechanical properties of roof formation of King seam of VK7 mine.



All dimensions are in meters

Figure 7 : Roof and floor formations of coal seam of Churcha mine RO.



All dimensions are in meters

Figure 8 : Manner of extraction adopted in VK7 mine.

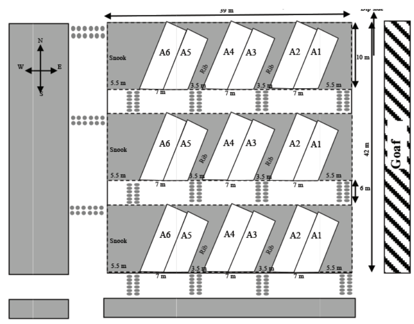


Figure 9 : Manner of pillar extraction in a panel of Churcha mine RO.

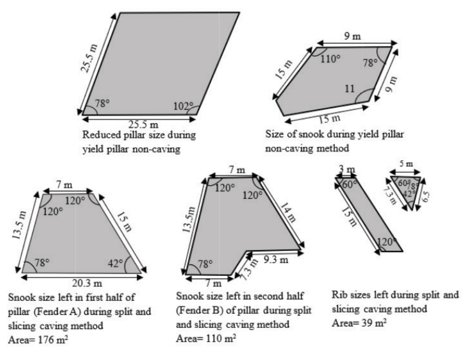
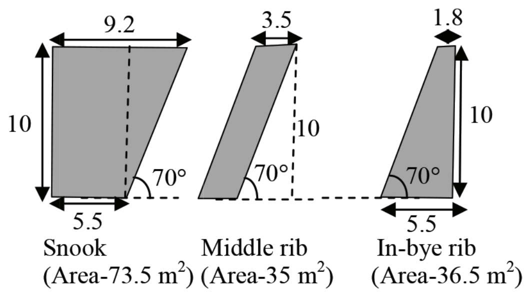


Figure 10 : Different shapes of rib/snook left during MD using CM at VK7 mine.



All dimensions are in meters

Figure 11 : Different size and shape of snook, middle rib and in-bye rib at Churcha mine RO.

Numerical Simulation Study

Simulation studies are shown for the development of rhomboid pillars (acute angle corners) in a virgin mine CMT. Pillar design study has been carried out considering elastic model of FLAC3D package. In-situ stresses are simulated according to following equations :

$$\sigma_v = 0.025\,H \quad \text{MPa} \quad (2)$$

$$\sigma_H = \sigma_h = 2.4 + 0.01H \;\; \text{MPa} \quad (3)$$

where, H = depth cover in meter, σ_v = Vertical in-situ stress, σ_H= Major horizontal in-situ stress and σ_h= Minor horizontal in-situ stress.

In order to assess the stability of natural supports and the exposed span, safety factors are calculated using CSIR-CIMFR failure criterion in the numerical models as given below :

$$\sigma_1 = \sigma_{cm}\left(1 + \frac{\sigma_3}{\sigma_{tm}}\right)^{b_m} \quad \text{MPa} \quad (4)$$

$$\sigma_{cm} = \sigma_c e^{\frac{RMR-100}{20}} \text{MPa} \quad (5)$$

$$\sigma_{tm} = \sigma_t e^{\frac{RMR-100}{27}} \quad \text{MPa} \quad (6)$$

$$b_m = b^{\frac{RMR}{100}} \quad b_m < 0.95 \quad (7)$$

where, σ_1= triaxial strength of rock mass (MPa), σ_3= confining stress (MPa), σ_c= compressive strength of intact rock (MPa), σ_t= tensile strength of intact rock (MPa), b= exponent in failure criterion, which controls the curvature of triaxial curve, σ_{cm}= compressive strength of rock mass, MPa and σ_{tm}= tensile strength of rock mass, MPa, RMR = Bieniawski (CMRI) Rock Mass Rating.

The factor of safety is defined as

$$SF = \frac{\sigma_1 - \sigma_{3i}}{\sigma_{1i} - \sigma_{3i}} \text{when} \sigma_{3i} < \sigma_{tm} (8)$$

$$\text{Otherwise, } SF = \frac{-\sigma_{tm}}{\sigma_{3i}} \text{ when } \sigma_{3i} > \sigma_{tm} (9)$$

where, σ_{1i}= induced major principal stress (MPa) and σ_{3i}= induced minor principal stress (MPa).

Rhombus shaped pillar is developed with different acute angle corners and gallery width. Gallery width is decided based on encroachment of higher value of vertical stress and also less value of safety factor contours shifting towards the core of the pillar. It is found that pillar width with 6m gallery width is more stable comparison to 6.5m and 7.0m gallery width (Figure 12, Figure 13 & Figure 14). Also, it is found that the rock load height (RLH) is minimum for the pillar with 70^0 acute corners and 6.0m width gallery.

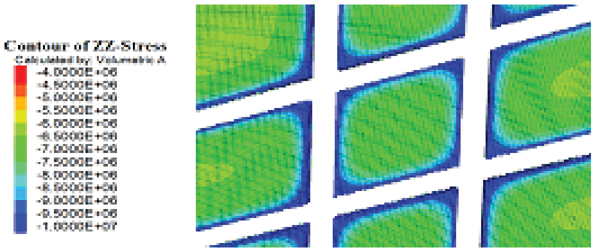
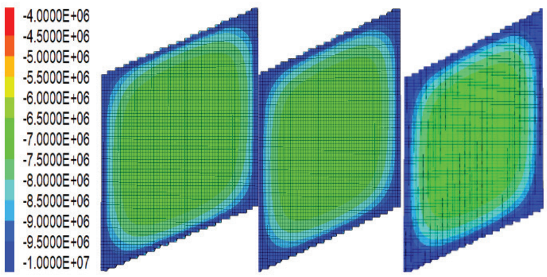
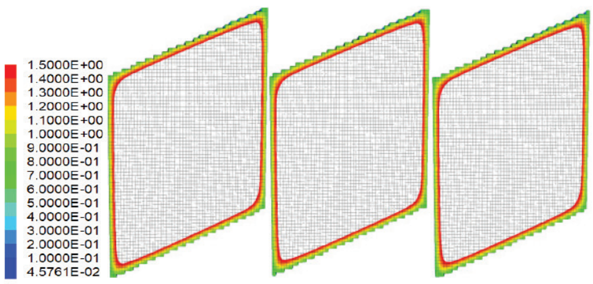


Figure 12 : Rhomboid pillars with 70⁰ acute corners and gallery development in a virgin mine using continuous miner technology.



(a) 6.0m (b) 6.5m (c) 7.0m

Figure 13: Vertical stress distribution on rhombus pillar with 70° acute corners and different gallery widths.



(a) 6.0m (b) 6.5m (c) 7.0m

Figure 14 : Safety factor contour on rhombus pillar with 70°acute corners and different gallery widths.

Discussion

Developed pillars is locked-up to a value around 3200 Mt of coal in Indian coalfields (Dixit and Mishra 2010). These pillars need to be extracted-for depillaring the lower coal-seam horizons. CMT has proved its potential in the extraction of coal at a faster rate in BPMM. It has also become the priority of mining industry; therefore, a number of mines have started introducing CMT for the purpose. Galleries width of less than 5 m needs to be widened and reduction of pillar corners are required for easy manoeuvrability of the cutting machine (CM). Therefore, extra rock bolts supportare to be installed at the corners, junctions and roadways (Figure 15 & Figure 16). Reduction of corners and spalling due to increased induced stress affects the proposed design of rib/snook (Figure 17). It is required to consider the reduction of corners and spalling while planning for the design of rib/snook in a given geo-mining condition.

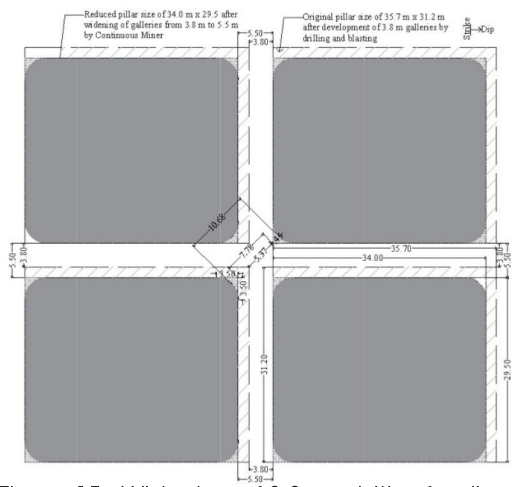
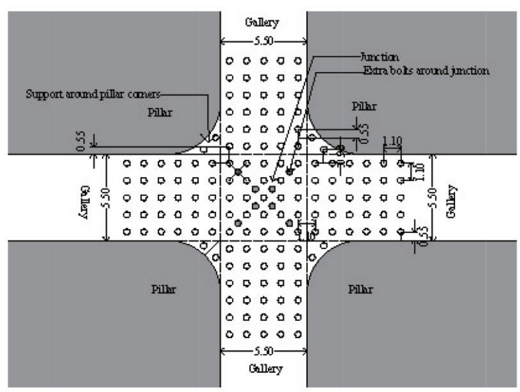


Figure 15 : Widening of 3.8 m width of gallery to 5.5 m for adaptability of Continuous Miner machine.



All dimensions are in meters (to-the scale)

Figure 16 : Proposed support plan in the widened gallery with curved corner of pillars for turning of continuous miner machine.

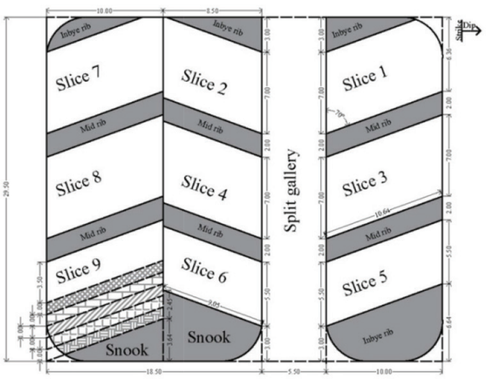


Figure 17 : Curve corners and spalling affecting the design of rib/snook.

Conclusions

This paper has described the importance of estimation of spalling and factors affecting it. Field study has been conducted and used the empirical relationship and simulation study for measurement of side spalling in the pillar. Further, it also mentions about the relation of side spalling of pillar with prediction of roof fall and hanging span in the goaf. A comprehensive detailed study is required for prediction of pillar spalling in Bord and Pillar and Longwall mining method in Indian coalfields with varying geo-mining conditions. Monitoring of spalling with the help of geotechnical instruments at different stages of workings will help in estimation of hanging overlying strata in the goaf and understanding the mechanics of roof-pillar interaction at different stages of workings and varying treatment of goaf techniques (caving/stowing)

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APPLICATION OF ARTIFICIAL INTELLIGENCE TO CREATE VIRTUAL COPY OF PHYSICAL MINE TO ENHANCE PRODUCTIVITY, SAFETY AND PROFITABILITY

Badal Manna*

Abstract

Coal is the main source of energy and contributes about 70% of the overall power generation of our country. In 2022-23, India's coal production was 893.08 MT and Coal India alone produced 703.21 MT of coal. Out of the total coal produced by Coal India, about 94 to 95% is being mined by opencast mining. Many large opencast mines with peak annual capacity up to 70Mty are being operated to meet the high demand for coal. The application of Artificial Intelligence in all large mines should be a must and not an option for better controlling and monitoring. A virtual copy of the physical mine may be created through the application of Artificial Intelligence and it would help to monitor all the work activities through a Centralized Mine Control Room(CMCR) situated beside the mine entry point just like the Air Traffic Control Room (ATCR). It would enhance productivity, safety and profitability for large as well as small mines. The creation of a virtual copy (digital Twin) of a physical mine through the application of Artificial Intelligence would help to make the working cycle work faster and be more efficient. It increases the effective productive hours, tech-based safety and profitability of the mine.

Keywords : *Artificial Intelligence, Digital Twin technology, Integrated mine digitalization, IoT Automation, Centralized Mine Control Room*

1. INTRODUCTION

Coal is a crucial source of energy for India, used primarily for electricity generation and industrial processes. Open-cast mining contributes significantly to the nation's energy needs. Coal is the main source of energy and contributes about 70% of the overall power generation of our country. In 2022-23, the coal production of India was 893.08 MT and Coal India itself produced 703.21 MT of coal. Out of the total coal produced by Coal India, about 94 to 95% is being mined by opencast mining. The Indian mining industry has adopted modern technologies and equipment to enhance efficiency and safety in open-cast mining operations. This includes the use of large excavators, haul trucks, and advanced surveying and monitoring systems. India is gradually shifting towards cleaner and more sustainable energy sources, but coal still plays a significant role in its energy mix. The government has taken several initiatives to improve the efficiency of coal-fired power plants and reduce emissions. Open-cast coal mining continues to be a vital component of India's energy and industrial sectors. Balancing the need for coal with environmental and safety concerns is an ongoing challenge, and efforts are being made to make the mining process more sustainable and environmentally responsible.

The creation of a virtual copy (digital Twin) of a physical mine through the application of Artificial Intelligence would help to make the mining process efficient, more sustainable and environmentally responsible. It would make the working cycle work faster and be more profitable. It increases

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the effective productive hours, tech-based safety and profitability of the mine.

2. MINE DIGITALISATION

Mine digitalization refers to the integration of digital technologies and data-driven solutions into various aspects of mining operations to improve efficiency, safety, and decision-making. This transformation has become increasingly important in the mining industry to optimize processes, reduce costs, and ensure sustainable resource extraction. Figure1 shows the pictorial conceptualised view of a mine digitalisation.

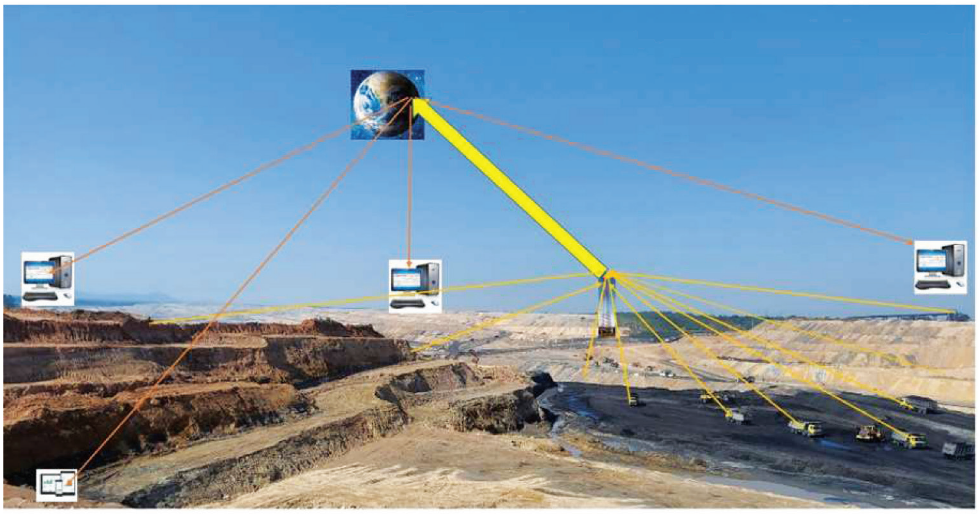

Fig. 1 : Pictorial conceptualised view of a Mine Digitalisation.

Some key aspects of a mine digitalization are given below :

(i) **Automation :** Automation of mining equipment, such as autonomous haul trucks and drilling rigs, allows for continuous and efficient operations. These machines may be equipped with sensors and GPS technology to operate without direct human intervention.

(ii) **Data Collection and Analysis :** Sensors and IoT (Internet of Things) devices are used to gather real-time data on various parameters, including equipment health, geology, and environmental conditions. Advanced analytics and machine learning are applied to this data to make informed decisions and predict maintenance needs.

(iii) **Remote Monitoring :** Remote monitoring allows mining operators to oversee operations from a central control room, reducing the need for on-site personnel. This enhances safety and minimizes exposure to hazardous conditions.

(iv) **Digital Twin Technology :** Digital twin technology creates virtual replicas of mining operations, enabling simulations and optimizations before implementing changes in the real mine. It enhances planning effectiveness and better decision-making.

(v) **Mine Planning and Optimization :** Digital tools and software are used for mine planning, scheduling, and optimization. This includes resource modelling, reserve estimation, and production planning to maximize the efficient extraction of coal.

(vi) **Safety Enhancements :** Digitalization contributes to safety by monitoring worker health and safety conditions, implementing collision avoidance systems, real-time slope stability monitoring and providing emergency response capabilities.

(vii) **Environmental Monitoring :** Environmental sensors and monitoring systems help track the impact of mining activities on the environment, ensuring compliance with regulations and sustainable practices.

(viii) **Supply Chain and Logistics Optimization :** Digitalization extends to supply chain management, optimizing the transportation of coal from the face to the pit top and beyond.

(ix) **Energy Efficiency :** Digital solutions can help manage and optimize energy consumption in mining operations, reducing costs and environmental impact.

(x) **Digital Skills and Workforce :** The adoption of digital technologies in mining necessitates a skilled workforce proficient in data analytics, automation, and technology management.

Mine digitalization offers numerous benefits, including improved safety, increased productivity, reduced environmental impact, and better resource management. It is a crucial step toward making mining operations more sustainable and efficient in the modern era.

3. IMPROVEMENT IN HEMM PERFORMANCE

Improving Heavy Earth Moving Machinery (HEMM) productivity through IoT automation involves a comprehensive analysis of data and processes to identify areas for enhancement. IoT automation can improve mining HEMM productivity as follows:

(i) **Real-Time Monitoring :** Operators and analysts have access to real-time data through a centralized dashboard. They can monitor the status and performance of HEMM equipment in real-time, identifying issues as they arise. HEMM operators are allocated autonomously by the system to increase shift productive hours.

(ii) **Predictive Maintenance :** By analysing historical and real-time equipment data, machine learning algorithms can predict when maintenance is needed. This allows for proactive scheduling of maintenance activities during planned downtime, reducing unexpected equipment failures.

(iii) **Fuel Efficiency Analysis :** Fuel consumption data is analysed to identify areas for improvement. This may involve optimizing engine settings, suggesting more fuel-efficient routes, or identifying opportunities to reduce idle times.

(iv) **Load Management Optimization :** Data on load status and weight distribution are used to optimize load management. Operators can ensure that HEMM equipment is carrying the maximum safe payload, reducing the number of trips required.

(v) **Route Optimization :** Data on equipment location and traffic within the mine are analysed to optimize routes and minimize travel times. This can reduce fuel consumption and improve overall productivity.

(vi) **Safety Enhancements :** IoT data is used to monitor equipment and environmental conditions for safety purposes. Alarms and automated shutdowns can be triggered when unsafe conditions are detected, ensuring the well-being of operators.

IoT automation in mining HEMM productivity improvement involves a holistic approach that encompasses operator allocation, data collection, analysis, predictive maintenance, route optimization, safety enhancements, and continuous improvement initiatives. By leveraging IoT technology and data-driven insights, mining companies can enhance productivity, reduce costs, and operate more sustainably in the long term.

4. POWER MANAGEMENT THROUGH IOT AUTOMATION

Power management through IoT automation involves the use of smart devices and sensors to monitor and control electrical systems efficiently. This approach helps optimize energy consumption, improve reliability, and reduce costs. The overview of power management through IoT automation isgiven as follows:

(i) **Energy Monitoring:** IoT sensors are installed on various electrical equipment, including transformers, generators, motors, and lighting systems. These sensors continuously collect data on energy consumption, voltage levels, current flow, and other relevant parameters.

(ii) **Load Management:** IoT automation can optimize load management by monitoring and controlling the operation of electrical devices. For example, it can automatically adjust HVAC (heating, ventilation, and air conditioning) settings based on occupancy or weather conditions to reduce energy waste.

(iii) **Fault Detection and Alerts:** IoT automation can quickly detect faults or anomalies in electrical systems and send alerts to maintenance teams. This proactive approach minimizes downtime and enhances system reliability.

(iv) **Remotely Control:** In some cases, IoT automation allows for remote control of electrical equipment. For instance, lighting, HVAC systems, or industrial processes can be adjusted remotely to conserve energy when necessary.

Overall, power management through IoT automation offers businesses and organizations a powerful tool for optimizing energy usage, reducing operational costs, and minimizing their environmental footprint. It enables more sustainable and efficient energy management practices across a wide range of industries and applications.

5. MINE DIGITALISATION IN GEVRA OC–A CASE STUDY

The Gevra Open Cast (70.0Mty) project is one of the largest coal mining projects in India. It is located in the Korba district in the state of Chhattisgarh. The Gevra OC project is operated by South Eastern Coalfields Limited (SECL) of Coal India Limited. Gevra OC primarily produces non-coking coal, which is used for power generation and various industrial purposes. The project involves a large volume of OB removal to expose coal for its extraction. It employs large machinery and belt conveyors for excavation and transportation. The Gevra OC project plays a significant role in meeting India's coal demand, particularly for thermal power generation. It has undergone expansions and modernization to enhance its coal production capabilities over the years.

Gevra OC 70Mty is very vast in its operational area and it has a quarry area of about 2600 Ha with a working strike length of upto 9.0 km. Many mining machinery like Shovels, dumpers, dozers, drills, tippers, belt conveyors, pumps etc are working in the vast quarry area. In addition, there are lot of pit top surface infrastructures like CHP, SILO, Railway siding, number of substations etc.Figure2 shows the planshowing the Silo, CHP, and Loadout coal evacuation infrastructure of Gevra OC.

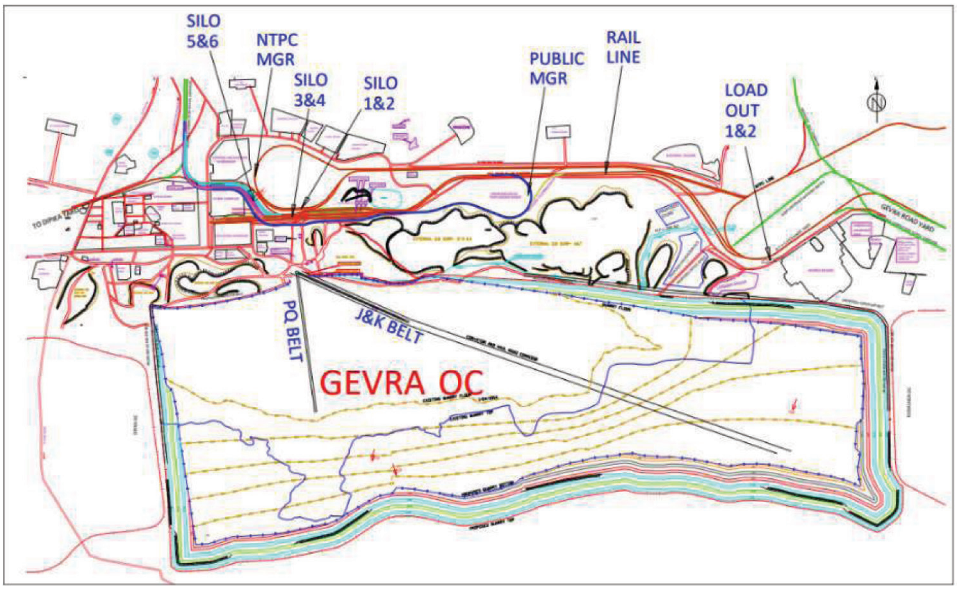

Figure 2 : Plan showing Gevra OC Silo, CHP, Loadout Infrastructure.

6. INTEGRATED MINE DIGITALISATION CONCEPT MODEL

Integrated mine digitalization towards Industry 4.0 is a customised concept model to monitor all the mining activities through a Centralized Control Room situated beside the mine entry point just like the Air Traffic Control Room. The Centralized Control Room should have all the modern facilities with sufficient space to accommodate all controlling display units. Most of the physical activities like attendance capturing, allocation of man to machine/HEMM, allocation of dumper to Shovel etc will be done autonomously based on a stored database and displayedin a digital display unit placed inthe Centralized Control Room.

The shift manager will get all the information of the physical mining activities to a digital world to monitor any operations centrally. All this information will also be stored in a server to retrieve any information later on. All this information will also be available to all senior officials as and when required to take any decisions about it. All the activities which are required to run the mine starting from land acquisition to final delivery of coal should be covered in Integrated mine digitalization to get maximum benefit from it. In Integrated mine digitalization each and every activity of mine operations may be covered in one go or different phases. The activities that should be covered in Integrated mine digitalization are as follows :

(i) **HEMM Management System:** In Gevra OC, the total department HEMM deployed is about 263 including OB removal and Coal extraction. There are additional auxiliary HEMMs which are plying at different locations in the quarry area. In Integrated mine digitalization, the system would allocate operators based on the stored database automatically to different HEMMs like dumpers, shovels, dozers, cranes etc. It would display through the display board about the health condition of HEMM like fuel level, battery level etc. It would display the health condition of HEMM to the workshop mechanic also. It would store the path movement details of HEMM for each trip. At any time the path movement details of the dumper may be re-displayed depending on the requirement.

(ii) **Human Resource Management System:** It will capture the attendance of all 2300 Human Resources of Gevra OC through thumb attendance capturing or face recognition system for each shift. It will allocate operators automatically to different HEMM and also allocate manpower to workshops, substations, CHP, Silo, pumps etc. It will show the location of individual employees at any specific time through RFID RFID-based tracking system.

(iii) **Coal Transportation Management System:** In Gevra OC, the Belt conveyor of Series J&K, L&R, PQ, D, AB and G series which are working at different locations of the quarry area. Number of SILOs 1&2, 3&4, 5&6 and Loadout 1&2 which are operating at different locations of infrastructures area. The System enabled for remote operation and control of the entire CHP and belt conveyor with the PLC System and will be monitored through the Central Control Room. All the parameters like running hours of the belt conveyor, TPH, vibration monitoring at CHP and motor health condition etc will be captured and displayed in the Central Control Room. It will help for any preventive maintenance of CHP, belt conveyor and CHP motors to avoid any production loss due to breakdown. Figure 3 shows the schematic diagram of the Silo, CHP, and Loadout coal evacuation infrastructure of Gevra OC.

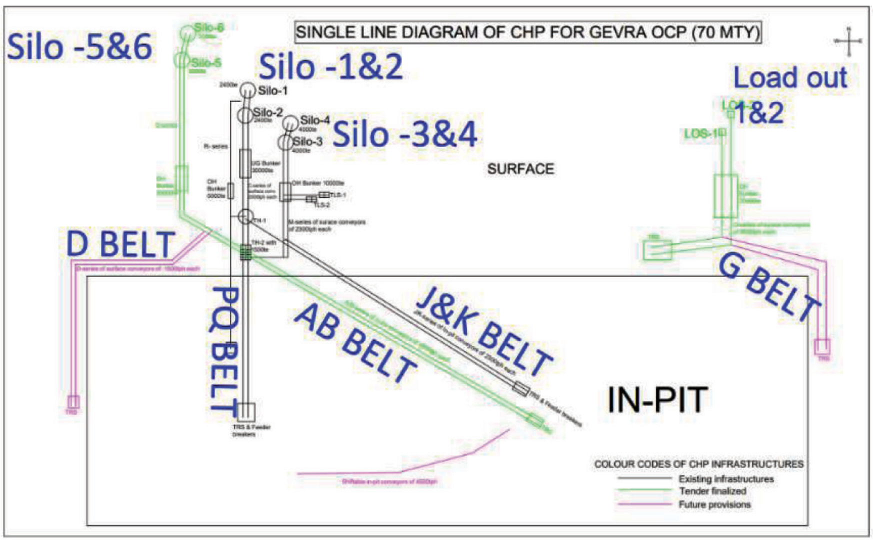

Figure 3 : Schematic Diagram of Silo, CHP and Loadout Infrastructure.

Table 1 : Silo/Loadout and annual capacity

Silo/Loadout	**Capacity (Mt)**
MGR SILO 1&2	15.00
SILO 3&4	10.00
SILO 5&6	30.00
Load Out 1&2	20.00
TOTAL	**75.00**

(iv) **Coal Dispatch Management System :** In Gevra OC, a number of silo and loadout systems are working to dispatch coal. The coal Dispatch Management System enables the remote operation of the coal dispatch system. It will capture the actual loading time, per wagon weight of coal, coal quality, Temp, viscosity and pressure of Hydraulics used in the coal dispatch system and will be displayed at the Central Control Room. It will help for any preventive maintenance of the silo, pre-weigh system, and loading system of coal to avoid any production loss due to breakdown. The Silo/Loadout system of Gevra OC and its annual capacity has been shown in Table 1.

(v) **Power Management System :** In Gevra OC, there are one 220kv Substation, one 232kv Substation and three 33kv Substations which are operating at different locations of the infrastructure area. The Power Management System enables the remote operation and control of the power supply system. The health of all electric motors used in mines may be monitored like Motor current, temp, bearing vibration level, etc. It will help for any preventive maintenance to avoid any production loss due to breakdown.

(vi) **Safety Management System :** In Gevra OC, there is one continuous slope monitoring system, about 21 number of 225lps pump and about 43 number 190lps pump which are operating at different locations of the quarry area. Real-time slope stability monitoring system may be connected to the Central Control Room to monitor Strata movement information and graphical presentation of captured data. The alarm may be set for any Strata movement that reaches the danger level. Remotely operated mine water and pumping management system may be implemented through continuous sensor-based monitoring by generating continuous information about water level readings at sumps and nearby nala that may endanger mine working. The alarm may be set for any water danger level. It will monitor the health condition of pumps, running hours, water discharge quantity etc.

(vii) **Environment Management System :** The total project area of Gevra OC is about 4700 Ha. For monitoring of environmental parameters for such a large area, automatic sensor-based monitoring of environmental parameters may be implemented. All environmental parameters like PM10, PM2.5 etc would be monitored through the automatic sensor-based monitoring system. Based on the requirement automatic dust suppression system through a fixed water sprinkler would be activated.

(viii) **Land Acquisition Management System:** The total project area of Gevra OC is about 4700 Ha. Digital land acquisition process may be implemented through digitisation of land records like quantity of land, owners and their family details etc. Drone-based aerial survey data generation may be conducted at regular intervals to detect encroachment.

(ix) **Drill and Blast Management System:** The performance of drilling and blasting may be monitored through dashboard system by optimising blast hole design, charging and sequence of blasting. It will also use image analysis of post-blast material for fragmentation monitoring.

7. FINANCIAL BENEFIT ANALYSIS

Application of IOT automation would increase productivity and production from mine and it would increase production level of about 5 to 10%. In Gevra OC produced coal of 52.5 Mt in the year 2022-23. In 2022-23 coal production, cost of production, average selling price and profit are given in Table 2.

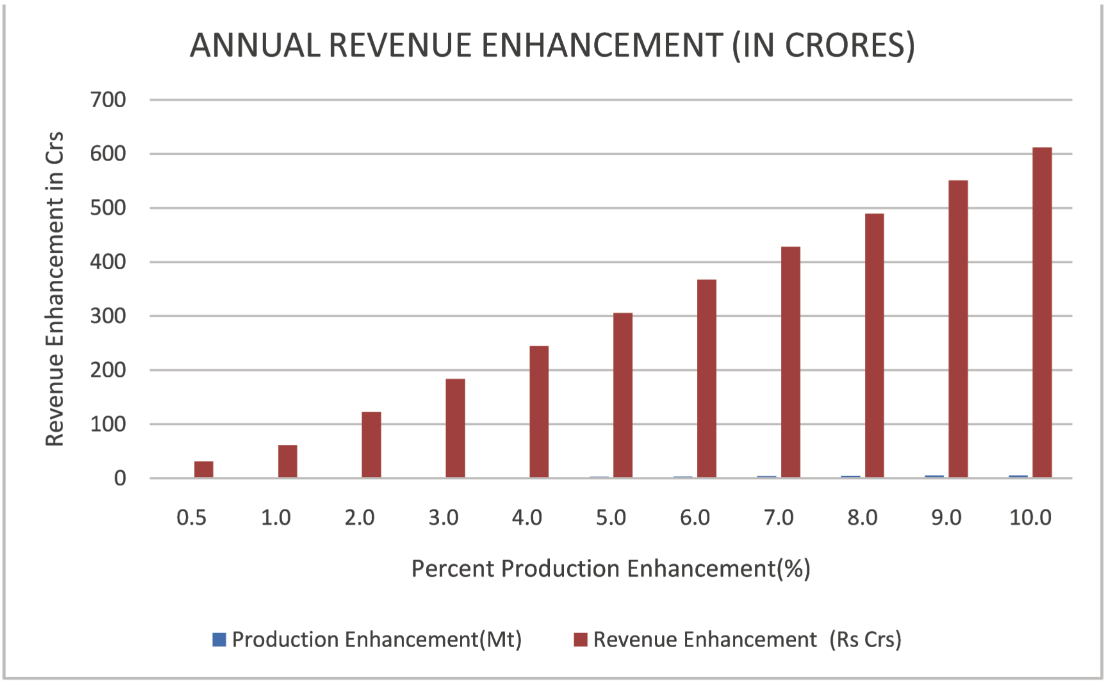

Figure 4 : Graphical representation of annual production enhancement percentage vs annual revenue enhancement.

Table 2 : Production and Earnings of Gevra OC in 2022-23.

Sl	Particulars	Unit	Value
1	Coal production	Mt	52.50
2	OB removal	Mcum	69.07
3	Cost of production	Rs/t	586.51
4	Average selling price	Rs/t	1165.20
5	Profit	Rs/t	587.60

Projected Revenue Enhancement Analysis : Present production of Gevra OC is 52.50Mt in 2022-23. With the application of IOT automation, if only 0.50% production enhancement is made the annual coal production would be enhanced by about 0.2625 Mt and the projected annual revenue of the mine would be enhanced by about 30.5865 crores. Similarly, if a 10% production enhancement is made the annual coal production would be enhanced by about 5.25 Mt and the projected annual revenue of the mine would be enhanced by about 611.73 crores. The projected annual production enhancement percentage from 0.50% to 10% with the corresponding projected annual revenue enhancement of mine has been shown in Table 3.

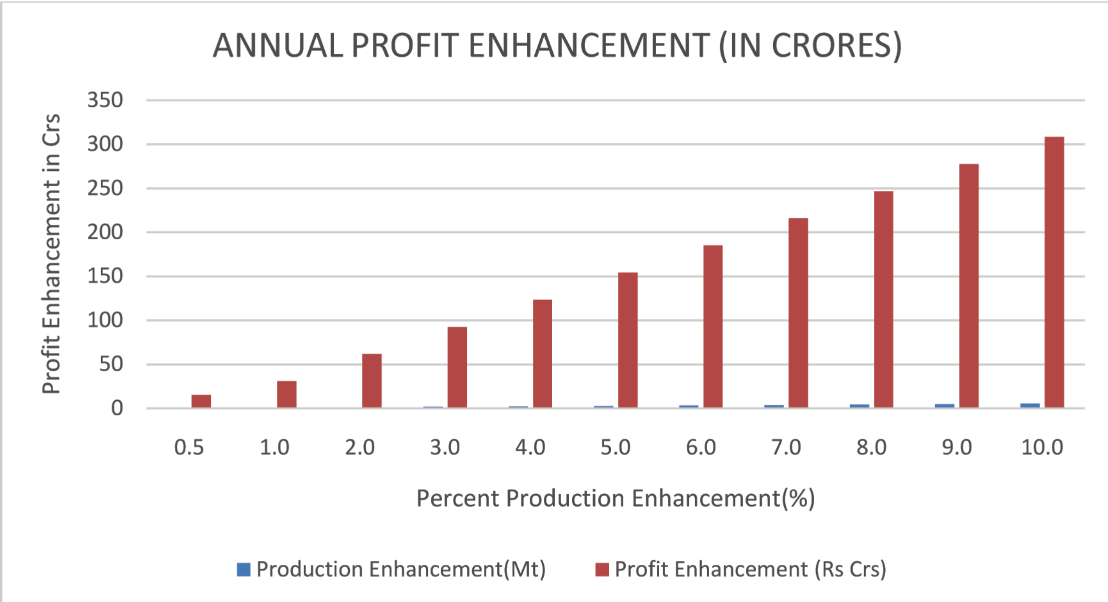

Figure 5 : Graphical representation of annual production enhancement percent vs. annual profit of mine enhancement

Table 3 : Projected production per cent enhancement and annual revenue enhancement

Production Percent Improvement	Annual Production Enhancement(Mt)	Annual Revenue Enhancement (Rs Crs)
0.5	0.2625	30.5865
1.0	0.525	61.173
2.0	1.05	122.346
3.0	1.575	183.519
4.0	2.1	244.692
5.0	2.625	305.865
6.0	3.15	367.038
7.0	3.675	428.211
8.0	4.2	489.384
9.0	4.725	550.557
10.0	5.25	611.73

Projected Profit Enhancement Analysis : With the application of IOT automation, if only 0.50% production enhancement is made the annual coal production would be enhanced by about 0.2625 Mt and the projected annual profit of the mine would be enhanced by about 15.42 crores. Similarly, if a 10% production enhancement is made the annual coal production would be enhanced by about 5.25 Mt and the projected annual revenue of the mine would be enhanced by about 308.49 crores. The projected annual production enhancement percentage from 0.50% to 10% with the corresponding projected annual profit enhancement of mine has been shown in Table 4.

Table 4: Projected Production Percent Enhancement and Annual Profit Enhancement

Production Percent Improvement	Annual Production Enhancement(Mt)	Annual Profit Enhancement (Rs Crs)
0.5	0.2625	15.4245
1.0	0.525	30.849
2.0	1.05	61.698
3.0	1.575	92.547
4.0	2.1	123.396

5.0	2.625	154.245
6.0	3.15	185.094
7.0	3.675	215.943
8.0	4.2	246.792
9.0	4.725	277.641
10.0	5.25	308.49

8. CONCLUSIONS

Every technology has some challenges and it should be faced and managed to take its benefits. The creation of a virtual copy (digital Twin) of a physical mine through the application of Artificial Intelligence would help to make the working cycle work faster and be more lucrative. It increases the effective productive hours of every working shift.

It may be noted that with the application of IOT automation in Gevra OC, if only 0.50% production enhancement is made the annual coal production would be enhanced by about 0.2625 Mt and the projected annual profit enhancement of the mine would be about 15.42 crores. Similarly, if a 10% production enhancement is made the annual coal production would be enhanced by about 5.25 Mt and the projected annual revenue enhancement of the mine would be about 308.49 crores. A similar profit enhancement study may be made for any other mine also.

The creation of a virtual copy (digital Twin) of a physical mine through the application of Artificial Intelligence, ensures smooth tech-based safety enhancement and reduces accidents and the company's overhead expenses. It makes human resources more self-motivated, energetic and more productive. It reduces the downtime of equipment, minimizes the cost of production and increases the profitability of the mine.

9. ACKNOWLEDGEMENT

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USING DATA ANALYTICS TO MEASURE SUCCESS

Toby J. Cressman

Abstract

Data analytics are key to managing a successful mine. They can provide a window into observing when first cuts are being made, shuttle car loading times, haulage travel times, productivity, utilization and more. This can all be trended by section and crew for longer term analysis of section and operator performance. This data can be used to coach and train operators on best operating practices to improve overall mine productivity. When changes are required at a mine, these analytics can also be used to support the change management process and continuous improvement.

Data can be used for more than just increasing production. Smart Solutions provides access into machine parameter reports, maintenance reports, and an alarm and event viewer. This can assist in remote trouble shooting by mine personnel, Komatsu's regional Service team, and Komatsu's engineering team sitting around the globe reviewing machine performance to best assess and diagnose any ongoing field issue to reduce downtime and get machines back up and running efficiently.

Keywords

Data Analytics, Smart Solutions, Continuous Miner, CM, Automation, Remote Health Monitoring

INTRODUCTION

Data analytics is playing an increasingly vital role globally in how mines are managing their operations. Komatsu's Smart Solutions is a service that can assist mines transform machine data into meaningful information. This information can be used to make short-, mid-, and long-term decisions. The data ranges from basic information like when first cuts were made on a given shift, to more calculated information showing current batch haulage travel and load times. This information can help guide the decision-making process that will help in optimizing mine performance, achieve the lowest cost per ton and enhance safety. This information is also commonly used to assist in the implementation of new technologies and help guide change management discussions. Thanks to the increasing amount of data and information available in real time from our equipment, this is now more achievable than ever. At Komatsu, it has become increasingly critical to leverage our technology and data to rapidly increase onsite insights, powering data-based decision making essential to today's modern mining operation.

2. THE TECHNOLOGY

To extract data off the machine, Broadband Power Line Modems (BPLMs) are used. From the machine, data is transferred to the power center where it is taken via fiber from the power center to the surface. Once on the surface, a specific surface PC (can be virtual) is set up where the data is split and a version is sent to the cloud for

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secure storage and a version is stored locally on a mapped drive. Data can be stored on the machine underground for up to 30 days in case the link is broken. Once reestablished, the data will backfill the system. The data that is sent to the cloud is stored by Komatsu and sent to our Smart Solution centers. At the Smart Solutions center it is processed to provide meaningful information to assist mines in operating efficiently. This information can be viewed live (15-minute batch files) or end of shift reports that are automatically emailed depending on customer preference. The data coming off the machine can also be linked into a mines Supervisory Control and Data Acquisition (SCADA) system to understand the current state of operations underground. For battery haulers that are not tethered, wireless nodes can be used to offload data at the continuous miner and be transferred out of the mine via the BPLM on the continuous miner.

In addition to the analytics, having connected machines enables Remote Machine Monitoring (RMM). The RMM is a valuable tool for both the monitoring center and customers. The RMM is a real-time copy of the display (Figure 1 – Onboard Faceboss Display) onboard the Continuous Miner. Troubleshooting as well as routine checks can be done from a remote location, safe from dust, noise, and traffic on the mining unit.

3. THE ANALYTICS

The three basic reports that most customers get are a daily shift, machine health status, and machine activity.

Sometimes, a manager needs to know productivity details not available watching the live machine. For these cases, unit shift reporting is an option. These reports monitor activities throughout the day. Identifying peak times of day, or slow times, aid in improving the entire process. These reports are available by the shift (Figure 2 – Static Shift Report) or as a daily summary. If a manager does need to know information in real time throughout the shift, it can now be populated live (Figure 3 –Dynamic Shift Report) in the Grafana platform. This gives mine personnel near real time access to what is currently going on underground. This report will populate as the shift progresses enabling a manager to make changes mid shift to appropriate allocate assets.

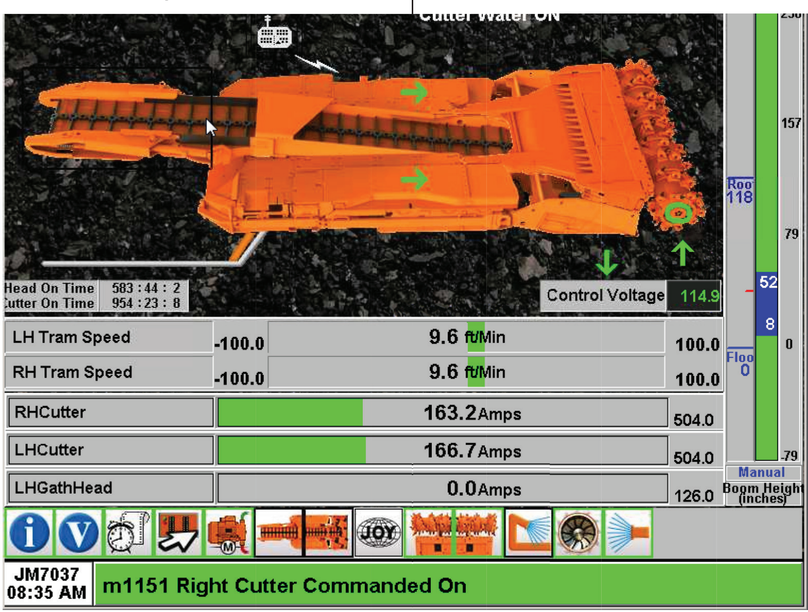

Figure 1 - Onboard Faceboss Display

The next report is the machine health status report (Figure 4 – Machine Health Status Report). Long term machine health is always a concern of productive mining. jams and thermal overloads, as well as starts and running hours are indicators of the level a machine is being used. Motor currents indicate the loading level compared to label rating. Service frequency may even be adjusted based on the health status of a machine.

Figure 2 - Static Shift Report

Figure 3 - Dynamic Shift Report

Tracking the health status as well as the tonnage on the machine, gives a more refined view of component life.

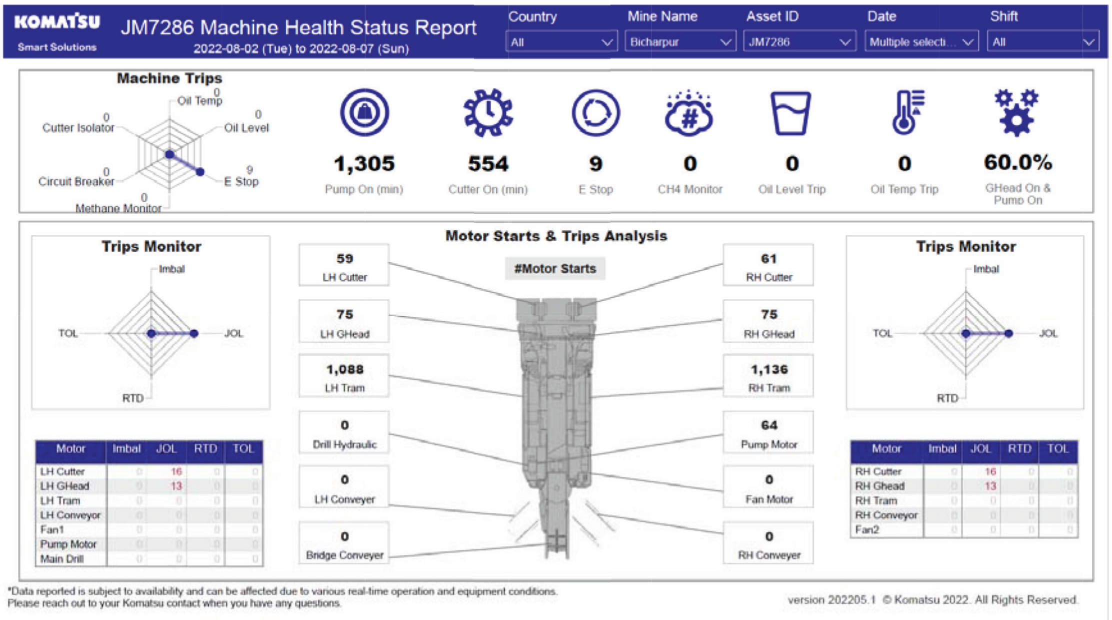

Figure 4 - Machine Health Status Report

The final standard report is the machine activity report (Figure 5 – Machine Activity Report). This report is used to tell immediately how the shift went and how the machine was utilized. It breaks down the major functions of the machine into categories and plots them along a time scale giving a clear view of how the machine was being used and when.

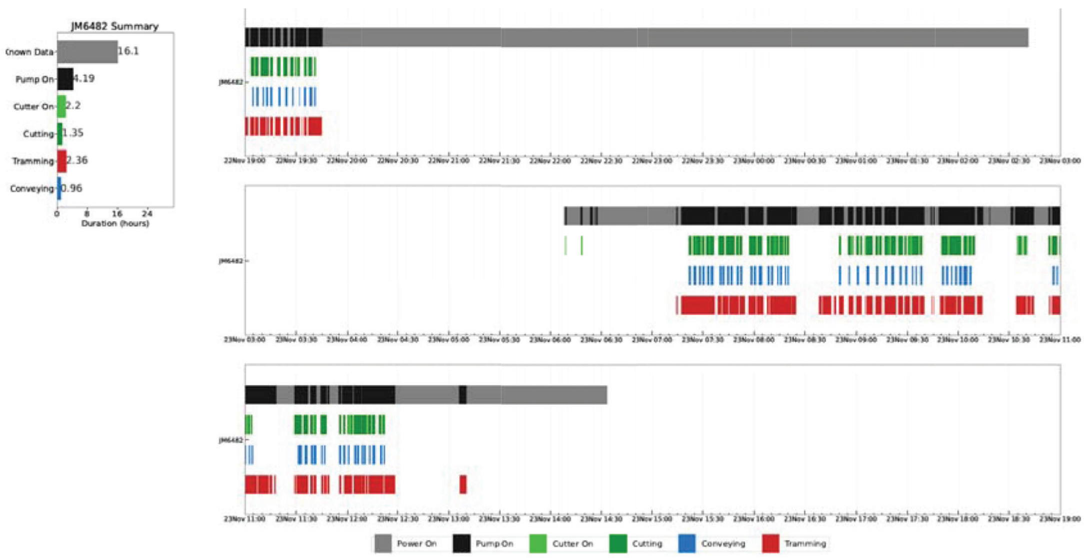

Figure 5 - Machine Activity Report

While these are the main reports that customers typically get daily, many mature data analytics customers use other tools available to help remotely monitor or trouble shoot their machines. One key tool is the Alarm and Event viewer. This viewer allows mine personnel to pull up a machine for a selectable time frame, and view and filter for various types of machine events. The number of times the event happened is also populated so it can be trended to determine if a given issue is growing in severity. All of these dashboards and tools can be pulled up remotely to enable mine personnel to trouble shoot and monitor the machine from a safe distance being the surface or anywhere in the world with internet access.

This connectivity also enables Komatsu personnel to better assist customers. While a machine is running in India, a local Komatsu Service Representative in the region, a Smart Solutions Data Analyst in South Africa, and an engineer in the U.S. can be watching the same data working together to best resolve an issue that might be going on underground live. Connected machines and data analytics make the world much smaller.

For machines that aren't connected to the surface, Komatsu does have the ability to backfill the system with manual data dumps using USB sticks. This needs to be done at least every 30 days. This machine is then loaded into the system and similar reports can be generated, they are simply not in real time.

4. UTILIZING DATA FOR CHANGE

While data can be very helpful in the daily management of a mine's operations, it can also be helpful in the implementation of new technologies. When it comes to the rollout of operator assist and automation features, it has been seen over the last decade to be helpful in making these changes. For this discussion, it is important to know the three basic levels of our Continuous Miner Automation (CMA) :

CMA Level 0 – Fully manual

In this level, the operator is in full control of the machine. While the control system will still provide protection via overloads, jams, and feedback algorithms, the operator is controlling the sump and shear cycles.

CMA Level 1 – One touch shear

This level of automation enables an operator to set roof and floor points via the remote. The operator controls how long the machine sumps and the heading/steering of the machine. Once the sump is complete, the operator will initiate the one touch shear cycle. The machine will shear down to the floor point. Once this is complete, the operator will tram the machine as needed. When the machine is back in position, the operator will initiate one touch shear again and the cutter head will return to the roof set point.

CMA Level 2 – Sequence table based

This level of automation provides a sequence table-based sump and shear cycle. Sequence tables can control all motor functions except the pump. While the sump depth is not an absolute measurement, the algorithms have proven to provide consistent sump depths via the control system. The operator is responsible for controlling the heading and placing the machine in the appropriate location to start the cycles. The heading can be adjusted by the operator using the tram controls during automation without stopping the automation sequence. The machine will continue to complete these sump and shear cycles until it is commanded by the operator. This software also has allocations to pause the sequence and reinitiate as needed. This is helpful for batch haulage applications or in an instance where the machine trips, the cycle will restart where it left off. Various sequence tables can be loaded on the machine to support different cutting conditions.

In a recent installation of CMA, the customer wanted to understand the automation levels and the impact on productivity. The data analytics team quickly created an analytic to study the data over a six-week period to try and capture a fair timeline to study the data. There will always be a handful of operators that over a short period of time outperform automation, but at what cost and for how long? The analytic captured the number of sump and shear cycles run in Level 1 automation (O/T in Figure 6 – CMA Utilization) and number of sump and shear cycles in Level 2 automation (CMA in Figure 6 – CMA Utilization). The analytic also captured the cycle time for each one of those cycles over the six-week period. The bars in yellow represent Level 1 cycles, and the bars in green represent Level 2 cycles. The results showed that operators were running 71% of the time in Level 2 automation and 29% of the time in Level 1 automation. Over that six-week period, cycle times for the Level 2 automation averaged 147.8 seconds and 167.7 seconds for Level 1 automation. This is a 12% reduction in cycle time for Level 2 automation.

From the data, the impact on cutting equipment can also be reviewed. Pulling data from the analytics platform and reviewing the cycles, visually assessing cycle consistency and cutter motor amperages operating in Level 1 and Level 2 CMA. In the figures below, for clarity given the size restrictions, note that the light blue line is cutter boom height, and the bottom yellow lines are cutter motor amperages. The Y-axis is dual unit height and amps while the X-axis is time.

Looking at Figure 7 below, focusing on the light

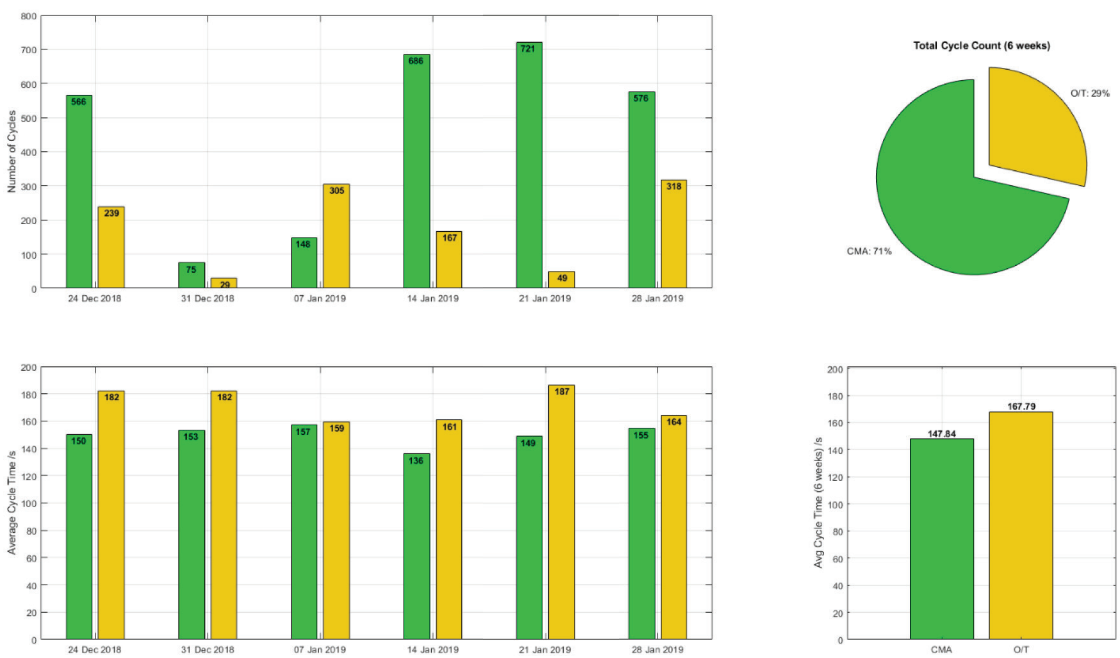

Figure 6 - CMA Utilization

blue line (cutter boom height) note that you see fairly consistent cycles. There is some variation in cycle time due to the operator being in control of sump depth in Level 1 automation. Looking at the cutter motor amperages and visualizing an average amperage as designated by the red line, the estimated average cutter motor amperage around 75 amps.

Looking at Figure 8, again focusing on the light blue line (cutter boom height) note that there is an increase in the consistency of the cycles. With the control system now managing the sump depth and shear cycles, operator inconsistencies are minimized. Looking at the cutter motor amperages and visualizing an average amperage as designated by the red line on the charts below, an average cutter motor amperage around 62 amps can be averaged.

The utilization of Level 2 CMA versus Level 1 CMA

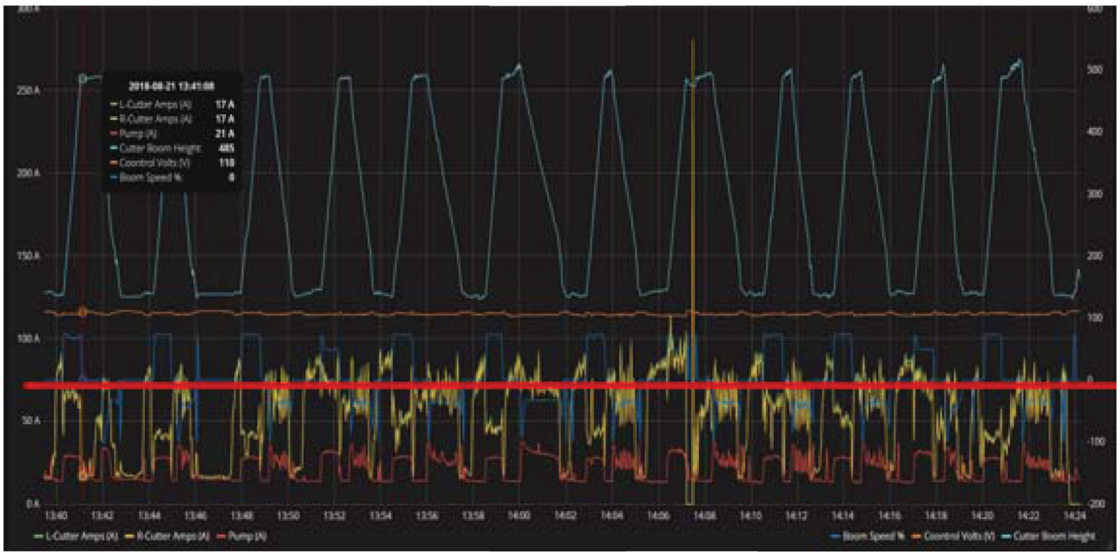

Figure 7 - Level 1 CMA Cut Cycles

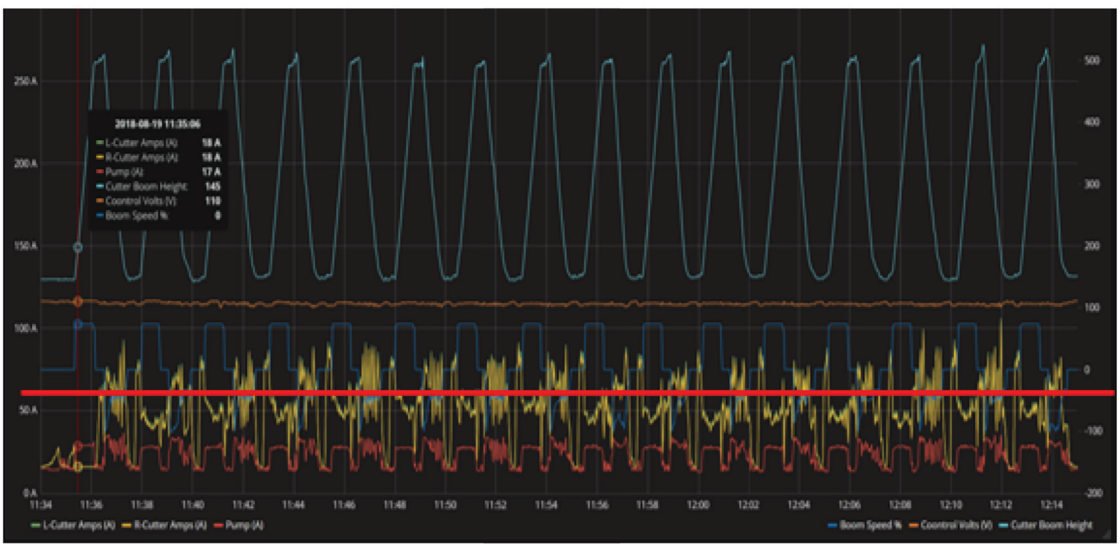

Figure 8 - Level 2 CMA Cut Cycles

has resulted in an approximate decrease of 17% in cutter motor amperages. While a good way of measuring impact through the entire cutting system (motors, frames, gearboxes, pins, bushings, etc.) hasn't been developed, it can be assumed that if cutter motor amps have decreased, impact to the entire system by operating in level two automation has been decreased. From this data, a reduced cycle time of 12% has resulted and a reduced cutter motor amperage of 17% utilizing Level 2 automation.

5. CONCLUSIONS

Data analytics will play an increasingly vital role in the management of underground operations. Getting shift data from manual sources comes with a loss of accuracy, integrity, and completeness. As the level of digitalization in mines continues to increase, it is key to think about connecting our sections to allow for accurate and real time data to be transmitted to the surface directly from the source, the machine. This data can be transformed into crucial information used to provide a deeper understanding of what is going on at a given operation, section, machine, or even operator. This level of detail can assist in not only day-to-day operations and goals for increased productivity, but also validating operational changes ranging from various cutting bits to automation.

A CASE STUDY ON STABILITY AND ROCK SUPPORT ASSESSMENT FOR A COMPLEX UNDERGROUND MINE IN THE USA

Pinnaduwa H.S.W. Kulatilake

Abstract

The stability and deformation of rock masses around tunnels in underground mines play significant roles in the safety and efficient exploitation of the ore body. Therefore, understanding geo-mechanical behavior around underground excavations is important. In this study, a three-dimensional numerical model was built, and stress analyses were performed by using 3DEC software for an underground mine in the USA using the available information on stratigraphy, geological structures, and mechanical properties of rock masses and discontinuities. Investigations were conducted to study the effect of the lateral stress ratio (K0), parameters of the material constitutive models, and rock support systems on the stability of rock masses around the tunnels. Results of the stress, displacement, failure zone, accumulated plastic shear strain, and post-failure cohesion distributions were obtained for these cases. Finally, comparisons of the deformation were made between the field deformation measurements and numerical simulations.

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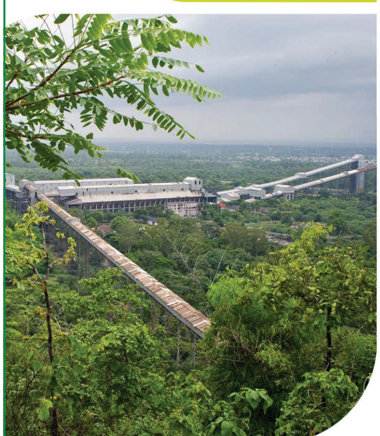
धरती का करें रक्षण, स्वच्छ रखें पर्यावरण।



पर्यावरण को स्वच्छ रखना हम सभी का सामुदायिक व सामाजिक दायित्व है।

NTPC Limited delivers stellar half yearly performance in FY 2023-24, in producing coal from its four operational captive coal mines i.e Pakri Barwadih & Chatti-Bariatu Coal Mines in Jharkhand, Dulanga Coal Mine in Odisha and Talaipalli Coal Mine in Chhattisgarh.

Till date, NTPC has produced about 85+ million metric tonnes (MMT) of coal since inception. NTPC's captive coal mining fits strategically in its backward integration initiative for providing fuel security to its power generation business.

In FY 22-23, NTPC had produced 23.20 MMT of coal from its four captive coal mines.The coal production in this fiscal till Sept, 2023, was 16.05 MMT, posting a robust 83% growth over the coal production of 8.76 MMT achieved in the same period of last year. NTPC thus achieved its highest ever production in Q1, Q2 and H1 in FY 23-24.

Further, NTPC has incorporated its 100% wholly owned subsidiary namely, NTPC Mining Limited (NML) for developing the focussed mining competency by creating a dedicated business and committed to the development of mines. NML has won and secured the rights to develop and extract coal from the North Dhadu (East) coal block in Jharkhand. This will be the first commercial coal mine of NML.

At present NTPC-NML is developing eight coal mines i.e. Pakri-Barwadih, Dulanga, Talaipalli, Chatti-Bariatu, Kerandari, Badam, Banhardih & North Dhadu (East). NML has put the step forward for its target to reach the peak rate capacity of 100 Million Tonnes per Annum by 2030.

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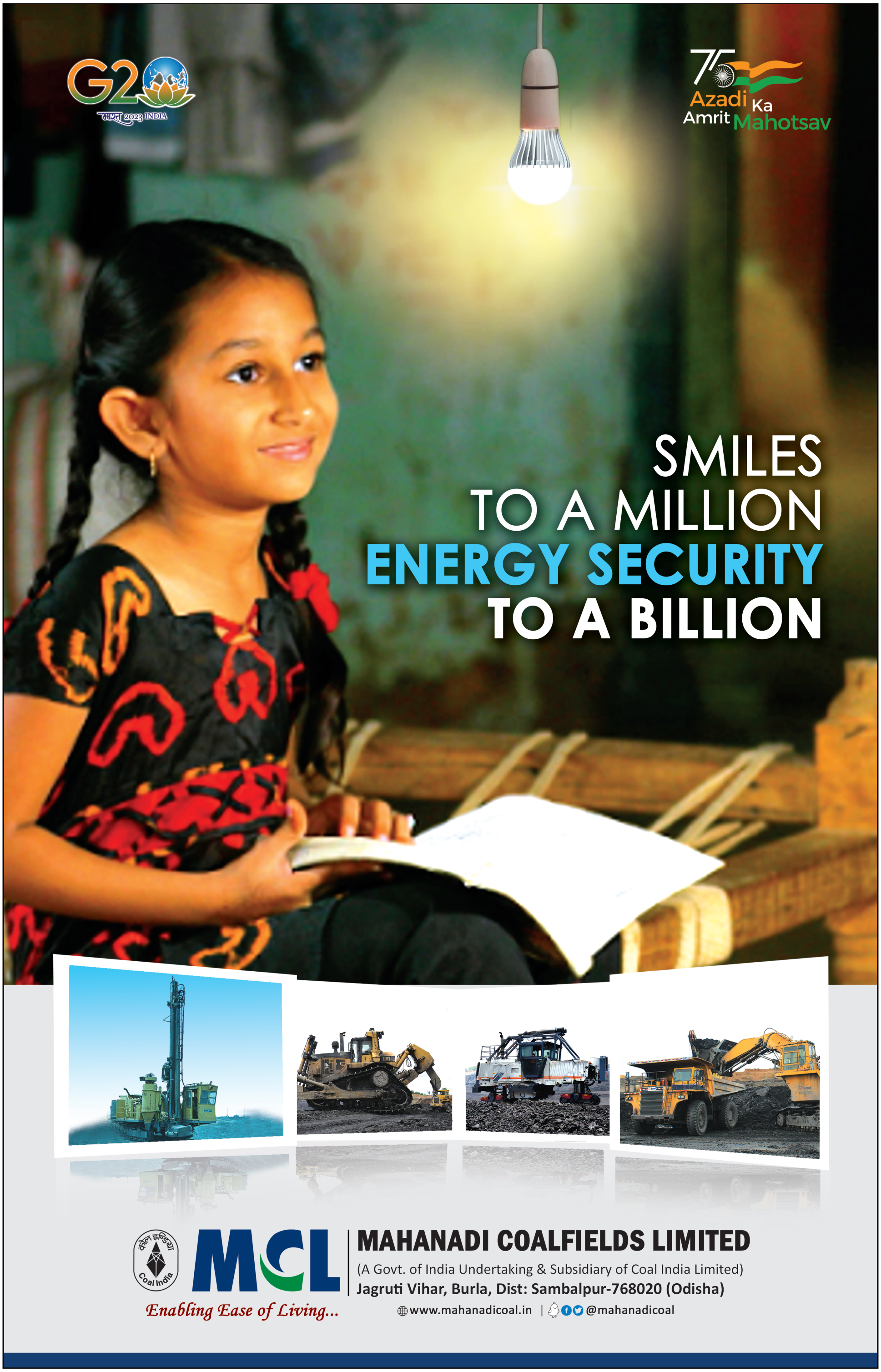
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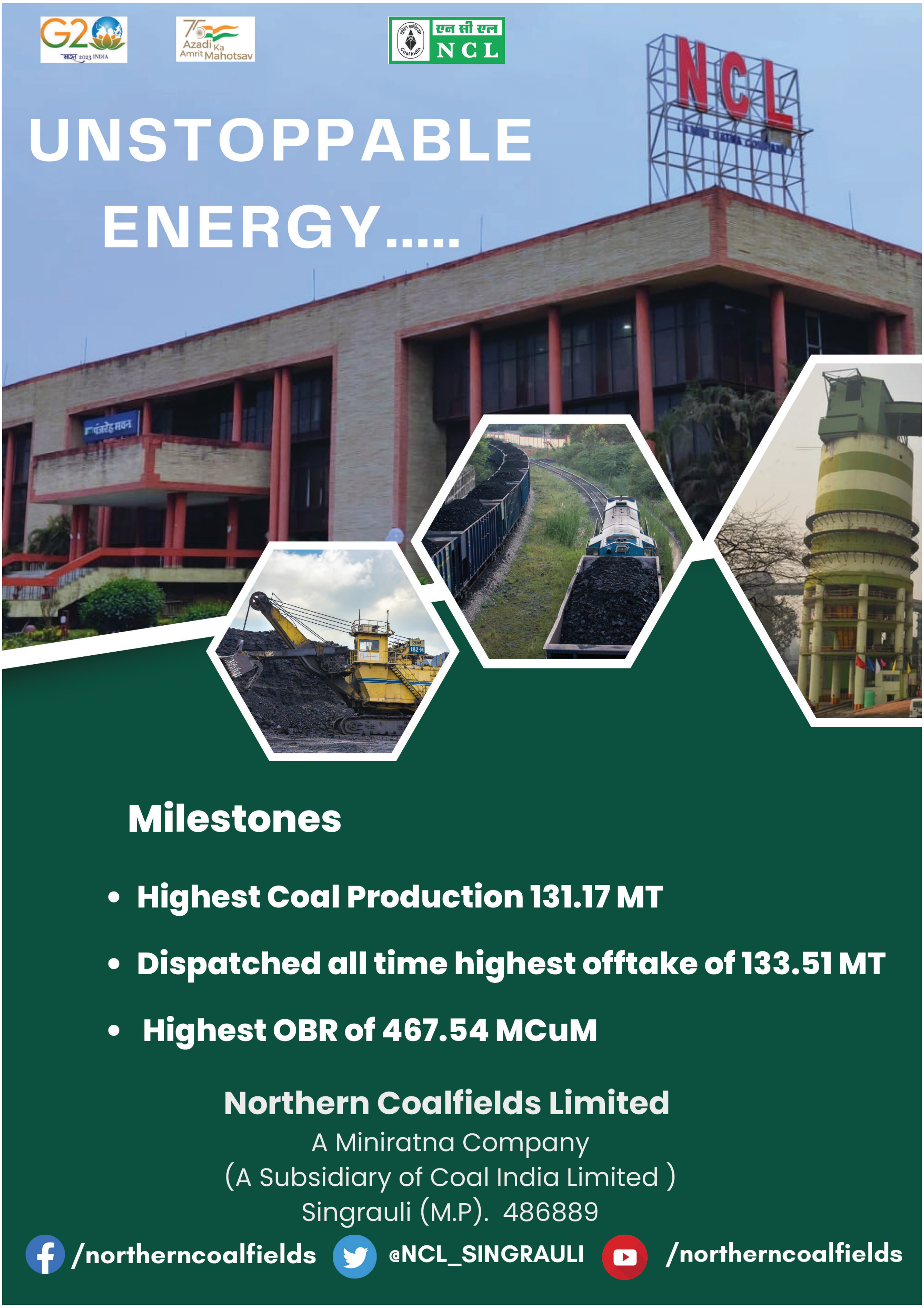
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विज्ञान एवं प्रोद्योगिकी मंत्रालय, भारत सरकार, नई दिल्ली के अंतर्गत सीएसआईआर की एक अंगीभूत प्रयोगशाला

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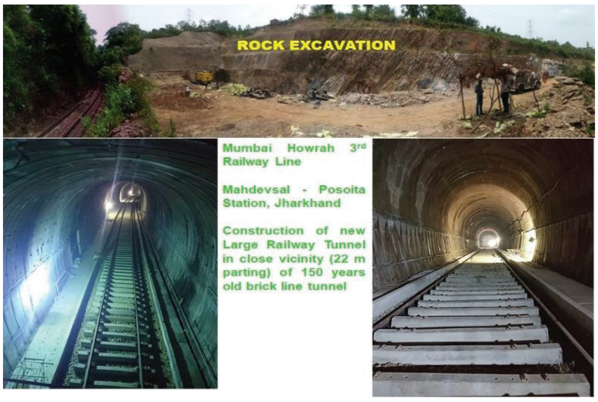

Major Contributions of CSIR-CIMFR are:

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- Design of Safe Blasting Patterns of Mines
- Assessment of Subsidence and Ground Movement due to Mining
- Design of Environmental Management Plan for Eco-Friendly Mining and Coal Based Industries
- Investigations on Methane Emission due to Mining and GHG Inventories
- Resource Evaluation and Reservoir Modeling of Coal bed Methane
- Evolution of Methods to Control Mine Fire
- Design of Support Systems for Mines
- Design & Development of Equipment, Instruments and Components for Safe Mining
- Coal Quality Assessment
- Basic Studies on Coal Science
- Coal Preparation
- Coal Carbonization
- Coal Liquefaction – Direct and Indirect routes
- Coal Gasification
- Coal Combustion
- Non Fuel Uses of Coal/ Value Added Chemicals
- Fly Ash Utilization

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For Further Information Please Contact:
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